Contents

ABSTRACT

Abrasive flow machining is a nontraditional finishing process and is used to polish metallic components, internal inaccessible cavities or recesses using a semi liquid paste. It was developed to deburr, polish, and radius surfaces having complex geometries and edges by flowing abrasives with a viscoelastic polymer (called as media) over them. Abrasion occurs wherever the medium passes through the highly restrictive passage. In this work, two way abrasive flow machining is used to optimize the material removal and % improvement in surface roughness on brass material. In this study three parameter are used level of carbon nano tube, level of pressure, number of cycle. The abrasive media is formed with the combination of polymer and gel, abrasive particle and carbon nano tube (CNT). Polymer is made with the help of some chemical like as silicon oil , boric acid and ferric chloride ($FeCl_{3.}6H_2o$) and ammonia carbonates (NH_4CO_3). This media is mixed with the level of CNT and experiment is conducted on brass work-piece.

Three process parameter level of CNT, Extrusion pressure and Number of cycle have been used for experiment to study the effect of these process parameter on % improvement in surface roughness and material removal of brass work-piece. L_9 orthogonal array based on Taguchi method has been used to study the effect of various process parameter on selected on response parameter. All three parameter affects the material removal and surface finish, by using level of CNT material removal continuosly increased among other parameter while surface roughness is improved up to second level after decreases. In case of No of cycle from first level to second level material is decreased after that increased but for surface roughness improvement is little bit significant. Third parameter extrusion pressure have little bit significant on MR but highly significant for surface roughness improvement. Effect of CNT on material removal is continuosly increases. The percentage contribution of CNT is 14.98%.and the effect of other parameter on MR are percentage contribution of Extrusion pressure is 15.56% and the percentage contribution of Number of cycle is 21.22%. Optimum level is selected for material removal is C_3 P_1 $N_{3.}$ Effect of CNT on improvement on surface finish the percentage contribution of CNT is maximum is 23.84%.The percentage contribution of number of cycle is 23.14% and extrusion pressure which contribute 15.90%.

CHAPTER 1

INTRODUCTION

Abrasive flow machining (AFM) was invented by U.S.A based Extrudes Hones Corporation in 1960. Abrasive Flow Machining (AFM) is widely used in the fine finishing of complex inaccessible shapes, miniaturized parts, and for simultaneous finishing of many areas of a part or many parts itself [1]. Abrasives laden media (made up of a liquid polymer with abrasive particles) is forced through a controlled passage for the simultaneous finishing of the required external/internal surface with a large number of randomly oriented cutting points. The medium made by abrasives and polymer has low viscosity and good abrading capability. This media is also known as abrasive laden medium, not-so-silly putty [2]. Layer thickness of material being removed is of the order of about 1 to 10 μm. It can produce best surface finish achieved up to 50nm [3].

Due to Industrial revolution, manual work has been replaced by machines in many of the industrial processes. But there is increasing demands (viz. increasing miniaturization and higher demands) for improved surface finish, economic viability, processing of multi-parts, where our mechanical systems are decidedly too clumsy in case of complex task. In this process tooling has a very important role in finishing of material. The media acts have a good fluidity and viscosity and because of that cutting tools gets better flexibility. In AFM, polishing, deburring all are performed simultaneously in a single operation. The effects of various parameters of the abrasive flow machining process on different responses have been largely reported in a number of studies.

AFM minimizes the surface roughness up to 75 to 90 percent on machined surfaces and the surfaces being cast. AFM has its need to increase surface quality, enhance high cycle fatigue strength, increase air flow, extend component life, increase engine performances, improve fuel economy and reduces emissions, reduce product cost, increase throughout production. AFM process has many applications in field of aerospace electronics, automotive, surgical component. It is also used for removing recast layer from the surface produced by EDM process. AFM process can finish surfaces up to 0.05 micrometer[4] ,deburr holes of minimum size is 0.2 mm, radiusing edges from 0.02 to 1.5 mm and bilateral hole tolerance up to 5 micro meter can be achieved [4]. It saves 90% time in finishing operation as compared to hand finishing operation [5].

On the basis of working and configuration, AFM is classified into three major categories one way AFM [6], two way AFM [7] and orbital AFM [3].

1.1 NON CONVENTIONAL MANUFACTURING PROCESS

During the last 55 year, over 20 different non- traditional manufacturing process have been invented and successfully implemented into production. Machining process that involve compression shear chip formation have a number of inherently adverse characterstics and limitation. There are situation where these processes are not satisfactory or economical when the hardness and strength of the material is very high. The workpiece is too flexible or slender to support the cutting or grinding forces, or parts are difficult to clamp in workholding device.

These requirements led to the development of chemical, electrical and other means of material removal in the 1940. These method are called advanced machining but have also been called non conventional or non traditional machining. When selected and applied properly, these processes offer significant economic and technical advantages over the conventional machining methods. The conventional manufacturing processes in use today for material removal primarily rely on electric motors and hard tool materials to perform tasks such as sawing, drilling and broaching. Conventional forming operations are performed with the energy from electric motors, hydraulics and gravity. Likewise, material joining is conventionally accomplished with thermal energy sources such as burning gases and electric arcs. In contrast, non-traditional manufacturing processes harness energy sources considered unconventional by yesterday's standards. Material removal can now be accomplished with electrochemical reaction, high temperature plasmas and high-velocity jets of liquids and abrasives. The rapid developments in the field of materials have given an impetus to the non-conventional manufacturing (NCM) technology to develop, modify and discover newer technological processes with the view to achieve result that are far beyond the scope of conventional manufacturing processes. In taguchi [8] has concluded that high accuracies can not be achieved by conventional machining method in which material is removed in the form of chips.

Merchant [9] analyzed the needs and trends of future of manufacturing technology by assuming that past and present manufacturing activities can be conveniently projected into the domain of future requirements. The non-conventional manufacturing processes may be classified on the basis of type of energy namely, mechanical, electrical, chemical, thermal or magnetic, apply to the work piece directly and have the desired shape transformation or material removal from the work surface by using different scientific mechanism. There are some non conventional machining process classified as-

1.1.1 ELECTRICAL DISCHARGE MACHINING

Electrical discharge machining (EDM) is a thermal process in which material is removed by a erosive action of electrical discharge . spark providing by generator. It is primarily used for hard metals or those that would be impossible to machine with traditional technique. EDM can be used only for conductive material. EDM is an effective technique in the production of micro component that are smaller that are smaller than 100 micro meter. When two electrode is separated by di-electric medium ,come closer to each other , die electric medium that is initially non conductive breaks down and becomes conductive . during this period spark will be generated between electrodes than thermal energy release will be used material removal by melting and evaporation.

1.1.2 WIRE ELECTRIC DISCHARGE MACHINING

wire electric discharge maching have same principle as EDM but the only differences is that electrode in wire EDM is in the form of wire. The work piece is fed continuously and slowly past the wire in order to achieve the desired cutting path. Numerical control is used to control the work-part motions during cutting. As it cuts, the wire is continuously advanced between a supply spool and a take-up spool to present a fresh electrode of constant diameter to the work. This helps to maintain a constant kerfs width during cutting. As in EDM, wire EDM must be carried out in the presence of a dielectric. This is applied by nozzles directed at the tool-work interface as in the figure, or the work part is submerged in a dielectric bath. Wire diameters range from 0.08 to 0.30 mm, depending on required kerfs width. Materials used for the wire include brass, copper, tungsten, and molybdenum. Dielectric fluids include demonized water or oil.

1.1.3 ULTRA SONIC MACHINING

Ultrasonic means those vibrational waves having frequency above the normal hearing range the frequency used are 19 KHz to 25 KHz. Ultrasonic machining is a process in which material is removed due to action of abrasive grains . The abrasive particle are driven into the work surface by a tool oscillating normal to workpiece at high frequency, where the work material is removed by repetitive impact of abrasive particle carried in a liquid medium in the form of slurry under the action of shaped vibrating tool attached to a vibrating mechanical system “Horn”. . The basic process is that a ductile and tough tool is pushed against the work with a constant force. A constant stream of abrasive slurry passes between the tool and the work (gap is 25-40 µm) to provide abrasives and carry away chips. The majority of the cutting action comes from an ultrasonic (cyclic) force applied.

1.1.4 ABRASIVE JET MACHINING

The fundamental principle of abrasive jet machining involves the use of high velocity stream of abrasive particle carried by the pressure gas on workpiece through nozzle. The metal removal occurs due to erosion caused by abrasive particle impacting the work surface at high speed. Abrasive jet machining is used for removing flash and parting lines from injection moulded parts, deburring and polishing plastic, cleaning metallic mould cavities. Abrasive jet machining have low power and low investment , very little heat generation but it have low material removal and poor surface finish.

1.1.5 ABRASIVE WATER JET MACHINING (AWJM)

Water –jet cutting and water jet machining (WJM) is similar to laser beam machining (LBM) and electron beam machining (EBM) in this respect that a given amount of energy 10^{10} watt/mm^2 is concentrated onto a very small point to cause material removal. In Abrasive Water Jet Cutting, a narrow, focused, water jet is mixed with abrasive particles. This jet is sprayed with very high pressures resulting in high velocities that cut through all materials. The presence of abrasive particles in the water jet reduces cutting forces and enables cutting of thick and hard materials (steel plates over 80-mm thick can be cut). The velocity of the stream is up to 90 m/s, about 2.5 times the speed of sound Abrasive Water Jet Cutting process was developed in 1960s to cut materials that cannot stand high temperatures for stress distortion or metallurgical reasons such as wood and composites, and traditionally difficult-to-cut materials, e.g. ceramics, glass, stones, titanium alloys.

1.1.6 ELECTRO CHEMICAL MACHINING

Electro chemical machining referred to as anodic cutting. If two electrodes are placed in both containing a conductive liquid and D.C potential is applied across them , metal can be deplated from the anode and platted on cathode. This principle was in use for a long time in a process called electoplatting with certain modification ECM is the reverse of electroplating. ECM uses a shaped tool or electrode , since in term of machining , removal of material from workpiece. The tool is made the cathode and workpiece the anode. An electrolyte is pumped through the small gap which is maintain between tool and workpiece. The chemical properties of this electrolyte are such that the constituents of the work material go into the solution by the electrolytic process but do not deposited on the tool. Electro chemical machining is used for die-sinking ,contouring , drilling, broaching.

1.2 AFM PROCESS

Abrasive flow machining is a nontraditional finishing process and is used to polish metallic components, internal inaccessible cavities or recesses using a semi liquid paste. It was developed to deburr, polish, and radius surfaces having complex geometries and edges by flowing abrasives with a viscoelastic polymer (called as media) over them. Media is extruded through or over the work piece with motion usually in both direction. The velocity of the extruded media is dependent upon the principle parameter of viscosity , pressure , passage size, geometry and length [10,11]. In abrasive flow machining many abrasive are used like as alumina oxide (Al_2O_3), silicon carbide (S_iC),diamond dust , boron carbide and carbon nano tube (CNT) also. AFM minimizes the surface roughness up to 75 to 90 percent on machined surfaces and the surfaces being cast It is also used for removing recast layer from the surface produced by EDM process. AFM process can finish surfaces up to 0.05 micrometer[4] ,deburr holes of minimum size is 0.2 mm, radiusing edges from 0.02 to 1.5 mm and bilateral hole tolerance up to 5 micro meter can be achieved [10].

1.3 BASIC PRINCIPLE OF AFM

Basic principle of AFM Process, abrasive media is passed through the restricted passage of workpiece effectively for higher material removal and surface finish improvement under the extrusion pressure. Media is forced through the work piece by a hydraulic ram where it act as The fluid is forced through the work piece by a Hydraulic ram where it acts as a flexible file, or slug, molding itself precisely to the shape of the work piece. The highest amount of material removal occurs in areas where the flow of the fluid is restricted; according to Bernoulli's principle, the flow speed and pressure of the fluid increase in these areas, facilitating a higher material removal rate. The pressure exerted by the fluid on all contacting surfaces also results in a very uniform finish. AFM process is use large number of cutting edges with indefinite orientation and geometry for effective removal of material and surface finish.

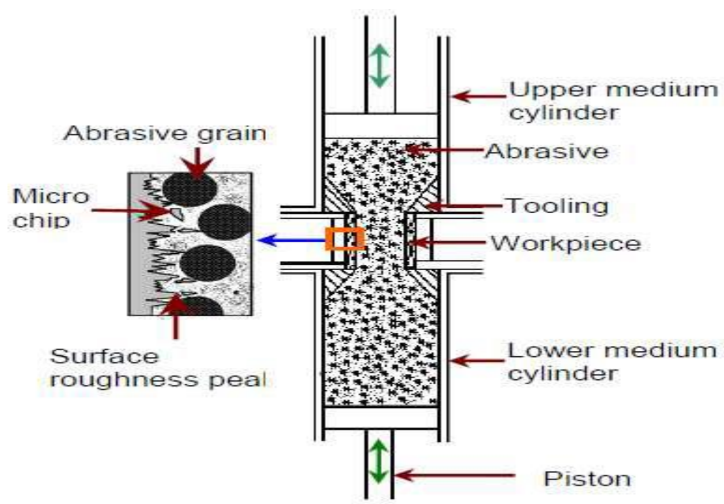

Figure 1.1: Principle of material removal mechanism in two way AFM process[6]

1.4 CLASSIFICATION OF AFM PROCESS

There are three types of AFM process, one way AFM, two way AFM and Orbital AFM but normally two way AFM is used for commercial application.

