COMPUTATIONAL AND EXPERIMENTAL STUDY OF CNT PARTICLES BASED ABRASIVE MEDIA USED IN ABRASIVE FLOW MACHINING FOR ALUMINIUM WORKPIECE

A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

PRODUCTION ENGINEERING

BY

PARVESH ALI

(ROLL NO- 2K12/PRD/14)

GUIDED BY

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CANDIDATE'S DECLERATION

I hereby certify that the work which is being presented in this thesis entitled, "**Computational and Experimental study of CNT particles based abrasive media used in Abrasive flow Machining for Aluminium workpiece**" in partial fulfillment of the requirements for the award of **Master of Technology Degree** in **Production Engineering** at **Delhi Technological University**, **Delhi** is an authentic work carried out by me under the supervision of Prof. Vikas Rastogi and Dr. R.S. Walia in Mechanical, Production, Industrial and Automobile Engineering department.

The matter embodied in this report has not submitted to any other university/institute for award of any degree.

(Parvesh Ali)

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

Prof. Vikas Rastogi **Dr. R.S Walia**

Date:

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While bringing out this thesis to its final form, I came across a number of people whose contributions in various ways helped my field of research and they deserve special thanks. It is a pleasure to convey my gratitude to all of them.

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Parvesh Ali

INDEX

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

CHAPTER 7

CHAPTER 8

LIST OF FIGURES

LIST OF TABLE

LIST OF SYMBOLS

S.No.	Symbol	
1.	S/N	Signal to Noise Ratio
2.	L_N	OA designation
3.	f_{LN}	Total degree of freedom of an OA
4.	R	Number of repetitions
5.	$\bar{T}$	Overall mean of the responses
6.	$\bar{A}_2, \bar{B}_2$	Average values of responses at the second level of parameters A&B
7.	CI_{CE}	Confidence Interval
8.	CI_{POP}	Confidence Interval of Population
9.	$F\alpha$	The F-Ratio at the confidence level of (1- α) against DOF 1
10.	f_e	Error DOF
11.	Ve	Error Variance

ABSTRACT

Abrasive Flow machining (AFM) is a fine finishing process for internal inaccessible cavities or recesses. It employs an abrasives laden semi-solid media, which is self-deforming and can finish the complex cavities under a hydraulic pressure. This method has a unique property of simultaneous improvement in material removal and surface finish. During the fine finishing of components using Abrasive flow Machining there is a important role of pressure distribution, velocity and temperature distribution at different points in Abrasive Flow Machining. To improve the efficiency of the process, it is very important to know the critical parameter. A three dimensional model of Abrasive flow machining was developed to analyze the effect of parameters (Pressure, Velocity, Temperature) by using Ansys 14 and Fluent software. Abrasive flow Machining has a limitation of low material removal. To minimize this limitation an experiment has been conducted by using (carbon nano tube)CNT as abrasive along with Al_2O_3 in the AFM to get more material removal and better surface quality.

Chapter 1

INTRODUCTION

Finishing of a part improves its aesthetics and functional performance i.e. the fine finished parts have better dimensional controls, endurance strength and thus more life. In the recent times, there are requirements of fine finished products with close dimensional controls along with increasing complexity in their shapes. For such finishing requirements, Abrasive flow machining (AFM) process is a most suitable non conventional finishing process. It is a nontraditional polishing process to polish metallic components using a semi-liquid paste, and with which complicated or miniaturized parts requiring high surface finish can be economically produced [1]. Extrusion of abrasives laden media (made up of a liquid polymer with abrasive particles) through a controlled passage results in the abrasion of the required surfaces due the cutting action of a number of randomly oriented cutting points of abrasives. This process is mainly suitable for the complex shaped internal cavities or for the fine finishing of micro size holes/slots (even for the simultaneous polishing of different cavities).

1.1 NON CONVENTIONAL MANUFACTURING PROCESSES

From the last many years different nontraditional manufacturing processes have been invented and successfully implemented into production. The conventional manufacturing processes which are being used these days mainly rely on the electric motors and hard tool materials to perform task such as swaging, drilling and broaching. Conventional forming operations are performed with the energy from electric motors, hydraulics and gravity.

Merchant [2] analyzed the need 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. According to him three outstanding needs of future manufacturing technology are:

- Sustained productivity in face of rising strength barrier.

- Higher accuracy consistent with the increasing demand for better tolerances.
- Versatility of automation

Among various mechanical non conventional processes, Abrasive Flow machining process possesses special capabilities for providing very good surface finish, low damage to mechanical surface and fine complex details inside the inaccessible regions on the workpiece when compared to other processes in the category.

1.2 AFM Process

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 [3]. 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 [4]. 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 [5].

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.