1.4.1 ONE WAY AFM

One way AFM process as shown in figure.1 consists a hydraulically actuated piston and an extrusion medium chamber having capability to receive and pressurize the medium to flow in a single direction across the internal surface of workpiece having internal passage. Fixture directs the flow of medium from the extrusion medium chamber to the internal passage of workpiece. Medium extruded out from the internal passages is collected by medium collector.

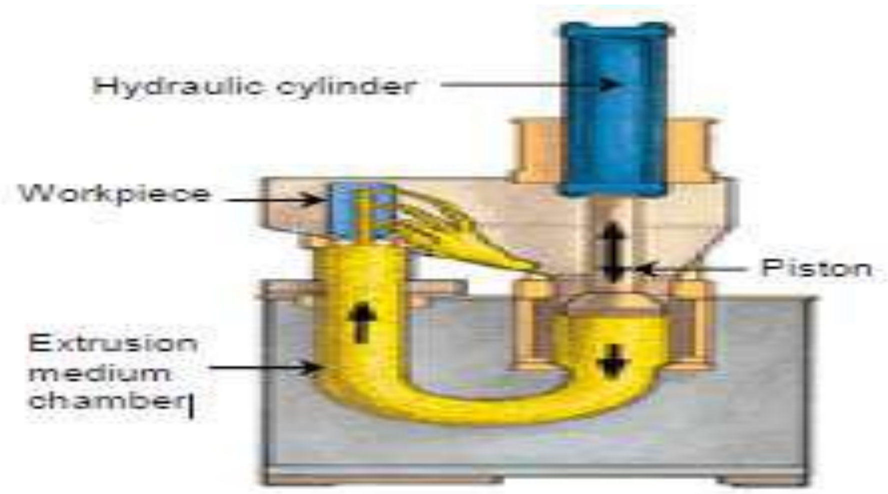

Figure 1.2: Shown operation of One way AFM [6]

It has advantages such as faster cycle processing, easy clean up, media temperature control generally not required, able to process larger parts, simpler tooling and part change-over. Both one way AFM and two way AFM process was developed by Extrudes Hones Corporation in 1960.The disadvantage associated with One way AFM is poor process control and radius generation.

1.4.2 TWO WAY AFM PROCESS

Two way AFM process was developed by Extrudes Hones Corporation in 1960. In two way AFM, it consists two hydraulic and two media cylinders shown in figure 2. The abrasive media is extruded in the forward and backward direction through the passage formed by the workpiece and tooling with the help of hydraulic pressure employed by two opposed cylinders. When the medium passes through the restrictive passages, material from work piece is removed by abrasion action.

The piston is used to pressurize the medium presented in the cylinder to flow in the forward or backward direction depending upon the pressure differences created in the hydraulic cylinders. Workpiece is abraded by the abrasive laden medium align co-axially with media cylinder with the help of fixture. The procedure is reversed and a combination of both forward and backward strokes makes a process cycle [7]. Two way AFM has advantages as excellent process control, can finish both inner and outer diameter, good control of radius generation and faster change-over of media.

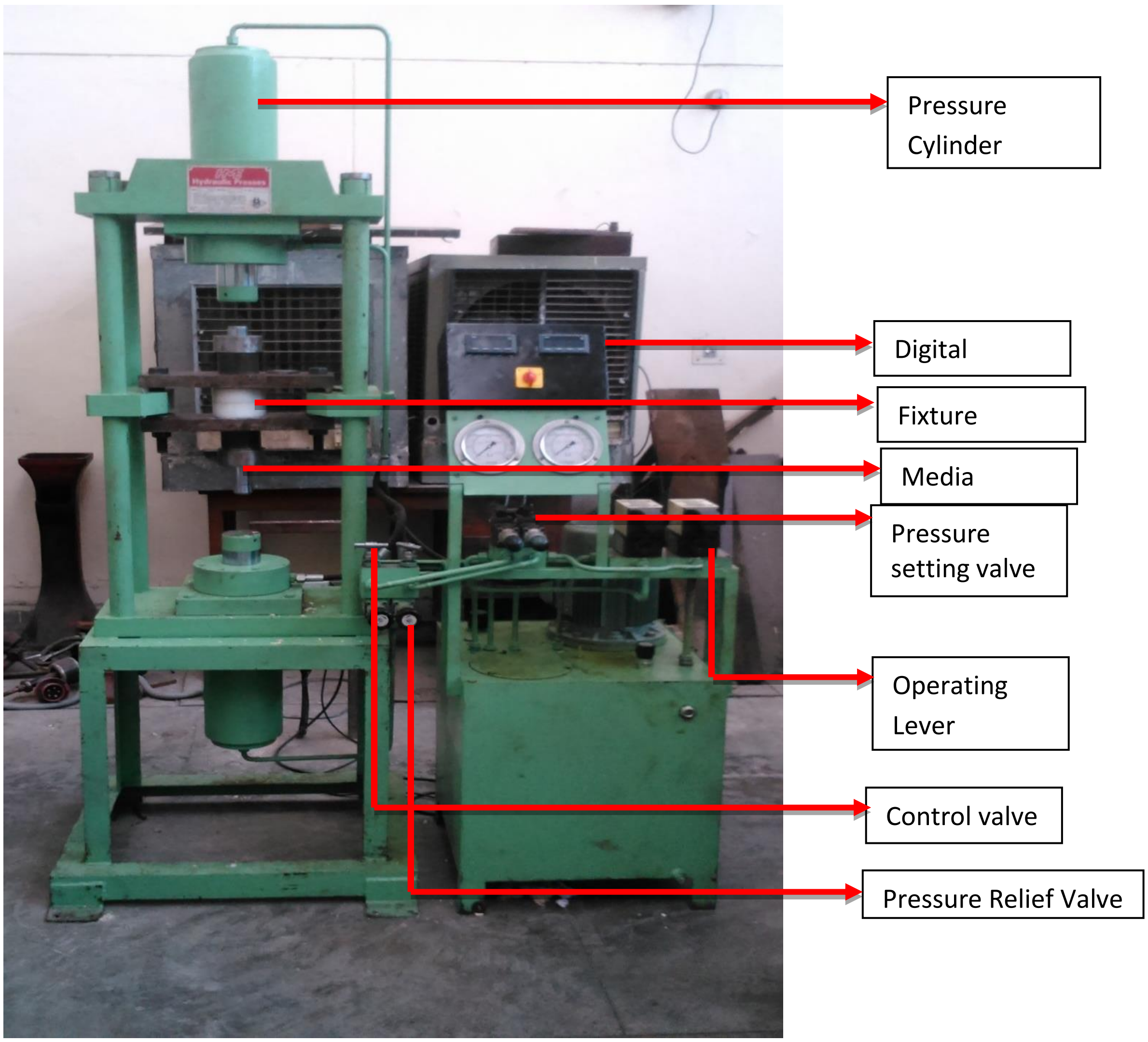

Figure 1.3: Shows the fabricated Two way AFM setup

1.4.3 ORBITAL AFM

In this process good surface finishing is obtained by producing low-amplitude oscillations of the work piece [3].

The tool consists a layer of abrasive-laden elastic plastic medium (i.e. same as used in two way abrasive flow finishing), and has a higher viscosity and more elastic in nature.

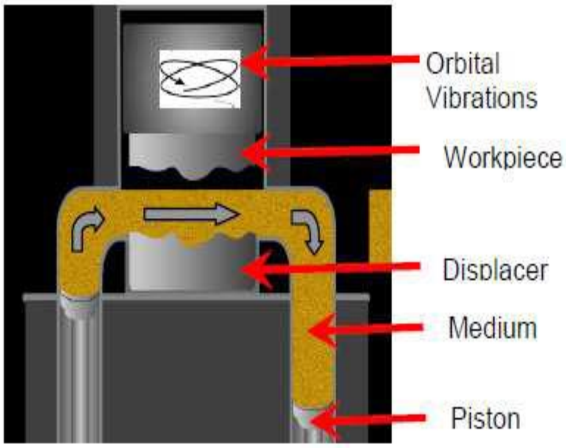

Figure 1.4: Operational set up of Orbital AFM before start of finishing [3]

In Orbital AFM as shown in figure 3&4 due to mechanical vibrations both flow and orbital motion is obtained in working zone. This process have capability to improve the surface finish of 20 to 30 times of the original surface finish. By using this process average surface roughness can be reduced to 0.01 micro meter or lower. This process can perform three dimensional precise polishing and finishing on the edges and surface for complex shape and cavities.

1.5 CONSTITUENT OF ABRASIVE FLOW MACHINING

Abrasive flow machining is required some constituent for completing the operation. The various component needed are fixture or tooling , machine and abrasive laden media. Fixture are designed according to desired location where complex and intricate profile are to be machined and fixture is responsible for holding the work piece against the abrasive particle.

1.5.1 FIXTURE

Nylon ,Teflon , steel ,urethanes and aluminium are following material can be used for fixture. Steel is limted to use and it is used only for its strength and durability. Generally aluminium and nylon are used because it have light weight and easy machinable. Fixture design is very important factor in getting desired effect. Siwet D.E [12] emphasize that the fixture design is often a very important for successful operation of AFM. In this study nylon fixture is used. Nylon was chosen as the material for the fixture because of its good wear properties . Basic function of fixture consist of

- Providing a restriction in the media flow path to control the media action in selected areas.
- holding the work piece in proper position between the media cylinders.
- Directing media flow to and from the areas of the part to be worked on, during the process cycle.

Figure1.5: Shows the work Fixture

1.5.2 ABRASIVE MEDIA

Abrasive flow machining uses abrasive media for material removal and surface finish. Non-newtonian liquid polymer containing abrasive particles of aluminium oxide, silicon carbide , boron carbide or diamond and CNT particle can be used in abrasive flow machining as the grinding medium and additives. The viscosity and the concentration of the abrasives can be varied Most widely used carrier is a high viscosity rheopetic fluid. The base materials has enough degree of cohesion and tenacity to drag the abrasive grains along with it through various passages/regions. AL_2O_3 and SiC are most suitable abrasives for many applications but Cubic boron nitride (CBN) and diamond are specifically used for special applications. Abrasive particles to base material ratio can be varying from 2 to 12.Abrasive are available in different mesh sizes. The abrasive have limited life. As a thumb rule, when the media has machined an amount equal to 10% of its weight, it must be discarded. Machine parts are properly cleaned by acetone or other chemicals before using the machine. Acetone is also used for work piece cleaning because some abrasive are deposited in the inside edge.

1.6 AFM APPLICATION

AFM is used in a wide range of finishing operation. it can simultaneously multiply parts of many areas of a single work piece. Inaccessible areas and complex internal passage can be finished economically and effectively. Automatic AFM system are capable handling thousand of parts perday, greatly reducing labour costs by eliminating tedious hand work. AFM process has many applications in field of aerospace electronics, automotive, surgical component. It is also used for removing recast layer from the surface produced by EDM process. Large surface irregularities , such as deep scratches or large bumps, can not br removed by AFM because material is removed equally from all surface . for the reason , imperfection , such as out of roundness and taper, can not be corrected (walia R S)[*13*]. AFM process can finish surfaces up to 0.05 micrometer[4] ,deburr holes of minimum size is 0.2 mm, radiusing edges from 0.02 to 1.5 mm and bilateral hole tolerance up to 5 micro meter can be achieved [4]. Some of the successfully application in different field listed below-

1.6.1 MEDICAL EQUIPMENT AND DEVICE MANUFACTURING

- Food processing
- Semiconductor (front-end) equipment
- Pharmaceutical manufacturers

1.6.2 MOLDS AND DIES

- Reduced production costs
- Increased production throughput

1.6.3 AERONAUTICAL COMPONENET MANUFACTURING

- Improved surface quality
- Enhanced high cycle fatigue strength
- Optimized combustion and hydraulics

CHAPTER 2

LITERATURE REVIEW AND PROBLEM FORMULATION

The complex finishing process require the manual handling which is very slow and sometimes these repetitive works are detrimental for the health of the workers too. Modern difficult to machine materials, there manufacturing and complex design of precision parts pose special machining and finishing challenge. With today's focus on total automation with machine tool in flexible machining system, the AFM process offer both automation and flexibility in final machining operation as integral part of the complete manufacturing cycle. AFM is such process which is the right answer of above problems. This AFM process replaces a lot of manual finishing process leading to more standardization of manufactured part. More hybridization is needed to improve material removal and surface finish because there is low material removal and surface finish is still a limitation. So more hybridization have done in AFM process. Some literature review is listed below-

S NO	TOPIC AND YEAR	AUTHOR	CONCLUSION
1	Abrasive Flow machining ;A case study(1991)	Rhoades L. J	When the medium is suddenly forced through restrictive passage then its viscosity temporarily rises. significant MR is observed only when the medium is thickened.