1.3 BASIC PRINCIPLE OF AFM

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

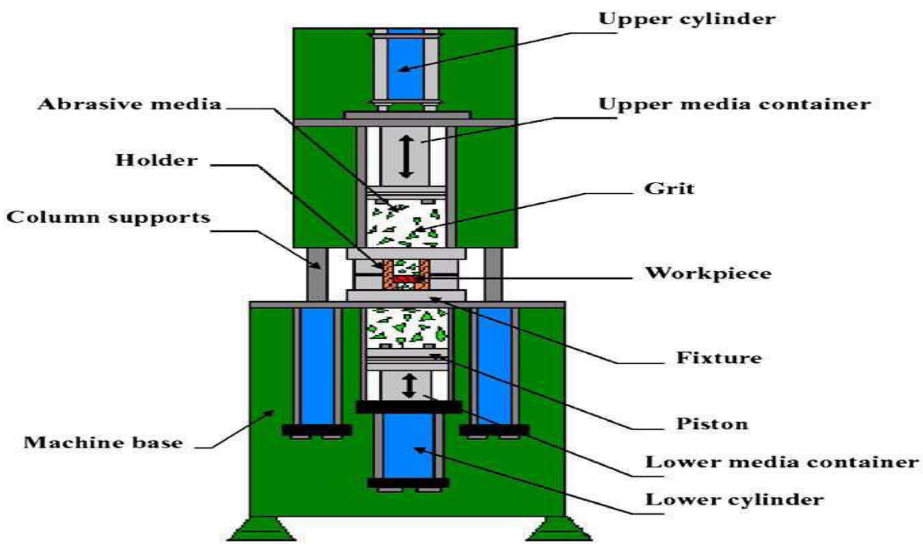

Figure 1: Schematic of Abrasive Flow Machining (Principle and Basic Operation) [6]

1.4 CLASSIFICATION OF AFM MACHINES

On the basis of working and configuration, AFM is classified into three major categories one way AFM [7], two way AFM [8] and orbital AFM [9], but normally two way AFM is used for commercial application.

1.4.1 ONE WAY AFM

One way AFM process as shown in Fig.2 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.

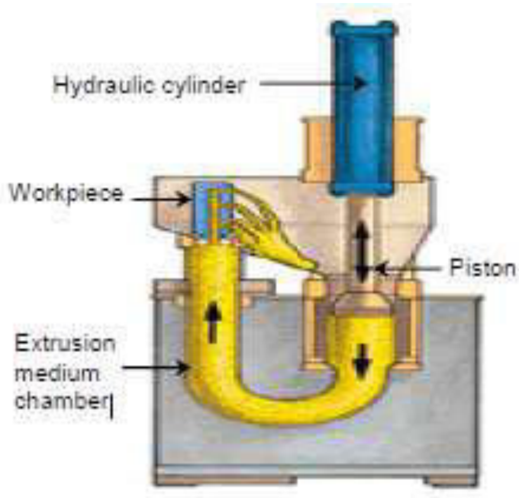

Figure2.Shown operation of One way AFM [10]

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 3. 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.[11]

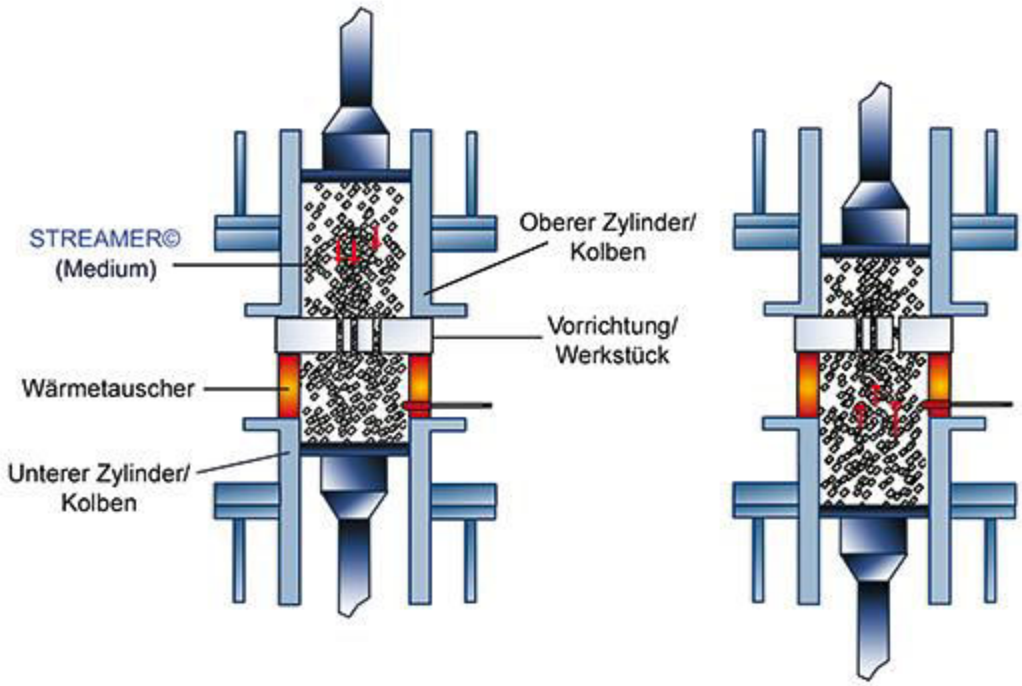

Fig 3. Shown operation of Two way AFM [12]

1.4.3 ORBITAL AFM

In this process good surface finishing is obtained by producing low-amplitude oscillations of the work piece [13].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.

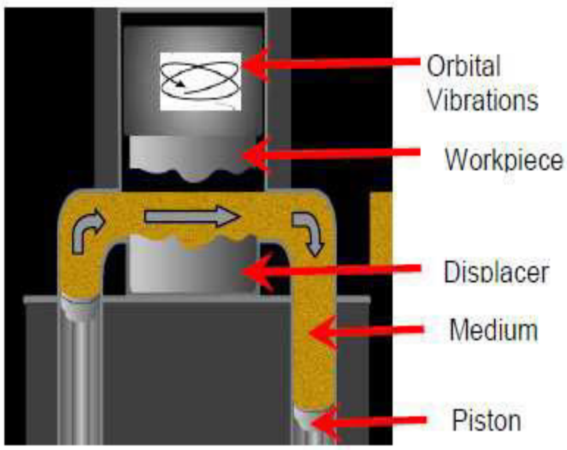

Figure.4. Operational set up of Orbital AFM before start of finishing [13]

In Orbital AFM as shown in Figure 4, due to mechanical vibrations both flow and orbital motion is obtained in working zone. This process can perform three dimensional precise polishing and finishing on the edges and surface for complex shape and cavities.

1.5 AFM ELEMENTS

The major elements of the equipment required to perform AFM include the machine, tooling and abrasive laden media. In general terms, the abrasive media determines what kind of abrasion occurs, the fixture determines exact location of abrasion, and machine decides the extent of abrasion.

1.5.1 MACHINE

All AFM machines used are positively displacement hydraulic systems, where workpiece clamps between two vertically opposed media cylinder. The media is extruded from one cylinder to the other by creating the pressure difference .An abrasion action is produced whenever the media passes through the restrictive passage .AFM systems are essentially provided with controls on hydraulic system pressure, clamping and unclamping of fixtures and advance and retract of pistons.

1.5.2 FIXTURE OR TOOLING

Fixture design is a very important factor in achieving the desired effects from the AFM process [14]. The functions of the fixture are:

- Holding the parts in the proper position between the two opposed media cylinders.
- It provides restriction in the path of media flow and controls the media action.
- Assisting, loading, unloading or cleaning operations.
- During the process cycle it directs the media to flow to and from the areas of the part to be worked on.
- Protecting edges or surfaces from abrasion due to media flow.

Fixture is made of Nylon, Aluminium, Steel, and Teflon. Mainly Nylon is used because of low cost and better machinability and lightweight.

1.5.3 MEDIA

AFM uses a non Newtonian liquid polymer containing abrasives particles of Aluminium oxide, Silicone carbide, Boron carbide or diamond as the grinding medium and additives [15]. The additives are used to modify the base polymer to get the desired flowability and rheological characteristics of media.

Fig 5. Extrude Hone's abrasive media [16]

1.6 AFM APPLICATIONS

AFM can simultaneously process multiple parts or many areas of a single workpiece. Inaccessible areas and complex internal passages can be finished economically and effectively. Large surface irregularities such as deep scratches or large bumps cannot be removed by AFM because material is removed equally from all surfaces. So imperfections, such as out-of-roundness and taper, cannot be corrected (Walia R.S) [17].

Some of the successful fields and applications of AFM are enlisted in this section:

- AFM allows for extremely fine finishes on very complex geometry and difficult to reach surfaces like the air inlet manifold of I.C Engines and in a broad range of materials.
- Chemical, Textile and Pharmaceutical industries (for deburring, rounding of edges and polishing in difficult to reach areas of process components of the

brewery, beverages dairy and food industries requiring high hygiene and sterile manufacturing conditions).

- Medical technology (such as machining implantable devices, Finishing cannula tubes for surgical implantation, Pharmaceutical machines).
- Polishing surfaces to mirror like requirements minimizes the amount of microscopic and/or inaccessible areas that enable contamination or entrapment.
- For process industry (Finishing impellers, Integrally bladed rotor, compressor wheels and gears).
- It can also be employed for removing left or light machining marks.
- Removing thermal recast layers after EDM, or LBM machining process.
- Automobile industry (Finishing of two stroke cylinder and four stroke engine head, splines, valve and fitting).

Figure 6 - Intake manifold after manual AFM processing[18]

Chapter 2

LITERATURE REVIEW AND PROBLEM IDENTIFICATION

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

2.1 EFFECT OF AFM PROCESS PARAMETERS

The material removed from the surface and surface quality depends on the following: (1) No. of Cycle (2) Extrusion Pressure (3) Temperature (4) Media Flow rate (5) Viscosity (6) Abrasive particle size (7) Abrasive concentration (8) Particle density (9) Particle Hardness

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

2.1.1 Number of Process Cycles

The travel of media from lower cylinder to upper cylinder and then back to lower cylinder is termed as a cycle. Several cycles are required to get a particular amount of material removal and final surface finish on a component. Various researchers have reported that the improvement in surface finish and required amount of material removal occurs in some of the initial cycles and then it stabilizes. Jain V.K. [19] concluded that initially the material removal is higher at the starting of cycle and after increasing no. of cycles the material removal decreases. Jain and Adsul [20] reported from the experimental observations that on increasing the no. of cycles the value of surface roughness decreases. Mamilla Ravi Sankar et al. [21] reported that as the no. of cycle increases, the total no. of indentations by abrasive also increases, so material removal increases. But as the number of cycle increases, the material removal decreases because initial unfinished surface has sharp peaks so shearing of these peak is easy.