2	Metal removal distribution and flow characterstics in AFM(1992)	William R.E, Rajurkar K.P, Kozak J	Study the effect of medium viscosity and extrusion pressure on MR and surface finish.Medium's viscosity effect is more significant on MR as compared to extrusion pressure.Major change in the surface finish is observed after finishing for a few cycle only
3	Modeling and computer simulation of media flow in AFM(1994)	Rajeswar.G,kozak.j,Rajukar.K.P	Determine the characterstics of medium flow during machining and a linear relationship exist between shear acting on the surface and layer thickness of material removed
4	Simulation of surface generated in abrasive flow machining(1999	Rajendra Kumar, Vijay Kumar .Jain	Analysis and simulation of profile of finished surface and MR
5	R-AFM process and its effect on finish surface(2004)	M.Ravi Sankar V.K.Jain ,J Ramkumar	Additional Force (tangential force and tangential velocity act on grain which assist the abrasive particle to shear the w/p surface peaks more easily and surface finish and MR increases.

6	Experimental investigation and Modelling of DBG-AFM process(2004)	Ravi Sankar M,mondal S, Ramkumar J,Jain V.k	Improving the MR and surface Texture By placing Drill bit in medium
7	Effect of providing a rotating rod inside the hollowcylindrical w/p on MR in AFM(2004)	Walia .R.S , Shan. H.S, Kumar .P	Better surface finished and MR is achieved Due to centrifugal action caused by the rod on abrasive with low viscosity medium
8	Specific energy andtemperature determination of abrasive flow machining process (2001)	Rajendra K,Jain, V.K.Jain	Specific energy remains almost constant with a change in abrasive mesh size , but its value is higher for higher hardness of workpiece material
9	Development of hydraulic circuit for AFM(2002)	B.S Brar,Mandeep Singh,R.S Walia,	Experimentation duration was reduced, lesser fatigue to operator
10	Development of magneto AFM process(2002)	Sehijpal Singh, H.Shan	Metal removal increases with magnetic field more than surface finish
11	Experimental investigation into cutting forces and active grain	V.K Gorana , V.K Jain, G.K. Lal	extrusion pressure,abrasive concentration and grain size affect the cutting forces, active grain density and finally reduction in

	density during abrasive flow machining(2004)		surface roughness
12	Forces prediction during material deformation in AFM(2004)	V.K Gorana,V.K Jain,G.K Lal	Axial force, Radial force, active grain density and grain depth of indentation have a significant influence on material removal
13	ECM in the aid of AFM process(2006)	B.S Brar ,R.S Walia,V.P Singh	Better surface finishing but at higher operating voltage surface become rough .
14	Investigation of one-way abrasive flow machining and in-process measurement of axial forces(2008)	Dirk Bahre, Martin Swat,Horst Brunnet	Better surface finishing but at higher operating voltage surface become rough .

15	Parametric optimization of developed AFM set up for micro finishing using taguchi method 2008	B.S,Brar ,Mandeep singh,R.S Walia, V.P singh,G.S walia	Abrassive to media ratio has highest contribution towards response charactersrics
16	Surface Integrity in Abrasive Flow Machining of Hardened Tool Steel AISI D2 2009	J.kenda,J.kopac, F.pusavec	EDM induces undesired high tensile stresses in and beneath the machined surface. surface integrity induced by EDM can be significantly improved
17	Helical abrasive flow machining(2012	B.S Brar, R.S Walia, Mohit Sharma	With contribution of helix and no. of cycles MR increases and surface finish improves
18	High-speed Internal Finishing of Capillary Tubes by Magnetic Abrasive Finishing(2012	Junmo Kang, Andrew George, Hitomi Yamaguchi	Highest tube revolution rate at which the high-speed internal finishing of a capillary tube using double pole-tip sets is successful

2.2 EFFECT OF AFM PROCESS PARAMETER

Many author proposed research on abrasive flow machining by varying different parameter. Some parameter which affects the material and surface finish are given below.

2.2.1 MEDIA VISCOSITY

Williams and Rajurkar [14], and Williams et. al. [15] have reported that viscosity of the media is one of the significant parameters of the AFM process. Keeping all other parameter constant, an increase in viscosity improves both material removal and surface roughness. Przyklenk [16] has observed that the material removal capacity of the least viscous media differs from the most viscous one. This difference could be as much as 300 times. A thumb rules has been suggested by Kohut [17] for the selection of viscosity in relation to work piece passage size. According to this if the passage length is substantially shorter than two times the passage width, a higher viscosity media should be used. On the other hand, if passage length is substantially longer than two times the passage width, a lower viscosity should be preferred. Concentration and abrasive particle size also affect the media viscosity, which may result in settling of particles thereby influencing the flow properties and overall abrasion process [18]. Experiments show that the viscosity of the media increases with the percentage concentration of abrasives and decreases with temperature [19]. It is further indicated that when media viscosity falls below 30 Pa the abrasive particle is less likely to remain in suspension within the media. There is a tendency of particles to sink under gravity to the bottom of the media cylinder.

2.2.2 MEDIA TEMPERATURE

Media temperature of media is as important monitor which can be used to judge the work efficiency in AFM process . Liang Fang et al. [20] investigate that media temperature increases with increasing cycle , which in result decreases materials removal and surface roughness decreasing efficiency.

2.2.3 MEDIA FLOW VOLUME

The volume of the media contained in the media cylinder is called the media flow volume . it is one of the dominant process parameter in AFM for controlling the amount of abrasion and surface finish by specific media composition. It has been noted by Kohut [17] that keeping all other process parameter constant, a large volume of media will cause more abrasion . the amount of abrasion or stock removal that occurs is directly related to the slug legth of flow, which in turn is governed by media flow volume.

2.2.4 MEDIA FLOW RATE

Media viscosity, extrusion pressure, and passage dimension determine the media flow rate (the speed of the abrasive slug passing through the restrictive passage) which affects the uniformity of the material removal and the formation of edge radius. Rhoades [21] has reported that media flow rate is less influential parameter in respect to material removal. Slower slug flow rates are best for uniform material removal and high slug flow rates produce large edge radii [Rhoades 22]. It has been noted by Williams et.al. [15] that if volume of flow is constant. The media flow rate is insignificant with regard to material removal. On the other hand, it has been claimed by Singh [23] and Jain and Jain [24] the media flow rate influences both of the material removal and surface roughness.

2.2.5 NUMBER OF CYCLE

A number of cycles are required to achieve the desired surface finish and material removal. It has been reported in a number of studies that abrasion is more pronounced in some initial cycles after which improvement in the surface finish stabilize or reduce in some cases [25, 26]. Total number of process cycles range from one to several hundred [10]. Within 1 to 8 cycles, a linear dependence between material removal and surface roughness versus number of cycles was indicated. In AFM the forward and backward extrusion back to the initial stage completes a cycle.

2.2.6 EXTRUSION PRESSURE

Jain et al. [27] and jain and Adsul [28] mention the same conclusion based on their experiment observations, arguing that increase in extrusion pressure decreases final surface roughness up to a certain value while it contniously decreases the surface the surface finish improvement. It has been found that cutting is faster at an increased extrusion pressure, with all other parameters remaining constant. A part of total pressure is lost within the media due to its internal resistance to flow and rest is imparted to abrasion particles contacting the work piece surface [15, 16, and 22]. Jain and Jain [24] reported that at higher pressure the improvement in material removal just tends to stabilize probably due to localized rolling of abrasion particles.

2.2.7 ABRASIVE PARTICLE SIZE

Sizes of abrasive particles used in AFM process range from #8 grit (roughing and stock removal application) to 500 grit (small hole application). Smaller size abrasive gives better surface finish and can reach into complex and narrow passages, while larger one cut faster. According to one thumb rule [29] finer abrasives should be used when the initial roughness of the work surface is less. The reason for a decrease in material removal is that with an increase in mesh size (or decrease in grain size in mm) the depth of penetration as well as width of penetration, decreases.

2.2.8 ABRASIVES CONCENTRATION

McCarty [30] mentions the possibility of using a large range of concentration of abrasive in the media (2 to 12 times weight of carrier media). However, suggested that abrasive particle to base material ratio (by weight) should vary from 4:1 to 1:4 with 1:1 as the most appropriate ratio [31]. As the concentration of abrasive in the media increase, material removal increases while the surface roughness value decrease. However, its effect is visible only up to a certain percentage of abrasive concentration, beyond which it becomes insignificant. At higher concentration of abrasive particles viscosity of the media increases leading to more material removal [32]. Further, a higher concentration of abrasive particles permits the media to sustain a larger cutting force.

2.3 PROBLEM FORMULATION

Development of abrasive flow machining is carried out by varying the different parameter or assisted with any advanced machining process. In this work, two way abrasive flow machining is used to optimize the material removal and surface finish on brass material. In this study three parameter are used ie level of carbon nano tube, level of pressure, number of cycle. The abrasive media is formed with the combination of polymer and gel, abrasive particle. Polymer is made with the help of some chemical like as silicon oil , boric acid and ferric chloride ($FeCl_{3}.6H_{2}o$) and ammonia carbonates ($NH_{4}CO_{3}$). This media is mixed with the level of CNT and experiment is conducted on brass work-piece.

Three response parameter level of CNT, pressure and NO. of cycle have been used for experiment to study the effect of these response parameter on surface roughness and material removal of brass work-piece. L_9 orthogonal array based on Taguchi method has been used to study the effect of CNT and other parameter. Here three main parameter are level of CNT(C), level of extrusion pressure (P) and No. of cycle(N) have been selected at three level ,considering no interaction among them. Abrasive flow machining have serious limitation low productivity in terms of rate of improvement in surface roughness. The present research focus on development of AFM setup for higher material removal and % improvement in surface roughness.

2.4.1 PROPOSED STUDY ON AFM SETUP

AFM process replace a lot of manual finishing processes leading tp better standardization of manufactured parts, hence there interchangeability, mass production and reduce cost. Since 1960's a lot of work has been done in the field of abrasive flow machining and their hybridization with other manufacturing method and are able to achieve better performance with these processes. But for some typical application like functional surface generation,from – correction, finishing of hard alloys and handling of delicate work- pieces, the various hybrid AFM processes are too slow or clumsy. There is strong need to explore more variety of hybrid AFM processes as per the ingenuity of the inventors. In this research project, a novel hybrid of AFM will be developed and tested with the aim to overcome the varied difficulties including low MR removal, longer cycle time, high operating pressure and higher energy consumption. Developed hybrid AFM process achieve synergetic machining action by hybridizing other advance machining processes with abrasive flow machining.

To explorer the possibility of integrating AFM with other technologies like magnetic assistance ,ultrasonic machining, CFAAFM, ECAAFM, and other non conventional processes with an objective o enhance its efficiency and surface finish. The proposal aims at the following objectives-

- Design and development of experimental setup capable of providing varying range of parameter of the hybrid AFM process.
- Development of rheological abrasive media and different abrasive particles used in AFM processes.
- Experimental study of the effect of various processes parameter on performance characterstics and to find the optimal performance parameter and associated parametric setting.
- Study of morphology of the finished surface.
- Develop scientific theory to explain the process mechanism of the hybrid AFM by conducting detailed study of the surface produce with this processs. In this context, the objective is to develop FEM model of the flow of non-newtonian media used in AFM process.
- To study the economic feasibility of AFM as a substitute to the present metal finishing technology being used in india.

CHAPTER 3

DEVELOPMENT AND STUDY OF AFM SETUP

3.1 MACHINE CONSTRUCTION

Abrasive flow machining works under pressure of an abrasive laden, viscoelastic compound or abrasive media, through a holding fixture and over the area to be polished, deburred or radiused. A 2-Way Abrasive Flow Machine (AFM) works on the 2-Way Process.