2.1.2 Extrusion pressure

It has been seen from the experiment that for better surface finish extrusion pressure should be high. If low extrusion pressure is used with low abrasive concentration and small grain size the surface finish will decrease. If low extrusion pressure is used with larger grains, it causes uneven distribution and that results the variation in the surface finish of two work pieces. So for better surface finish optimum combination of extrusion pressure, grain mesh size and abrasive concentration is required [22]. Jain et al. [23] and Jain and Adsul [20] mentioned according to their experimental observation that large extrusion pressure decreases the surface roughness up to certain value. Przyklenk K., Rhoades L.J., William R.E. et al. [24, 25, 26] reported that cutting is faster at high pressure when all other parameters are kept constant. Jain [27] reported that at higher pressure the improvement in material removal just tends to stabilize probably due to localized rolling of abrasion particles.

2.1.3 Media Temperature

Temperature is a very important parameter in AFM because it tells about the effectiveness of the AFM process. Liang Fang et al. [28] investigated that as the no. of cycle increases the temperature continuously increases. It causes less material removal.

2.1.4 Media Flow Volume

These are dominant process parameters controlling the amount of abrasion by a specific media composition. Keeping all factors constant a greater volume of media will cause more abrasion. If two passage of different cross sectional area are given the same media flow volume, smaller passage will abrade more than the larger one[29]. The volume of the media contained in the media cylinder is called media flow volume. It controls the amount of abrasion and surface finish on the workpiece. Kohut [30] reported that if all other process parameters are kept constant larger volume of media will cause more abrasion.

2.1.5 Media Flow Rate

Perry [31] reported that when the media flow rate is higher it causes more abrasion. Media flow rate depends upon the parameters such as viscosity of media, pressure that effects the uniformity of the material removal. Rhoades [25] reported that the effect of media flow rate in the material removal is negligible.

2.1.6 Media viscosity

Viscosity of media is the significant parameter affecting the quality of surface finish and amount of material removal in AFM process. Media viscosity is affected by type of abrasives, its concentration and size of grains. It is also strongly affected by the working temperatures. In general, increase in temperature causes appreciable decrease in media viscosity, which may result in 'settling' of grains thereby influencing the flow properties and overall abrasion process. Liang Fang et al. [28] reported that the media with high viscosity causes more material removal in comparison to low viscosity media. High viscosity media also causes the improvement in surface roughness. Davies and

Fletcher [32] reported by experiments that viscosity of the media is significantly affected by temperature. Viscosity of highly viscous medium reduces very fast with a small increase in temperature (2-10 °C). Material removal capacity of the low and high viscous media is different from each other [33].

2.1.7 Abrasive Particle Size

Abrasive grain sizes range used in AFM varies from 500 grit (tiny hole applications) to 8 grit (roughing and stock removal applications). Larger abrasives cut faster, while smaller size gives better finish and can reach into complex and narrow passages. Davies et al. [32] reported that smaller size abrasive gives better surface finish and can reach into complex and narrow passages because smaller size abrasive will cause finer but large number of cuts on the workpiece, while larger one cut faster.

2.1.8 Abrasives Concentration

It is the ratio of weight of abrasive particles to the weight of carrier compound multiplied by 100. Jain V.K. [34] concluded that as the abrasive concentration of abrasive in medium increases the material removal increases while surface roughness value decreases because number of active grains increases.

2.1.9 Initial Surface Condition

Jain V.K. concluded that material removal depends upon the hardness of the workpiece and the condition of the initial surface finish. Softer material has higher material removal. It has a good surface finish as compared to harder material. Loveless et al. [35] reported that the type of machining operation used to prepare the specimen prior to AFM is important and affects the improvement achieved during finishing.

2.2 OBJECTIVES OF CNT BASED ABRASIVE FLOW MACHINING

AFM process improves surface finishing but it has a limitation that the material removal in the AFM process is very low. So effort was done to increase the material removal by using harder abrasives (CNT) along with Al_2O_3 abrasive particles in AFM process.

- Development of Abrasive Flow Machining set up.
- Development of CNT particles and feasibility study to use CNT particles as abrasive in AFM.
- Experimental Study of the effect of various process parameters on the performance characteristics and to optimize the important parameters for the finishing of Aluminium workpiece.
- Modelling of media flow path in AFM process using Ansys 14.

Chapter 3

EXPERIMENTAL DESIGN AND ANALYSIS

Design of experiments (DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. However, in statistics, these terms are usually used for controlled. A properly planned and executed experiment is of the utmost importance for deriving clear and accurate conclusions from the experimental observations. 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. 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, Box and Draper, Hicks. Various types of matrices are used for planning experiments to study several decision variables. Among them, Taguchi's Method makes heavy use of orthogonal arrays.

3.1 TAGUCHI'S EXPERIMENTAL DESIGN AND ANALYSIS

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

3.2 PHILOSOPHY OF TAGUCHI METHOD

1. Quality should be designed into a product, not inspected into it. Quality is designed into a process through system design, parameter design, and tolerance design. Parameter design, which will be the focus of this article, is performed by determining what process parameters most affect the product and then designing them to give a specified target quality of product. Quality "inspected into" a product means that the product is produced at random quality levels and those too far from the mean are simply thrown out.

2. Quality is best achieved by minimizing the deviation from a target. The product should be designed so that it is immune to uncontrollable environmental factors. In other words, the signal (product quality) to noise (uncontrollable factors) ratio should be high.

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

3.3 Taguchi Method Design of Experiments

The general steps involved in the Taguchi Method are as follows:

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

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

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

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

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

3.4 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.

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

- 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.

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 the use of outer OA to force the noise variation into the experiment i.e. the noise is intentionally introduced into the experiment. Generally, processes are subjected to many noise factors that in combination strongly influence the variation of the response. For extremely 'noisy' systems, it is not generally necessary to identify controllable parameters and analyze them using an appropriate S/N ratio. In the present investigation, both the analysis: the raw data analysis and S/N data analysis have been performed. The effects of the selected Helical AFM parameters on the selected quality characteristics have been investigated through the plots of the main effects based on raw data. The optimum condition for each of the quality characteristics have been establish through S/N data analysis. No outer array has been used and instead, experiments have been repeated three times at each experimental condition.

3.5 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 [50]. 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.

The following two observations can be made

- The further the product's characteristic varies from the target value, the greater is the loss. The loss is zero when the quality characteristic of the product meets its target value.
- The loss is a continuous function and not a sudden step as in the case of traditional approach.

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:

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

Where

$y_1, y_2 \dots\dots\ y_n$ = 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.

Equation can be written as:

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 .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})

Where

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

2. Lower the better :

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

Where

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

3. Nominal the best :

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

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.

3.6 Taguchi Procedure for Experimental Design and Analysis

Figure 5.2 illustrates the stepwise procedure for Taguchi experimental design and analysis. It is described in the following paragraphs.

(A). 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 :

- 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 . 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. 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 [59]:

$f_{LN} \geq$ 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.

(B). 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

(C). 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.

(D). 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.

(E). 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.. 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 . 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.

(F). Parameter design strategy

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.

(G).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 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 .

(H). 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:

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

$$CI_{POP} = \sqrt{\frac{F_a\,(1, f_e) V_e}{n_{eff}}} \qquad \text{(Equation 2)}$$

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,

$$n_{eff} = \frac{N}{1+[\text{DOF associated in the estimate of mean responce}]} \quad \text{(Equation 3)}$$

(I). 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 .

Chapter 4

DEVELOPMENT OF CNT BASED ABRASIVE FLOW MACHINING

4.1 AFM COMPONENTS

The two way AFM pressurizes the abrasive media to flow through the internal cylindrical surface of the hollow workpiece. The abrasive laden media interacts with the surface and causes material removal from it. In the two way AFM the motion from top to bottom and from bottom to top constitutes a single cycle. The main components used in AFM set up are Hydraulic Power Pack, Hydraulic Cylinders, Media Cylinders, Fixture and Machine Frame. The main components used in the AFM are as follows-

4.1.1 Hydraulic Power Pack

It is the main driving component of the workpiece. It causes the back and forth movement of piston in the hydraulic cylinder. It consists motor, reservoir, filter and hydraulic pump along with accompanying hydraulic circuit.

Fig. 7 Photograph of Hydraulic power pack

4.1.2 Hydraulic Cylinders

In the AFM set up there are two vertical cylinders which are co axially opposite to each other. In this the piston moves from top to bottom and from bottom to top due to pressure difference in the cylinder barrel. The barrel is closed on one side by cylinder bottom and other end by cylinder head called as gland. The cylinder acts as a mechanical actuator by driving the piston through the action of a pressurized hydraulic fluid to generate a unidirectional force.

Fig. 8 Photograph of Hydraulic Cylinders

4.1.3 Media Cylinders

In the 2 way AFM, two media cylinders are used which are vertical and opposite to each other. The media cylinder consists the mixture of the gel, polymer and the abrasive particles which is forced to flow through the hollow workpiece.

Fig. 9 Photograph of Media Cylinder

4.1.4 Fixture

The fixture is made of Nylon. It holds the workpiece and causes the media to flow through the workpiece. The fixture is made of Nylon because it has good wear properties.

Fig.10 Photograph of Fixture

4.1.5 Machine Frame

It provides the support and the holding strength. By providing the holding strength to the machine components it reduces the chance of variability in the results during the experiments. It is required that during the experiments, noise value should be low for a given input (signal) as high S/N value is required. So it helps in maintaining high S/N value.

Fig.11 Photograph of Machine Frame

Fig 12. Photograph of developed AFM set up

4.2 CARBON NANO TUBE

A Carbon Nano tube is a tube-shaped material, made of carbon, having a diameter measuring on the nanometer scale. A nanometer is one-billionth of a meter, or about one ten-thousandth of the thickness of a human hair. The graphite layer appears somewhat like a rolled-up chicken wire with a continuous unbroken hexagonal mesh and carbon molecules at the apexes of the hexagons. Carbon Nanotubes have many structures, differing in length, thickness, and in the type of helicity and number of layers. Although they are formed from essentially the same graphite sheet, their electrical characteristics differ depending on these variations, acting either as metals or as semiconductors. As a group, Carbon Nanotubes typically have diameters ranging from <1 nm up to 50 nm. Their lengths are typically several microns, but recent advancements have made the nanotubes much longer, and measured in centimeters. The carbon network of the shells is closely related to the honeycomb arrangement of the carbon atoms in the graphite sheets. The amazing mechanical and electronic properties of the nanotubes stem in their quasi-one-dimensional (1D) structure and the graphite-like arrangement of the carbon atoms in the shells. Thus, the nanotubes have high Young's modulus and tensile strength, which makes them preferable for composite materials with improved mechanical properties.