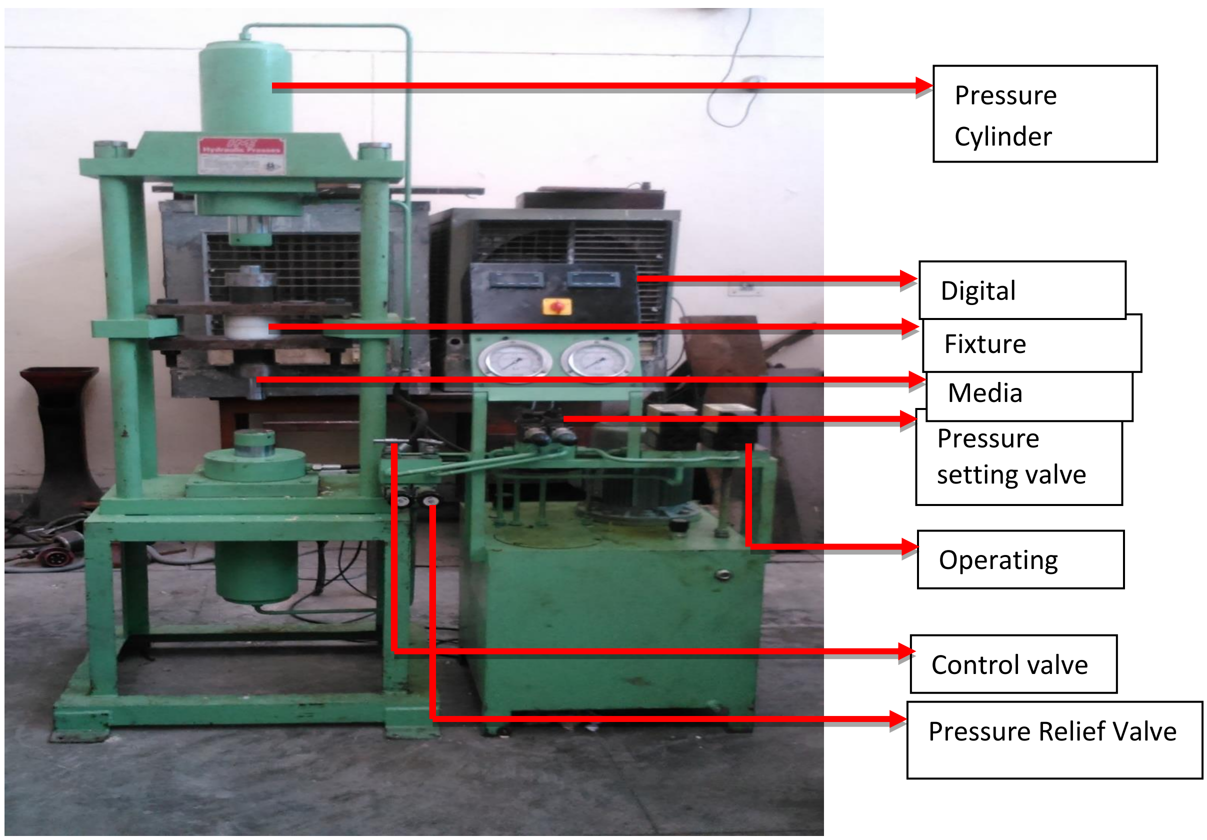

Figure 3.1: Fabricated two way AFM setup

It entrails the continuous back and forth extrusion of the pressurized abrasive media with the help of two opposed cylinders, along the surface of the work-piece. The cylinders are generally vertically mounted and are powered through hydraulic power systems.

Our 2-Way AFM setup consists of the following major components:

3.1.1 HYDRAULIC POWER PACK

It is the main driving component of the machine and is used to generate the back and forth movement of the piston in the hydraulic cylinders. It consists mainly of a motor, a reservoir, a filter and a hydraulic pump along with accompanying hydraulic circuit.

3.1.2 HYDRAULIC CYLINDERS

Our setup consists of two vertically opposed cylinders. The hydraulic cylinder comprises a cylinder barrel, in which a piston connected to a piston rod reciprocates linearly. The barrel is shut on one end by the cylinder bottom (also called the cap) and the other end by the cylinder head (also called the gland) where the piston rod arises out of the cylinder. The piston contains seals and sliding rings. The cylinder acts as a mechanical actuator by driving the piston through the action of a pressurised hydraulic fluid to generate a unidirectional force.

3.1.3 MEDIA CYLINDERS

Complementing the hydraulic cylinders are two media cylinders (opposed and vertically mounted) which are responsible for housing the abrasive media; and providing the working space for the action of the pistons.

3.1.4 FIXTURE DESIGN

Nylon was chosen as the material for the fixture because of its good wear properties. The basic design requirements of the fixture were that it provide:

- A constricting portion so that pressure is high and the abrasive grains lose their degree of freedom and act as cutting tools.
- A constant diameter portion in the middle for the work-piece to fit into.

- Constant pressure on the work-piece surface.

The dimensions of the tapering portion i.e. taper angle and taper length were decided after conducting fluid flow analyses on the software ANSYS CFX. The basic purpose of these analyses was to ensure that the design results in uniform pressure on the work walls which translates to uniform machining of the surface.

- Taper angle : **45 degrees**
- Taper length : **26 mm**
- Length of middle portion : **30 mm**

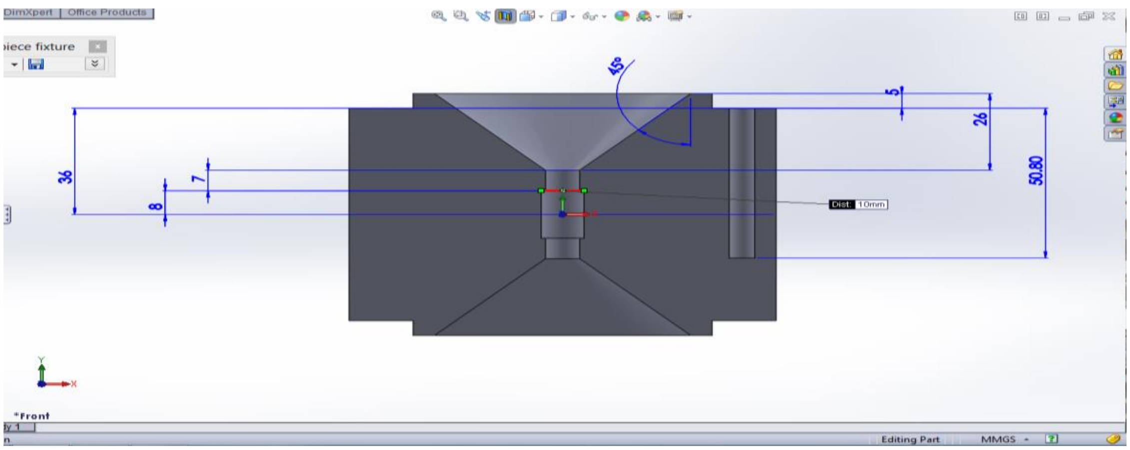

Figure 3.2: Solidworks Model of the fixture

3.2 MACHINE SPECIFICATIONS

Machine specifications were decided on the basis of the amount of abrasive media that had to be forced through the work-piece and the forces on the various components of the machine. Initially the pressure developing capacity of the machine was decided by our faculty advisor and on the basis of that calculations were carried out by the group using the theory studied in machine design.

The specifications for the reservoir used in the machine, the hydraulic cylinder and the motor to be used were finalised after discussions with the vendor "Hydromech Ltd." Our specifications were as follows:

1.	Type of the Press	2 Pillar Type Fabricated design
2	Capacity	25 + 25 Ton
3	Day Light Gap	1640 mm
4	Stroke length	96mm
5	Hydraulic Cylinder Bore dia.	2 No's.130 mm
6	Hydraulic Cylinder rod dia.	90 mm
7	Hydraulic cylinder Stroke	300 + 300 mm
8	Working Pressure	210 kg/cm ^{2}(3000 PSI)
9	Mode of Operation	HAND LEVER OPERATED
10	Electric Motor	1 No. 7.5 H.P. 3 Phase, 1440RPM
11	Flow Control Valve	2 No's (one for each Cylinder)
12	Oil Reservoir	1 No. 150 Litres

3.3 WORKING

A picture of the machine has been attached below with all the important parts labelled. The working is as follows:

3.3.1 PROVIDING TO AND FRO MOTION

The control valves are opened/ closed depending on which way the media is to be extruded. The LHS valve is for the upper hydraulic cylinder and the right one for the lower. Opening a valve basically allows the oil in the respective hydraulic cylinder to drain. So, downward stroke is obtained by closing the left valve and opening the right one and vice versa.

3.2.2 SETTING THE WORKING PRESSURE

The required working pressure is set using the pressure relief valves. A solid metallic bar is set between the hydraulic cylinder pistons and to and fro motion is provided using the control levers. During the downward stroke of the pistons, the lower side pressure is set using the RHS relief valve. Similarly, during the upward stroke the upper pressure is set using the LHS relief valve. The machine automatically decides on the higher pressures required.

Once the pressures are set, the polymer media is poured into the lower media cylinder with the piston in its bottom most position. The work-piece is inserted into the fixture and the two halves of the fixture are screwed together. The fixture is then set into place and the media cylinder flanges are bolted to the machine frame. The machine is then switched on, the hydraulic cylinders are made to come into contact with the media pistons and the required number of finishing cycles are completed.

3.3 VARIOUS MATERIALS USED FOR AFM CONSTRUCTION

Table 3.1: Materials used in AFM

Component	Constituents	Materials	Selection Criteria
Hydraulic cylinder	Cylinder barrel Bolts Piston Seal	Mild steel Cast Iron	Strength Wear resistant
Media Cylinder	Cylinder barrel Bolts Piston Seal	Mild steel	Stength, Sliding wear resistant
Piston	Head rod , Piston pad	Mild steel Nylon	Bearing and sliding resistance Strength
Work piece fixture	Fixture plate	Nylon	Wear resistane Strength

CHAPTER 4

EXPERIMENTAL DESIGN AND ANALYSIS

Design of experiment is considered to be a very useful strategy for accomplishing these tasks. The science of statistical experimental design originated with the work of Sir Ronald Fisher in England in 1920s. Fisher founded the basic principle of experimental design and the associated data-analysis technique called *Analysis of Variance* (ANOVA) during his efforts to improve the yield of agricultural crops [33]. The theory and applications of experimental design and the related technique of *response surface methodology* have been advanced by many statistical researchers as Box and Hunter [34].

4.1 TAGUCHI'S EXPERIMENTAL DESIGN AND ANALYSIS

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 are an intermediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

The Taguchi arrays can be derived or looked up. Small arrays can be drawn out manually; large arrays can be derived from deterministic algorithms. Generally, arrays can be found online. The arrays are selected by the number of parameters (variables) and the number of levels (states). This is further explained later in this article. Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic. The analysis of result in this approach is complex due to non- availability of generally guidelines [56].

4.1.2 EXPERIMENTAL DESIGN STRATEGY

Taguchi recommends orthogonal arrays (OA) for lying out of experiments. These OA's are generalized Graeco-Latin squares. To design an experiment is to select the most suitable OA and to assign the parameters and interactions of interest to the appropriate columns. The use of linear graphs and triangular tables suggested by Taguchi makes the assignment of parameters simple. The array forces all experimenters to design almost identical experiments[35] .

In the Taguchi method the results of the experiments are analyzed to achieve one or more of the following objectives[36] :

- To estimate the best or the optimum condition for a product or process.
- To estimate the contribution of individual parameters and interactions.
- To estimate the response under the optimum condition.

The optimum condition is identified by studying the main effects of each of the parameters. The main effects indicate the general trend of influence of each parameter. The knowledge of contribution of individual parameters is a key in deciding the nature of control to be established on a production process. The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments in determining the percent contribution of each parameter against a stated level of confidence. Study of ANOVA table for a given analysis helps to determine which of the parameters need control [37].

Taguchi suggests two different routes to carry out the complete analysis of the experiments. First the standard approach, where the results of a single run or the average of the repetitive runs are processed through main effect and ANOVA analysis (Raw data analysis). The second approach which Taguchi strongly recommends for multiple runs is to use signal-to-noise (S/N) ratio for the same steps in the analysis. The S/N ratio is a concurrent quality metric linked to the loss function. By maximizing the S/N ratio, the loss associated can be minimized. The S/N ratio determines the most robust set of operating conditions from variation within the results. The S/N ratio is treated as a response parameter (transform of raw data) of the experiment. Taguchi recommends [37] the use of outer OA to force the noise variation into the experiment i.e. the noise is intentionally introduced into the experiment.

4.1.3 LOSS FUNCTION AND S/N RATIO

The heart of Taguchi method is his definition of nebulous and elusive term *'quality'* as the characteristic that avoids loss to the society from the time the product is shipped [38]. Loss is measured in terms of monetary units and is related to quantifiable product characteristics. Taguchi defines quality loss via his 'loss-function'. He unites the financial loss with the functional specification through a quadratic relationship that comes from Taylor series expansion .

$L(y) = k(y-m)^2$

Where, L = loss in monetary unit

m = value at which the characteristic should be set

y = actual value of the characteristic

k = constant depending on the magnitude of the characteristic and the monetary unit involved.

This consequence of the continuous loss function illustrates the point that merely making a product within the specification limits does not necessarily mean that product is of good quality.

In a mass production process the average loss per unit is expressed as:

$$L(y) = \{k(y_1-m)^2 + k(y_2-m)^2 + \ldots\ldots\ldots\ldots + k(y_n - m)^2\} \qquad (4.1)$$

Where

y 1, y2 .... y_n = values of characteristics for units 1, 2,........n respectively

n = number of units in a given sample

k = constant depending upon the magnitude of characteristic and the monitory unit involve

m= Target value at which characteristic should be set.

L(y) =k (MSD)

Where MSD denotes mean square deviation, which presents the average squares of all deviations from the target value rather than around the average value.

Taguchi transformed the loss function into a concurrent statistic called S/N ratio, which combines both the mean level of the quality characteristic and variance around this mean into a single metric [33,34]. The S/N ratio consolidates several repetitions (at least two data points are required) into one value. A high value of S/N ratio indicates optimum value of quality with minimum variation. Depending upon the type of response, the following three types of S/N ratio are employed in practice.

1. Larger the better :

$(S/N)_{HB}$ = -10 log (MSD_{HB}) (4.2)

Where

MSD HB = $\frac{1}{2}\sum_{j=1}^{R}(\frac{12}{yj})$

2. Lower the better :

$(S/N)_{LB}$ = -10 log (MSD $_{LB}$) (4.3)

Where

MSD LB = 1/R $\sum_{j=1}^{R}(y21)$

3. Nominal the best :

$(S/N)_{LB}$ = -10 log (MSD $_{NB}$) (4.3)

Where

MSD NB = $\frac{1}{R}\sum_{J=1}^{R}\left(y_j - y_0\right)^2$

R = Number of repetitions

It is to be mentioned that for nominal the best type of characteristic, the standard definition of MSD has been used. For smaller the better type the target value is zero. For larger the better type, the inverse of each large value becomes a small value and again the target value is zero. Therefore, for all the three expressions the smallest magnitude of MSD is being sought. The constant 10 has been purposely used to magnify S/N number for each analysis and negative sign is used to set S/N ratio of larger the better relative to the square deviation of smaller the better.

4.1.4 TAGUCHI PROCEDURE FOR EXPERIMENTAL DESIGN AND ANALYSIS

Stepwise procedure for Taguchi experimental design and analysis and it is described in the following paragraphs.

4.1.4.1 SELECTION OF OA

In selecting an appropriate OA, the following prerequisites are required:

- Selection of process parameters and/or their interactions to be evaluated.
- Selection of number of levels for the selected parameters.

The determination of parameters to investigate, upon which hinges the product or process performance characteristics or responses of interest. Several methods are suggested by Taguchi for determining which parameters to include in an experiment. These are [39]:

- Brainstorming
- Flow charting
- Cause-effect diagrams

The total degrees of freedom (DOF) of an experiment are a direct function of total number of trials. If the number of levels of a parameter increases, the DOF of the parameter also increase because the DOF of a parameter is the number of levels minus one. Thus, increasing the number of levels for a parameter increases the total degrees of freedom in the experiment which in turn increases the total number of trials. Thus, two levels for each parameter are recommended to minimize the size of the experiment

[37]. If curved or higher order polynomial relationship between the parameters under study and the response is expected, at least three levels for each parameter should be considered [38]. The standard two-level and three-level arrays are:

a) Two-level arrays: L_4, L_8, L_{12}, L_{16}, L_{32}

b) Three-level arrays: L_9, L_{18}, L_{27}

The number as subscript in the array designation indicates the number of trials in that array. The degree of freedom (DOF) available in an OA is:

f_{LN} = N-1

Where f_{LN} = total degrees of freedom of an OA

L_N =OA designation N = number of trials

When a particular OA is selected for an experiment, the following inequality must be satisfied-

$f_{LN} \geq$ Total DOF required for parameters and interactions.

Depending on the number of levels in the parameters and total DOF required for the experiment, a suitable OA is selected.

4.1.4.2 ASSIGNMENT OF PARAMETERS AND INTERACTIONS TO OA

An ‘OA’ has several columns to which various parameters and their interactions are assigned. Linear graphs and Triangular tables are two tools, which are useful for deciding the possible interactions between the parameters and their assignment in the columns of ’OA’. Each ‘OA’ has its particular liner graphs and interaction tables.

4.1.4.3 SELECTION OF OUTER ARRAY

Taguchi separates factors (parameters) into two main groups:

- Controllable factors
- Noise factors

Controllable factors are factors that can easily be controlled. Noise factors, on the other hand, are nuisance variables that are difficult, impossible, or expensive to control.The noise factors are responsible for the performance variation of a process. Taguchi recommends the use of outer array for noise factors and inner array for the controllable factors. If an outer array is used the noise variation is forced into the experiment. However, experiments against the trial condition of the inner array may be repeated and in this case the noise variation is unforced in the experiment . The outer array, if used will have the same assignment considerations.

4.1.4.4 EXPERIMENTATION AND DATA COLLECTION

The experiment is performed against each of the trial conditions of the inner array. Each experiment at a trial condition is repeated simply (if outer array is not used) or according to the outer array (if used). Randomization should be carried for to reduce bias in the experiment.

4.1.4.5 DATA ANALYSIS

A number of methods have been suggested by Taguchi for analyzing the data: observation method, ranking method, column effect method, ANOVA, S/N ANOVA, plot of average responses, interaction graphs, etc. [37]. In the present investigation, following methods are used.

- Plot of average response curves
- ANOVA for raw data
- ANOVA for S/N data

The plot of average responses at each level of a parameter indicates the trend. It is a pictorial representation of the effect of a parameter on the response. Typically, ANOVA for OA’s are conducted in the same manner as other structured experiments [37]. The S/N ratio is treated as a response of the experiment, which is a measure of the variation within a trial when noise tors are present. A standard ANOVA is conducted on S/N ratio, which identified the significant parameters.

4.1.4.6 PARAMETER CLASSIFICATION AND SELECTION OF OPTIMAL LEVELS

ANOVA of raw data and S/N ratio identifies the control factors, which affect the average Kponse and the variation in the response respectively. The control factors are classified into four groups:

Group I : Parameters, which affect both average and variation

Group II : Parameters, which affect variation only

Group III : Parameters, which affect average only

Group IV : Parameters, which affect nothing

The parameter design strategy is to select the suitable levels of group I and II parameters to reduce variation and group III parameters to adjust the average values to the target value. The group IV parameters may be set at the most economical levels.

4.1.4.7 PREDICTION OF MEAN

After determination of the optimum condition, the mean of the response (u) at the optimum condition is predicted. This mean is estimated only from the significant parameters. The ANOVA identifies the significant parameters. Suppose, parameters A and B are significant and A2B2 (second level of both A and B) is the optimal treatment condition. Then, the mean at the optimal condition (optimal value of the response characteristic) is estimated [38] as:

$$\mu = T + (a_2 - t) + (b_2 - t)$$

$$= A_2 + B_2 - T$$

T= overall mean of the response

A_1 B_2= average values of response at the second levels of parameters A and B respectively

It may sometimes be possible that the predicated combination of parameter levels (optimal treatment condition) is identical to one of those in the experiment. If this situation exits, then the most direct way to estimate the mean for that treatment condition is to average out all the results for the trials which are set at those particular levels [37].

4.1.4.8 DETERMINATION OF CONFIDENCE INTERVALS

The estimate of the mean (p) is only a point estimate based on the average of results obtained from the experiment. It is a statistical requirement that the value of a parameter should be predicted along with a range within which it is likely to fall for a given level of confidence.

This range is called confidence interval (CI). Taguchi suggests two types of confidence intervals for estimated mean of optimal treatment conditions.

- CI_{CE} - Confidence Interval (when confirmation experiments (CE)) around the estimated average of a treatment condition used in confirmation experiment to verify predictions. Get; is for only a small group made under specified conditions.
- CI_{POP} - Confidence Interval of population; around the estimated average of a treatment condition predicted from the experiment. This is for the entire population i.e. all parts made under the specified conditions.

The confidence interval of confirmation experiments (CI_{CE}) and of population (CI_{POP}) is calculated by using the following equations :

$$CI_{CE} = \sqrt{F_a\,(1, f_e)V_e\,\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} \qquad (4.4)$$

$$CI_{POP} = \sqrt{\frac{F_a\,(1, f_e)V_e}{n_{eff}}} \qquad (4.5)$$

Where

F_{α} (l, f_e) = The F-ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom f_e., f_e = error DOF, N = Total number of result, R = Sample size for confirmation experiments, V_e = Error variance,

$$n_{eff} = \frac{N}{1 + [DOF\ associated\ in\ the\ estimate\ of\ mean\ responce]}$$

4.1.4.8 CONFIRMATION EXPERIMENT

The confirmation experiment is the final step in verifying the conclusions from the previous round of experimentation. The optimum conditions are set for the significant parameters (the insignificant parameters are set at economic levels) and a selected number of tests are run under specified conditions. The average values of the responses obtained from confirmation experiments are compared with the predicted values. The average values of the response characteristic obtained through the confirmation experiments should be within the 95% confidence interval, CI_{CE}. However, these may or may not be within 95% confidence interval, CI_{POP}. The confirmation experiment is a crucial step and is highly recommended to verify the experimental conclusions [37].

CHAPTER 5

PROCESSES PARAMETER SELECTION AND EXPERIMENTATION

Abrasive flow machining is used for ultra finishing and material removal. The response parameters are selected which may affect the machining characterstics such as material removal and surface finish. The scheme of experiment is also discussed in this chapter. Here experiment were conducted within the range of selected process parameter which includes level of CNT, extrusion pressure and number of cycle at different level. After conducting the experiment material removal and surface finish are measured.

5.1 MEDIA PREPARATION

The polymer was formed by reacting 1 kg of dimethyl silicone oil, 10 grams of $FeCl_3.6H_2O$ (Lewis Acid Reagent) and 60 grams of pyro-boric acid at a temperature of 200-250^{0}C with agitation so that a highly viscous boron-organo-silicon hetero-polymer was made. This was reacted with 30 grams of NH_4CO_3 to neutralize any acid remainder. The resulting material was slightly brittle, stiff and flaky.

The gel used to alter the polymer is made by the reaction of a metal soap with a hydrocarbon oil. The metallic soap component is generally a salt which is substantially water insoluble. These salts of metallic acids are also referred to as metallic stearates. The hydrocarbon oil is the second component which is used in the formation of the gel.

The gel was formed by mixing 30 grams of aluminum stearate with 500 grams of the hydrocarbon oil (naphthalene oil) at room temperature accompanied by constant stirring. The composition was heated to the gelation temperature and held there for 15 minutes to form a relatively thick gel.

5.1.1 ABRASIVES

The abrasive constituent of the composition or grit is of any orthodox abrasive materials used in honing applications i.e. aluminium oxide, silicon carbide, diamond dust etc. The size of the grid may vary over a wide range of depending upon the job to be done and the desired physical properties. The size may vary from 20 mesh to 600 mesh, and can also be as low as 2 to 5 microns.

Abrasive used : Aluminium Oxide + CNT particle

Mesh Size **:** 200

The media was prepared by mixing 300 grams of the polymer with 100 grams of the prepared gel at room temperature. After thorough mixing, the mixture was kneaded until it was homogeneous. Thereafter, 400 grams of aluminium oxide abrasive particles of 200 mesh size and CNT particle were added and mixed with the polymer and the gel composition. At this point, the mixture had taken to a paste like consistency.

5.1.2 CARBON NANOTUBES (CNT)

Carbon Nanotubes, long, thin cylinders of carbon, were discovered in 1991 by Sumio Iijima. These are large macromolecules that are unique for their size, shape, and remarkable physical properties[64]. They can be thought of as a sheet of graphite (a hexagonal lattice of carbon) rolled into a cylinder. These intriguing structures have sparked much excitement in recent years and a large amount of research has been dedicated to their understanding. Currently, the physical properties are still being discovered and disputed. Nanotubes have a very broad range of electronic, thermal, and structural properties that change depending on the different kinds of nanotube (defined by its diameter, length, and chirality, or twist). To make things more interesting, besides having a single cylindrical wall (SWNTs), Nanotubes can have multiple walls (MWNTs)-cylinders inside the other cylinders.

5.1.2.1 PROPERTIES OF CARBON NANOTUBES

The structure of a carbon nanotube is formed by a layer of carbon atoms that are bonded together in a hexagonal (honeycomb) mesh. This one-atom thick layer of carbon is called graphene, and it is wrapped in the shape of a cylinder and bonded together to form a carbon nanotube. Nanotubes can have a single outer wall of carbon, or they can be made of multiple walls (cylinders inside other cylinders of carbon).

Carbon nanotubes have a range of electric, thermal, and structural properties that can change based on the physical design of the nanotube.