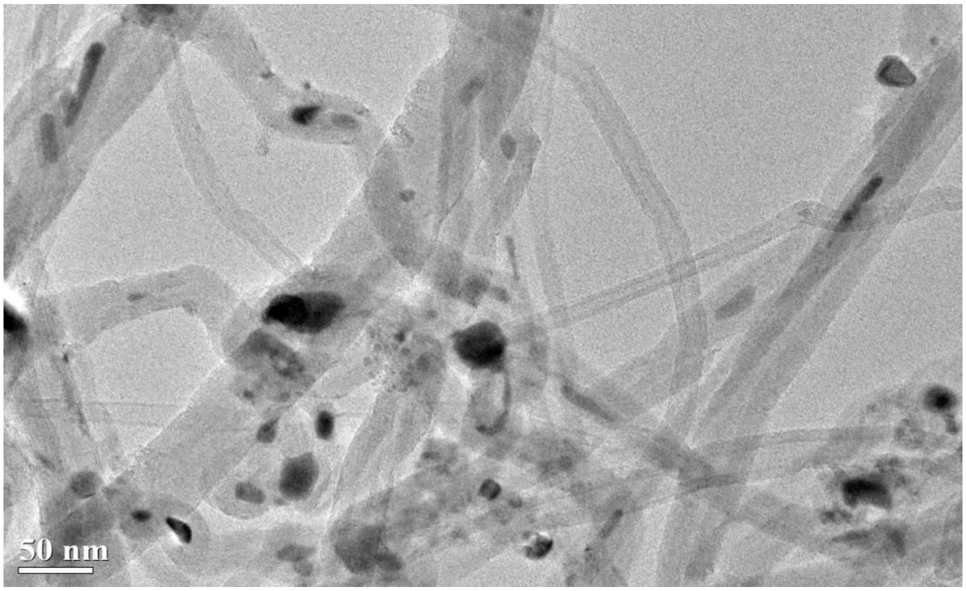

Fig 13. TEM image of CNT

4.3 APPLICATIONS OF CARBON NANO TUBE

- Conductive plastics
- Structural composite materials
- Flat-panel displays
- Gas storage
- Antifouling paint
- Micro- and nano-electronics
- Radar-absorbing coating
- Technical textiles
- Ultra-capacitors
- Atomic Force Microscope (AFM) tips
- Batteries with improved lifetime
- Biosensors for harmful gases
- Extra strong fibers

4.4 METHOD OF MAKING IRON BASED CARBON NANO TUBES

In the making of Carbon Nano Tubes main apparatus used were oven, tube, beaker, cylinders of argon and hydrogen for shielding. Firstly the oven is heated to achieve the temperature of about 800 degree Celsius. A beaker is taken then 1 gram of ferosene and 50 ml toluene is mixed in it and wait for the oven to achieve 800 degree Celsius. The tube is few angle tilted in oven. Then the mixed fluid is dropped in the tube and argon and hydrogen gas is provided around it because it is a inert gas and it is dropped into liquid. If the bubbles are being produced it means that gas is flowing. After some time switch off the button and allow it to cool slowly. Then after cooling 5 to 6 hours carbon nano tube is prepared. Figure 13 shows the flow diagram for producing carbon nano tube.

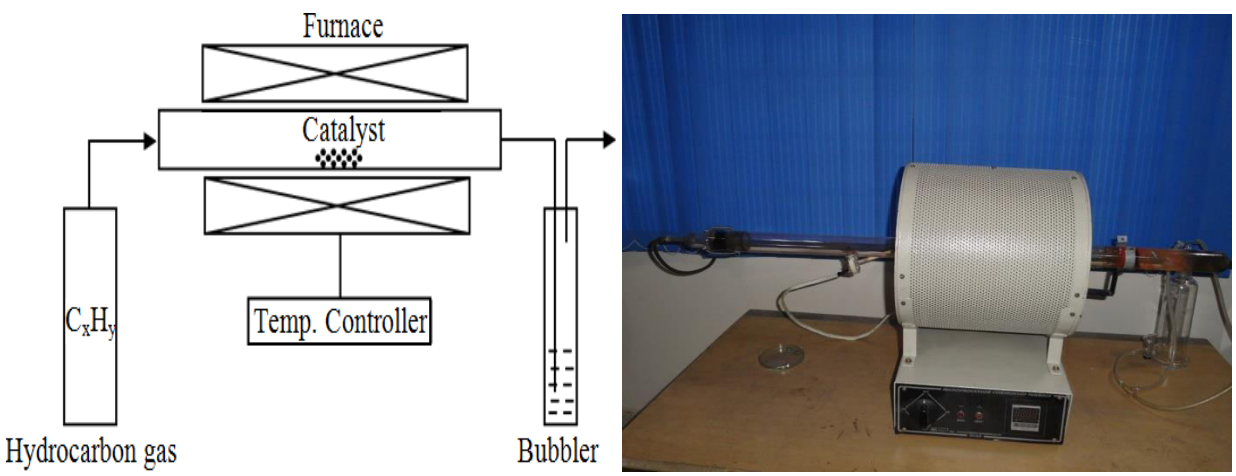

Fig 14.Flow diagram for production of CNT [36] & Photo of CNT apparatus

4.5 EFFECT OF USING CARBON NANO TUBE ALONGWITH ALUMINIUM OXIDE IN ABRASIVE FLOW MACHINING

The major limitation of Abrasive Flow Machining is less material removal. So to reduce this limitation, iron based carbon nano tubes is used along with aluminium oxide because it is more harder than the aluminium oxide.

Chapter 5

PROCESS PARAMETER SELECTION AND EXPERIMENTATION

AFM is a precisely controlled and thereby repeatable method of edge conditioning and surface finish enhancement on a broad range of base materials.

5.1 SELECTION OF WORKPIECE

The length to diameter (L/D) of the workpiece was decided on the basis of the recommendation given by Kohut [37]. The material selected for the workpiece is Aluminium. The cavity to be machined in the test specimen was prepared by drilling operation to the required size. The test workpiece is shown in the figure 14.The internal cylindrical surface was finished by AFM process. Each workpiece was machined for a predetermined number of cycles. The workpiece was taken out from setup and cleaned with acetone before the subsequent measurement.

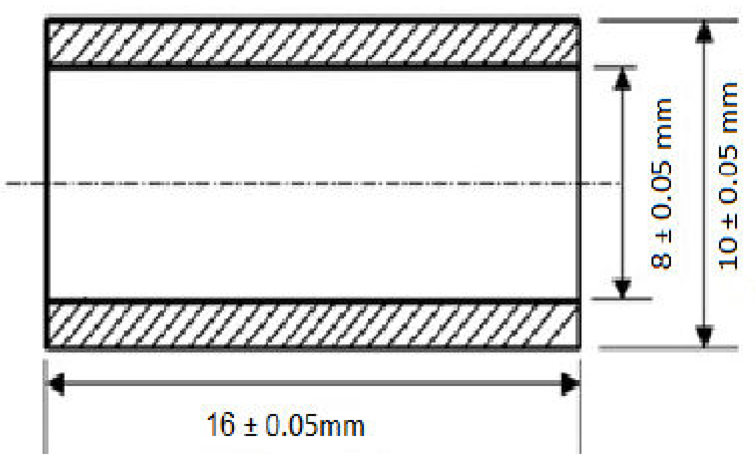

Fig 15. Test Piece

5.2 SELECTION OF PROCESS PARAMETER AND THEIR RANGES IN AFM

Following are the major process parameters using in AFM study

Table 5.1 Ranges of Process Parameter

S. No.	Process Parameter	Range	Unit
1	Extrusion Pressure	5-35	MPa
2	No. of Cycle	1-9	Number
3	Temperature	32± 2	°C
4	Media Flow volume	290	Cm^3
5	Capacity	25 + 25	Ton
6	Stroke length	96	mm
7	Hydraulic cylinder Bore diameter-2 No.	130	mm
8	Hydraulic cylinder Stroke	90	mm
9	Working Pressure	210	$\mathrm{kg/Cm}^2$
10	Maximum Pressure in the Cylinder	35	MPa
11	Stroke Length of Piston	300	mm

5.3 RESPONSE CHARACTERISTICS

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

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

5.4 PERCENTAGE IMPROVEMENT IN SURFACE FINISHING

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

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

5.5 Material removal (MR)

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

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

5.6 SCHEME OF EXPERIMENTS

The experiments were designed to study the effect of some of the AFM parameters on response characteristics of AFM process. Taguchi parametric design methodology was adopted. The experiments were conducted using appropriate orthogonal array (OA). An L9 (a standard 3-level OA) having 8= (9-1) degree of freedom was selected for the present analysis. The selected number of process parameters and their levels are given in the table:

Table 5.2 Process Parameters and their values at different levels

Symbol	Process Parameters	Unit	Level 1	Level 2	Level 3
P	Pressure	Bar	11	22	33
C	Amount of CNT	Gram	Without CNT	5 gram CNT	10 gram CNT
N	No. Of Cycle	Number	3	6	9
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 -1.1 - 2.96 microns					

Table 5.3 The $L_9(3^4)$ OA (Parameters Assigned) with Response

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

5.7 EXPERIMENTATION

The three process parameters Pressure, Amount of CNT, No. of Cycle were selected as in 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 condition specified by the L_9 OA (Table 5.2 and 5.3). Each experiment was repeated three times in each of the trial conditions. Thus twenty seven work-pieces were selected having initial surface in close range of (1.1 – 2.96 micron). 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 5.3.