5.1.2.2 APPLICATION OF CNT

- Field Emitters/Emission:
- Conductive or reinforced plastics
- Molecular electronics: CNT based non volatile RAM
- CNT based transistors
- Energy Storage
- CNT based fibers and fabrics
- CNT based ceramics

5.1.2.3 CNT MAKING THROUGH CHEMICAL VAPOR DEPOSITION

The CVD approach allows CNTs to grow on a variety of materials, which makes it more viable to integrate into already existent processes for synthesizing electronics. This process involves the chemical breakdown of a hydrocarbon on a substrate. It is main way to grow carbon nanotubes is by exciting carbon atoms that are in contact with metallic catalyst particles. The CVD method extends this idea by embedding these metallic particles in properly aligned holes in a substrate. There are 1 gm of ferrosene and 50 ml toluene is mixed it and wait until ovan temperature 800 degree Celsius is achieved. Then, a hydrocarbon such as acetylene is heated and decomposed onto the substrate.

.


Figure 5.1: CVD setup

The carbon comes into contact with the metal particles embedded in the holes and start to form nanotubes that are "templated" from the shape of the tunnel. It turns out that the carbon nanotubes grow very long and very well aligned, in the angle of the tunnel.

The advantages of this method are that the yield is very high, the alignment of the nanotubes is consistent (which is crucial for creating particular types of nanotubes, e.g. semiconductor or metallic), and the size of the growth area is theoretically arbitrary. The main disadvantage is that, though the size of the growth area is basically arbitrary, large sized areas (several millimeters) tend to crack, shrink, and otherwise warp. The substrates need to be dried very thoroughly to prevent against this.

5.1.3 MEDIA

The media relates to a flow-able, abrasive mixture encompassing a viscous carrier laden with abrasive grains for honing, abrading, de-burring etc. a surface, by reciprocating the composition along the surface under pressure at varying velocities.

The composition comprises a poly-boron-organo silicon (the polymer) compound and loaded with abrasive grains and altered with a considerably water insoluble gel made from a metallic soap and a hydrocarbon oil. The composition is characterized by the gel which produces and sustains the preferred consistency of the composition. The polymer, when altered with the gel of the metal soap and hydrocarbon oil is soft and readily flow-able and has a consistency changing between a paste and biscuit dough during mixing and use. The composition has varying degrees of inner lubricity with very little resilience when dropped with or without abrasive. The polymer, modified with the gel does not noticeably increase in hardness or reduce in flow-ability under static pressure. In general, the ratio of the gel to the polymer might vary between 1 to 4 and 4 to 1, preferably it should vary between 1 to 2 and 2 to 1 and most preferably is 1 to 1.

Figure 5.2: Al_2O_3 abrasive particle mixed with media

Figure 5.3: Media mixed with CNT and Al_2O_3 abrasive particle

5.2 SELECTION OF WORKPIECE

Experiment is conducted on the brass material with different level of parameter. The material brass have compostion of yellow brass: 65% cu, 35% zinc. The length to diameter of workpiece was decided on the basis of the recommendation given by Kohut [25]. The cavity to be machined in the test specimen was prepared by drilling operation followed by boring to the required size. The size of cylindrical work piece is of length 16 mm, internal and external diameters are 8 and 10 mm as shown in figure 5.1.

Each workpiece was machined for a predetermined number of cycle. The work-piece was taken out from from the setup and cleaned with acetone before measurement.

Figure 5.4: Brass workpiece used in AFM

5.3 SELECTION OF PROCESS PARAMETER AND THEIR RANGES

The major process parameter which may affect the machining characteristics were decided on the basis of literature . the selected parameter and their range for detailed experiment are shown in table 5.1

Table 5.1: Selected Process Parameters and their Range

S.No.	**Process Parameter**	**Range**	**Unit**
1	CNT	5-10	Gm
2	Extrusion Pressure	10-30	N/mm^2
3	Number of cycles	2-8	No.
4	Abrasive particle size	200-250	Grade
5	Media Flow Volume	300	Cm^3
6	Abrasive to media concentration	1.1 - 1:1	% by weight
7	Polymer-to-Gel Ratio	1:1	% by weight
8	Temperature of media	32 ±2	°C
9	Reduction Ratio	0.95	—
10	Initial Surface Roughness	1.46-2.704	μm

5.4 RESPONSE CHARACTERISTICS

The effect of selected process parameter was studied on the following response characteristics of AFM process:

- Percentage improvement in surface roughness (R_a)
- Material Removal (MR)

5.4.1 PERCENTAGE IMPROVEMENT IN SURFACE ROUGHNESS (ΔRA)

The surface roughness (R_a) was measured at several random locations on the internal cylindrical surface using a taylor hobson Surface Roughness Tester. The average of R_a was calculated and the percentage improvement in roughness was estimated as:

$$\Delta R_a = \frac{(initial\ Roughtness - Roughness\ after\ machining) x\ 100}{initial\ Roughness}$$

This characteristic was chosen for the reason that machining by drilling, turning, boring etc. Almost always has an unavoidable variability in surface roughness value, which may affect the final roughness value.

Figure 5.5: Taylor Hobson equipment

5.4.2 MATERIAL REMOVAL

Material removal rate was not taken as a response parameter in AFM process because the amount of material removal changes from time to time and it is a function of surface roughness or surface conditions. The material removal signifies the amount of material that has been removed from a specimen in a specified number of process cycles. It was estimated by citing the difference between initial weight of the specimen and final weight of the specimen after processing at a specified set of conditions by Drill bit assisted AFM. A precision electronic balance CAY 220 of least count 0.1 mg was used to measure the weight of the specimens.

5.5 SCHEME OF EXPERIMENTS

The experiments were designed to study the effect of some of the response parameters on the characteristics of AFM process. The design was accorded to an L9 orthogonal array based on Taguchi method to study the effect of helix rod and other main AFM process parameter. The main parameters of level of CNT (C), Extrusion pressure (p) , Number of cycle (N) have been selected at three levels considering no-interaction among them. The non-linear behavior, if exist among the process parameters can be studied if more than two levels of the process parameters are used. The quality characteristics under the consideration are material removal and percentage improvement in surface roughness (ΔRa). The selected no of process parameter and their levels are given in table no 5.2

Table 5.2: Process parameters and their values at different levels

Symbol	Process Parameters	Unit	Level 1	Level 2	Level 3
P	Amount of CNT	Gm	Without CNT	5 gram CNT	10 gram CNT
C	Pressure	Bar	10	20	30
N	No. Of Cycle	Number	2	5	8
Polymer to Gel ratio :1:1, Workpiece Material- Aluminium ,Abrasive type Al_2O_3 &CNT, Mesh Size:180, Extrusion Pressure: 5 MPa, Media Flow Volume :290cm3,Temperature:32 ± 2 °C, Initial surface roughness : 1.28 - 2.96 microns					

Table 5.3: L_9 (3^3)OA (Parameters Assigned) with Response

Exp. No.	Run Order	Parameters Trial Conditions				Response (Raw Data)			S/N Ratio (db)
		C	P	N	---------	R1	R2	R3	
		1	2	3	4				
1	1	1(0)	1(10)	1(2)	1	Y_{11}	Y_{12}	Y_{13}	S/N(1)
2	2	1(0)	2(20)	2(5)	2	Y_{21}	Y_{22}	Y_{23}	S/N(2)
3	3	1(0)	3(30)	3(8)	3	Y_{31}	Y_{32}	Y_{33}	S/N(3)
4	4	2(5)	1(10)	2(5)	3	Y_{41}	Y_{42}	Y_{43}	S/N(4)
5	5	2(5)	2(20)	3(8)	1	Y_{51}	Y_{52}	Y_{53}	S/N(5)
6	6	2(5)	3(10)	1(2)	2	Y_{61}	Y_{62}	Y_{63}	S/N(6)
7	7	3(10)	1(10)	3(8)	2	Y_{71}	Y_{72}	Y_{73}	S/N(7)
8	8	3(10)	2(20)	1(2)	3	Y_{81}	Y_{82}	Y_{83}	S/N(8)
9	9	3(10)	3(30)	2(5)	1	Y_{91}	Y_{92}	Y_{93}	S/N((9)
Total					Σ		Σ	Σ	

R1, R2, R3 represents response value for three repetitions of each trial. The 1's,2's, and 3's represents levels 1,2,3 of the parameters, which appear at the top of the column.(---) represents no assignment in the column. Y_{ij} are the measured values of the quality characteristics (response)

5.6 EXPERIMENTATION

The three process parameters viz. CNT, Extrusion Pressure and Number of Cycles are selected as given in Table The parameters which were kept constant are also given in the Table 5.2. The process parameters were varied according to the values as shown in Table 5.2. Experiments were conducted according to the test conditions specified by the L_9OA (Table 5.3). Each experiment was repeated three times in each of the trial conditions. Thus, 27 work-pieces were selected having initial surface in close range of (1.42-2.70). In each of the trial conditions and for every replication, the percentage improvement in surface roughness and material removal were measured. The data is recorded in Table 5.4.

Table 5.4: Experiment Result of Various Response Characteristics

Exp No.	Run Order	% Improvement in Ra			S/N ratio (db)	Material Removal (MR) (mg)			S/N ratio (db)
		R1	R2	R3		R1	R2	R3	
1	1	34.91	40.18	35.94	31.39	1.2	1.8	1.5	3.16
2	2	24.30	25.56	33.64	28.64	1.2	1.5	1.9	3.26
3	3	33.02	33.76	30.02	30.14	1.2	1.5	2	3.34
4	4	36.74	36.87	27.7	30.33	1.5	1.7	2	4.59
5	5	31.23	27.63	25.38	28.87	2.1	2.1	2.4	6.79
6	6	39.92	38.53	45.42	28.87	1.4	1.9	1.1	2.69
7	7	24.02	32.89	26.05	28.61	2.7	2.1	2.4	7.46
8	8	27.75	30.54	26.09	28.90	1.8	2.1	2.1	5.95
9	9	25.91	28.04	26.18	28.51	1.5	1.8	1.2	3.16
Total		277.6	294	276.42		14.6	16.5	16.6	
		$T_{\Delta Ra}$ = Overall mean of **ΔRa=31.40%**				T_{MR} =Overall mean of MR =1.76 mg			

CHAPTER 6

ANALYSIS AND DISCOURSE OF RESULTS

6.1 ANALYSIS AND DISCUSSION OF RESULTS

The experiments were planned by using the parametric approach of the Taguchi's method. The standard procedure to analyze the data as suggested by Taguchi's , is employed. The same method has been used here. The average values and S/N ratio of quality/response characteristics for each parameter at different levels are calculated from experimental data. The main effect of process parameter both for raw data and S/N data are plotted. The response curves (main effect) are used for examining the parametric effect of response characteristics. The most favorable condition (optimal setting) of process parameters in term of mean response characteristics by analyzing response curves and the ANOVA tables.

The results of experiments provide insight into the surface wear behavior of selected brass material when it is processes by AFM. The effect independent AFM process parameters of level of CNT, Extrusion pressure, Number of cycle (while keeping other parameter constant) on selected response characteristics (material removal and percentage improvement in surface roughness) have been discussed further. The average values of response characteristics and S/N ratio (in db) for each parameter at the selected three different levels (L_1, L2, and L3) are calculated from table 5.4.

6.1.1. EFFECT ON MATERIAL REMOVAL

The average values of response characteristics and S/N ratio (in db) for each parameter at the selected three different levels (L_1, L2, and L3) are calculated. The average value of material removal (MR) and S/N ratio for each parameter at levels L_1, L_2, L_3 are calculated and given in table 6.1.

Table 6.1: Average Values and Main Effect: Material Removal, MR (in mg)

Process Parameter	Level	Amount of CNT(C)		Pressure(P)		No. of Cycle (N)	
Type of Data		Raw Data	S/N Ratio	Raw Data	S/N Ratio	Raw Data	S/N Ratio
Average Values(%Ra)	L1	1.53	3.25	1.87	5.07	1.65	3.93
	L2	1.8	4.69	1.91	5.33	1.58	3.67
	L3	1.96	5.52	1.51	3.06	2.05	5.86
Main Effects(%Ra)	L2-L1	0.26	1.4	0.03	0.25	-0.06	-0.26
	L3-L2	0.16	0.83	-0.4	-2.26	0.46	2.19
Difference (L3-L2)–(L2-L1)		-0.1	-0.60	-0.43	-2.52	0.53	2.45
(L2-L1) is the average main effect when the corresponding parameter changes from Level 1 to 2. (L3-L2)is the main effect when the corresponding parameter changes from Level 2 to Level 3.							

The main effects of different process parameter on the MR are plotted in figure 6.1(a), (b), (c) :

Figure 6.1(a) material removal increases when cycle increases 0 to 5 gm at second level and when cycle is operating at third level material removal is increases but lower than second cycle. Material removal is more in second level of CNT as compared to third level of CNT because initially more cutting edges are in contact with the workpiece, hence the number of peaks that can be sheared increases , leading to more material. It concluded overall effect of level of CNT on material removal is increased , observed by ANOVA tables (table nos. 6.2 and 6.3) for raw data and S/N ratio data. Material removal is more in second level of CNT as compared to third level of CNT.

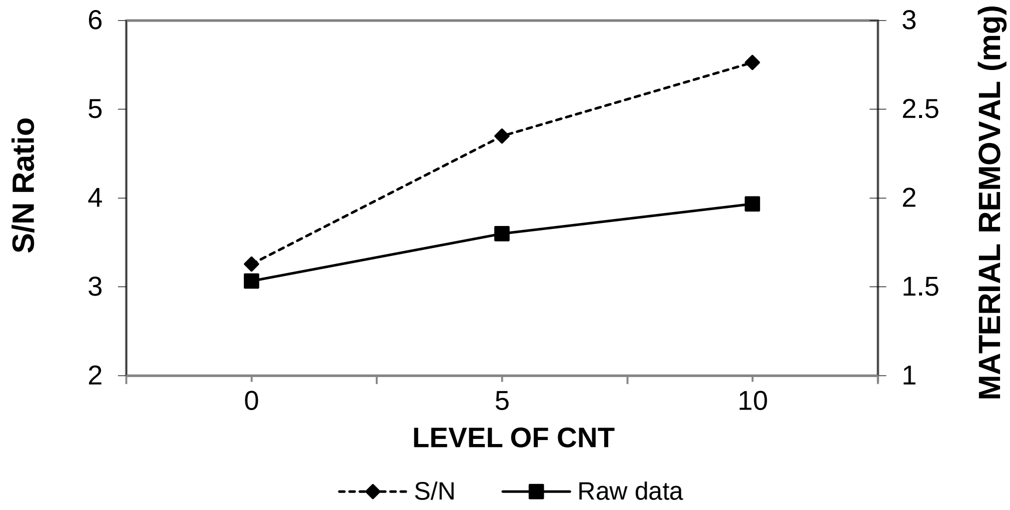

Figure 6.1(a): Effect of CNT on (MR and S/N Ratio)

Figure 6.1(a) material removal increases when cycle increases 0 to 5 gm at second level and when cycle is operating at third level material removal is increases but lower than second cycle. Material removal is more in second level of CNT as compared to third level of CNT because initially more cutting edges are in contact with the workpiece, hence the number of peaks that can be sheared increases , leading to more material. It concluded overall effect of level of CNT on material removal is increased , observed by ANOVA tables (table nos. 6.2 and 6.3) for raw data and S/N ratio data.

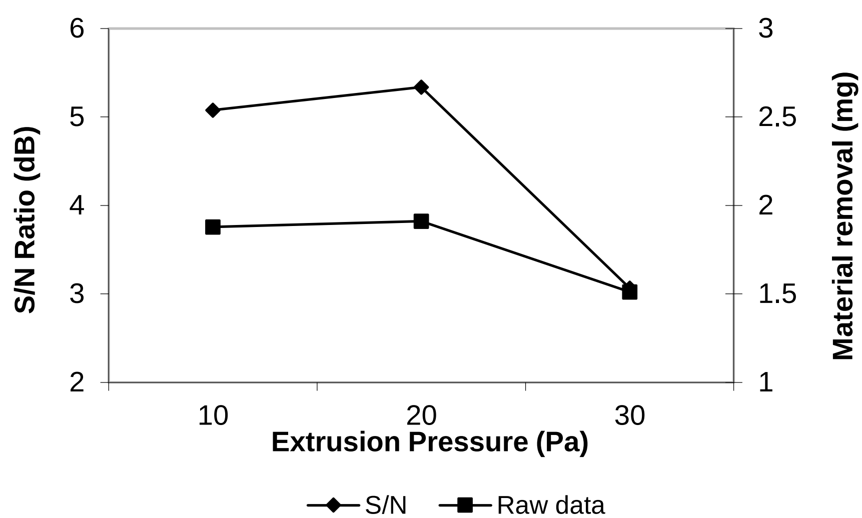

Figure 6.1(b): Effect of Extrusion Pressure on (MR and S/N Ratio)

Figure 6.1 (b) show that with increases of extrusion pressure material increases which is maximum at second level i.e. at 20 MPa and material removal is reduced at third level of extrusion pressure i.e. at 30 MPa. With increases the extrusion pressure at third level reduced in material removal , this is due to cutting edge deteriorates with higher pressure . The effect of extrusion pressure on material removal is observed by ANOVA table based on Raw data and S/N ratio (6.2).

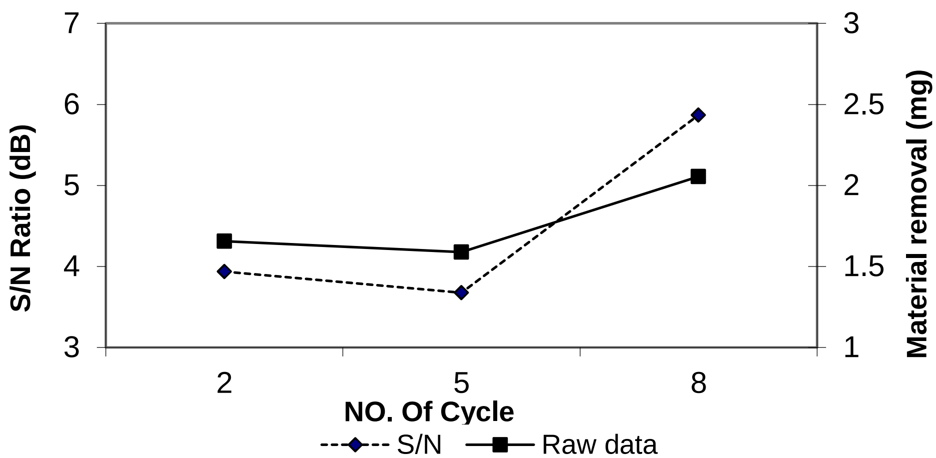

Figure 6.1(c): Effect of Number of Cycle on S/N Ratio (db) and MR

Figure 6.1(c) shows the effect of number of cycle is on material removal .when number of cycle is increased from 2 to 5 cycle then it is observed that material removal is little bit decreases but as increases number of cycle significant material removal is observed. This is due to more number of active cutting edge comes in contact with the workpiece. More rubbing action takes place with no of cycle increases which result in more material removal is observed. However rubbing action deteriorate the surface finish. The effect of NO of cycle is significant in ANOVA table based on Raw data and S/N ratio table (6.3).

6.1.1.1 SELECTION OF OPTIMAL LEVELS

The study of significance parameter towards the MR, analysis of variance (ANOVA) was performed. The pooled version of ANOVA of raw data and S/N data for MR are given in tables 6.2 & 6.3.The percentage contribution of CNT is 14.98%, percentage contribution of Extrusion pressure is 15.56% and the percentage contribution of Number of cycle is

21.22%. As we know that material removal is "higher the better" type quality characteristic. Therefore, higher value of MR is considered to be optimal. It is clear from the figure 6.1 (a,b,c) that material removal is higher at level of C_3 P_1 N_3 .

Table 6.2: Pooled ANOVA (Raw Data MR)

Source	SS	DOF	V	F-Ratio	SS'	P%
Amount of CNT	0.86	2	0.43	5.03*	0.68	14.98
Pressure	0.88	2	0.44	5.19*	0.71	15.56
No. of Cycle	1.146	2	0.57	6.71*	0.97	21.21
Error (e)	1.70	20	0.085	…………	2.21	48.23
Total (T)	4.6	26	----------	----------	4.6	100
*Significant at 95% confidence level, F critical =3.4928						

S/N ratio analysis suggest (P_2) levels of parameter as the best levels for max MR.

Table 6.3: Pooled ANOVA (S/N Ratio Data, MR)

Source	SS	DOF	V	F-Ratio	SS'	P%
Amount of CNT	7.92	2	3.96	79.38*	7.82	30.19
Pressure	9.25	2	4.62	92.74*	9.15	35.34
No. of Cycle	8.62	2	4.31	86.44*	8.52	32.91
Error(e)	0.099	2	0.049	------	0.39	1.54
Total (T)	25.89	8	--------	-------	25.89	100
*Significant at 95% confidence level, F critical =19 SS-Sum of Squares, DOF-Degree of Freedom, V-Variance, SS'-Pure sum of Squares						

6.1.2 EFFECT ON % IMPROVEMENT IN SURFACE ROUGHNESS

The average value of %age improvement in surface roughness and S/N ratio for each parameter at level L_1, L_2, $L_3$are calculated and given in table 6.4.

Table 6.4: Average values and Main effect; %age improvement in R_a (ΔR_a)

Process Parameter	Level	Amount of CNT(C)		Pressure(P)		No. of Cycle (N)	
Type of Data		Raw Data	S/N Ratio	Raw Data	S/N Ratio	Raw Data	S/N Ratio
Average Values(%Ra)	L1	32.37	30.03	32.81	30.08	35.45	30.82
	L2	34.38	30.48	27.99	28.80	29.43	29.16
	L3	27.47	28.67	33.42	30.30	29.33	29.21
Main Effects(%Ra)	L2-L1	2.01	0.45	-4.82	-1.58	-6.01	-1.66
	L3-L2	-6.90	-1.80	5.43	1.41	-0.10	0.048
Difference (L3-L2)–(L2-L1)		-8.91	-2.26	10.2544	3.08	5.91	1.71
L1,L2,L3 represent levels 1,2 and 3 respectively of parameters. (L2-L1) is the average main effect .When the corresponding parameter changes from Level 1 to Level 2. (L3-L2)is the main effect .When the corresponding parameter changes from Level 2 to Level 3							

Figure 6.2(a) shows the variation of % improvement of surface finish with level of CNT. When the level of CNT is increased from 0-5 gm then surface finish % increased but as level of CNT at third level (10gm) ,surface finish improvement decreases.

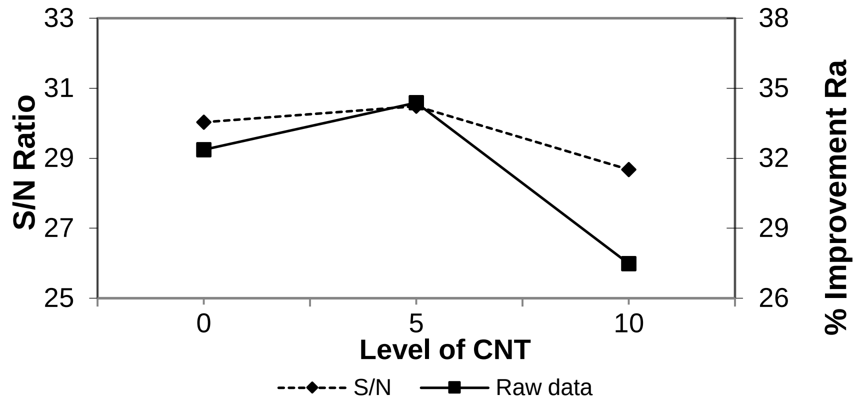

Fig 6.2(a): Effect Of level of CNT on %age improvement in R_a

It can be observed from the figure 6.2 (b) that increases in pressure first decreases surface finish up to second level and after second level surface finish starts improving. According to raw and S/N ratio data the maximum surface finish is achieved at 30 pressure. Both the analysis pedicts the deterioation of surface finish up to second level.

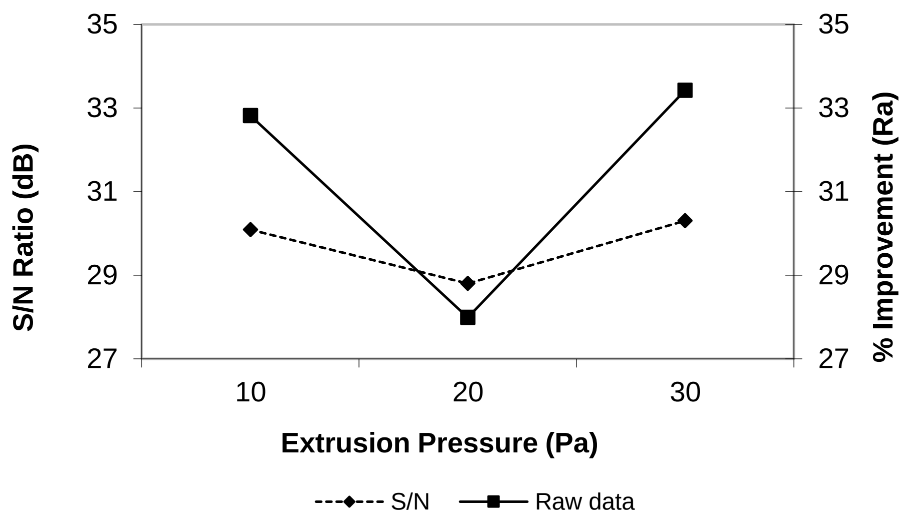

Figure 6.2(b): Effect of Extrusion Pressure on % improvement Roughness (ΔRa)

from figure 6.2 (c), it can be noted that increases in the number of cycle initially leads to deteriorating surface finish and after the second level small change in surafce finish. It is observed increasing the number of cycle deterioation of the surafce finish.

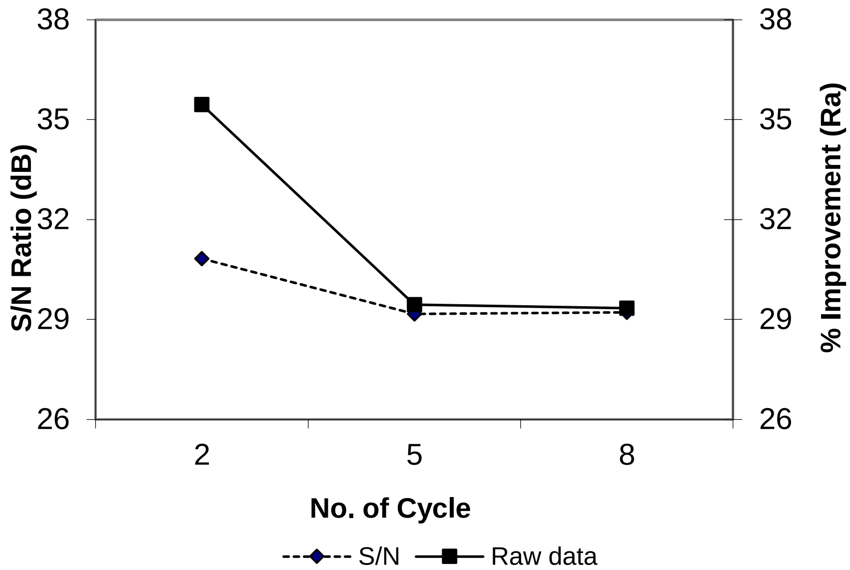

Fig 6.2(c): Effect of Number of Cycle on (ΔRa and S/N Ratio)

6.1.2.1 SELECTION OF OPTIMUM LEVELS

Analysis of variance (ANOVA) wae performed to study the significance of of process parameter towards the percentage improvement in R_a.

Table 6.5: Pooled ANOVA(Raw Data,%age imp in ΔRa)

Source	SS	DOF	V	F-Ratio	SS'	P%
Amount of CNT	226.84	2	113.42	9.35*	202.59	23.84
Pressure	159.39	2	79.69	6.57*	135.14	15.90
No. of Cycle	220.83	2	110.41	9.10*	196.58	23.13
Error (e)	242.47	20	12.12	……..	315.22	37.10
Total (T)	849.54	26	…..	…….	849.54	100
*Significant at 95% confidence level, F critical =3.4928 SS-Sum of Squares, DOF-Degree of Freedom, V-Variance, SS'-Pure sum of Squares						

The pooled version of ANOVA of raw data and the S/N data for ΔR_a are given in Table 6.5& 6.6. The percentage contribution of level of CNT is maximum is 23.84%.The percentage contribution of number of cycle is i.e. 23.14% followed by extrusion pressur which contribute 15.90% .The percentage improvement in R_a.is “higher the better” type of quality characteristics. There for heigher value of ΔR_a are considered to be optimal. Optimal level are selected for improvement of surface finish is C_2P_3 N_1.

The S/N ratio analysis (refer table 6.6 and figure 6.2) suggest (C_2P_3 N_1) levels of parameter as tha best level for maximum % improvement in ΔRa of brass workpiece in AFM process.

Table 6.6: Pooled ANOVA (S/N Ratio Data, %age imp in ΔR_a)

Source	SS	DOF	V	F-Ratio	SS’	P%
Amount of CNT	5.29	2	2.64	43.81*	5.17	35.11
Extrusion pressure	3.93	2	1.96	32.57*	3.81	25.89
No of cycle	5.38	2	2.69	44.55*	5.26	35.71
Error(e)	0.12	2	0.06	------	0.48	3.28
Total (T)	14.74	8	--------	------	14.74	100
*Significant at 95% confidence level, F critical =19 SS-Sum of Squares, DOF-Degree of Freedom, V-Variance, SS’-Pure sum of Squares						

6.2 ESTIMATION OF OPTIMUM RESPONSE CHARACTERSTICS

The optimum values of the response characteristics along with their respective confidence intervals have been predicted. The results of confirmation experiments have also been presented to validate optimal result .The optimal level of the process parameters have been identified from the selected response characteristics. The optimal value each response characteristic is predicted considering the effect of the significant parameters only. The average value of the response characteristic obtained through the confirmation experiments must lie with in the 95% confidence level, CE_{CE} (equation 4.5).However the average value of quality characteristic obtained from the confirmation experiments may or may not lie within 95% confidence interval, CL_{POP} (calculated for the mean of the population, equation 4.6), The Taguchi approach for the predicted means has been presents in section (Chapter 4).It is observed that optimum values for the maximum MR are level C_3P_1 N_3 for raw data and C_2P_3 N_1 for S/N data.

6.2.1 MATERIAL REMOVAL (MR)

The mean at the optimal MR (optimum values of the response characteristics) is estimated [55] as $MR = C_3 + P_1 + N_3 - 2\,T$

T = overall mean of the response = 1.76 mg (referTable 5.4)

Average value of MR at the third level of CNT

= 1.97 mg (refer table 6.1)

Average value of MR at the first level of Extrusion pressure

= 1.91 mg (refer table 6.1)

Average value of MR at the third level of no.of cycle

= 2.06 mg (refer table 6.1)

Substituting these values, MR = 2.42 mg

The confidence interval of confirmation experiments (CL_{CE}) and of population (CL_{POP}) is calculated by using the following equation [4.1]

$$CI_{CE} = \sqrt{F_a\,(1, f_e)V_e\,\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]}$$

$$CI_{POP} = \sqrt{\frac{F_a\,(1, f_e) V_e}{n_{eff}}}$$

Where $F_{\alpha}\,(1, f_e)$ = The F- ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom f_e = 3.49 (Tabulated value)

f_e = error DOF = 20 (Table 6.2)

N = Total no of result =27 (treatment =9, repetition =3)

R = Sample size for confirmation experiments = 3

V_e = Error variance =0.09 (Table 6.5)

$$n_{eff} = \frac{N}{1+[DOF\ associated\ in\ the\ estimate\ of\ mean\ responce]} \qquad = 3.86$$

So, $CL_{CE} = \pm\ 0.42$

and $CL_{POP} = \pm\ 0.28$

The 95% confirmation interval of predicted optimal range (for confirmation run of three experiment) is:

Mean MR – CI_{CE} < MR < MR + CI_{CE}

2 < MR < 2.84

The 95% confirmation interval of the predicted mean is :

Mean MR – CI_{pop} <MR < MR + CI_{pop}

2.14 < MR < 2.7

6.2.2 PERCENTAGE IMPROVEMENT IN SURFACE ROUGHNESS

The mean of the percentage improvement in R_a optimum values of the response characteristics is estimated as :

$$\Delta R_a = C_2 + P_3 + N_1 - 2T$$

T = overall mean of the response = **31.40%** (Table 5.4)

Average value of % age improvement in R_a at the second level of CNT

= 34.38 %

Average value of % age improvement in R_a at the third level of pressure

= 33.42% (refer table 6.4)

Average value of % age improvement in R_a at the first level of number of cycle

= 35.45 % (refer table 6.4)

Substituting these values, % improvement in R_a = 40.43 %

The confidence interval of confirmation experiments (CL_{CE}) and of population (CL_{POP}) calculated by using the following equation :

$$CI_{CE} = \sqrt{F_a\,(1, f_e)V_e\,\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]}$$

$$CI_{POP} = \sqrt{\frac{F_a\,(1, f_e)V_e}{n_{eff}}}$$

Where $F_\alpha(1, f_e)$ = The F- ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom fe = 3.4928(Tabulated Value)

fe =error DOF = 20 (Table 6.5)

N= Total no of result =27 (treatment =9, repetition =3)

R = Sample size for confirmation experiments = 3

Ve = Error variance =12.13 (Table 6.5)

$$n_{eff} = \frac{N}{1+[DOF\ associated\ in\ the\ estimate\ of\ mean\ responce]}$$

= 3.86

So, CL_{CE} = ± 5.00

and CL_{POP} = ± 3.31

The 95% confirmation interval of predicted optimal range (for confirmation run of three experiment) is:

34.56 < %age improvement in $\Delta \mathbf{R_a}$ < 45.44

The 95%age confirmation interval of predicted mean is

37.11 <%age improvement in $\Delta \mathbf{R_a}$ < 43.74

6.3 CONFIRMATION EXPERIMENTS

In order to validate the results obtained, three confirmation experiments have been conducted for response characteristics of MR and %age improvement surface roughness .For the maximum MR, the optimal levels of the process parameter are C_3P_1 N_3.Whereas for the maximum %age improvement surface roughness the optimal parameters settings are C_2P_3 N_1.

C_3 –3 level of CNT are used(10gm).

C_2 –2 level of CNT are used(5gm).

N_2 – Second level of number of cycles (5 cycles)

N_3 - Third level of number of cycle(8cycle)

P_1 – Extrusion Pressure at the first level (10 MPa)

P3 – Extrusion Pressure at the third level (30 MPa)

The results are given in Table 6.7. The values of MR and %age improvement in Ra obtained through the confirmation experiments are within 95% of CI_{CE} of respective response characteristic. It is to be pointed out that these optimal values are within the specified range of process parameters (Table 5.2). Any exploration should be confirmed through additional experiments.

Table 6.7: Predicted Optimal Values, Confidence Intervals and Results of Confirmation Experiments

Response Characteristic	Optimal Process Parameters	Predicted Optimal Value	Confidence Intervals 95%	Actual Value(Avg of Confirmation Exp)
MR	C_3P_1 N_3.	2.42 mg	CI_{CE} : 2 <MR< 2.84 CI_{POP}: 2.14 < MR < 2.7	2.49 Mg
%Improvement	C_2P_3 N_1	40.43%	CI_{CE}: 34.56 < ΔR_a < 45.44 CI_{POP} :37.11< ΔR_a < 43.74	41.29 Mg
CI_{CE} – Confidence interval for the mean of the confirmation experiments CI_{POP} – Confidence interval for the mean of the population				

CHAPTER 7

CONCLUSION AND SCOPE FOR FUTURE WORK

The investigation into abrasive flow machining (AFM) process for exploring the possibility of improvement in its process efficiency by varying different response parameter as CNT, extrusion pressure and no. of cycle and modified abrasive media etc . The hybrid abrasive flow machining (AFM) suggested in the research work can be considered as one of the important processes in the field of micro-finishing or machining of precision components.

7.1 CONCLUSIONS

The important conclusion for this research work are enlisted below:

1. The study of abrasive flow machining process was done successfully.
2. Effect of CNT and other parameter are observed during study to optimize the material removal and surface finish.
3. AFM setup was tested for the internal finishing of brass work-piece.
4. The main process parameter of level of CNT, extrusion pressure and number of cycle have been optimized using the Taguchi's method.
5. The three parameter have significant effect on the response parameter of MR and percentage improvement in surface finish.
6. Three parameter affects the material removal and surface finish, by using level of CNT material removal continuosly increased among other parameter while surface roughness is improved up to second level after decreases. In case of No of cycle from first level to second level material is decreased after that increased but for surface roughness improvement is little bit significant. Third parameter extrusion pressure have little bit significant on MR but highly significant for surface roughness improvement.
7. Effect of CNT on material removal is continously increases. The percentage contribution of CNT is 14.98%.and the effect of other parameter on MR are percentage contribution of Extrusion pressure is 15.56% and the percentage

contribution of Number of cycle is 21.22%. optimum level is selected for material ermoavl is C_3 P_1 $N_{3.}$

8. Effect of CNT on improvement on surface finish the percentage contribution of CNT is maximum is 23.84%.The percentage contribution of number of cycle is 23.14% and extrusion pressur which contribute 15.90%.Optimal level are selected for improvement of surface finish is C_2P_3 $N_{1.}$

7.2 SCOPE FOR FUTURE WORK

1. Design and development of experimental setup capable of providing varying range of parameter of the hybrid AFM process.
2. Development of rheological abrasive media and different abrasive particles used in AFM processes.
3. Experimental study of the effect of various processes parameter on performance characterstics and to find the optimal performance parameter and associated parametric setting.
4. Study of morphology of the finished surface.
5. Develop scientific theory to explain the process mechanism of the hybrid AFM by conducting detailed study of the surface produce with this processs. In this context, the objective is to develop FEM model of the flow of non-newtonian media used in AFM process

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