Table 5.4 Experimental results 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	7.23	8.32	8.76	18.09	0.9	0.4	0.3	-7.92
2	4	16.1	17.1	17.88	24.60	0.7	0.6	0.2	-9.97
3	7	15.5	16.85	15.60	24.05	0.7	0.8	0.6	-3.27
4	2	16.43	17.95	17.23	24.69	0.5	0.6	0.4	-3.28
5	5	29.04	31.86	31.90	29.78	1.2	1.1	1.3	1.52
6	8	20.84	23.74	28.30	27.51	1.5	1.9	1.8	4.64
7	3	9.55	10.44	10.85	20.20	0.6	0.5	0.6	-5.03
8	6	13.94	14.87	13.31	22.92	0.9	0.7	0.8	-2.08
9	9	14.51	14.25	15.66	23.39	0.7	0.9	0.8	-2.07
Total		143.14	155.38	159.49		7.7	7.5	6.8	
		$T_{\Delta Ra}$ = Overall mean of **ΔRa=16.96%**				T_{MR} =Overall mean of MR =0.81mg			

Chapter 6

SIMULATION OF ABRASIVE FLOW MACHINING

6.1 SIMULATION METHODOLOGY

Simulation of Abrasive flow machining was carried out to know the critical parameters during the machining. With the help of critical parameters we can increase the efficiency of the process. For this simulation three dimensional model of AFM was prepared.

A three dimensional model of Abrasive flow machining was prepared firstly.

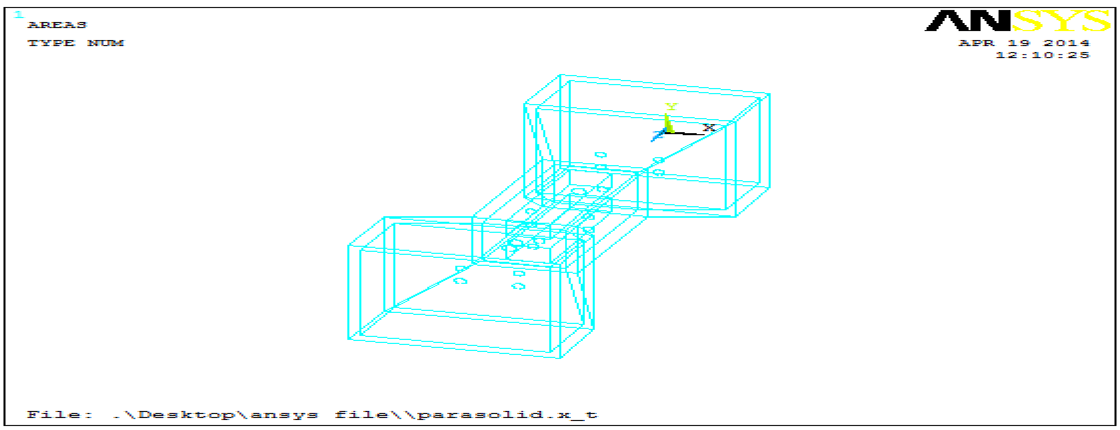

Fig 16. Three dimensional model of abrasive media flow path in Abrasive flow Machining

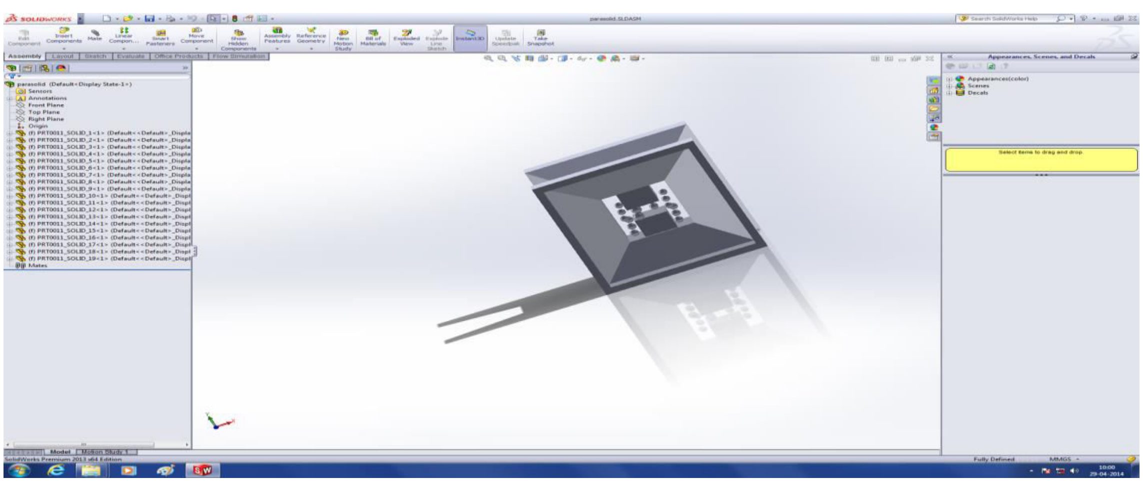

Fig 17. Top view of abrasive media flow in AFM

After making three dimensional model it was imported in the Ansys 14 software. To analyze the variables in AFM, Fluent software is used**.** For converting the solid body into the fluid body. Fluid inlet and Outlet was selected and then meshing was done in Ansys 14. After meshing it was imported in Fluent software.

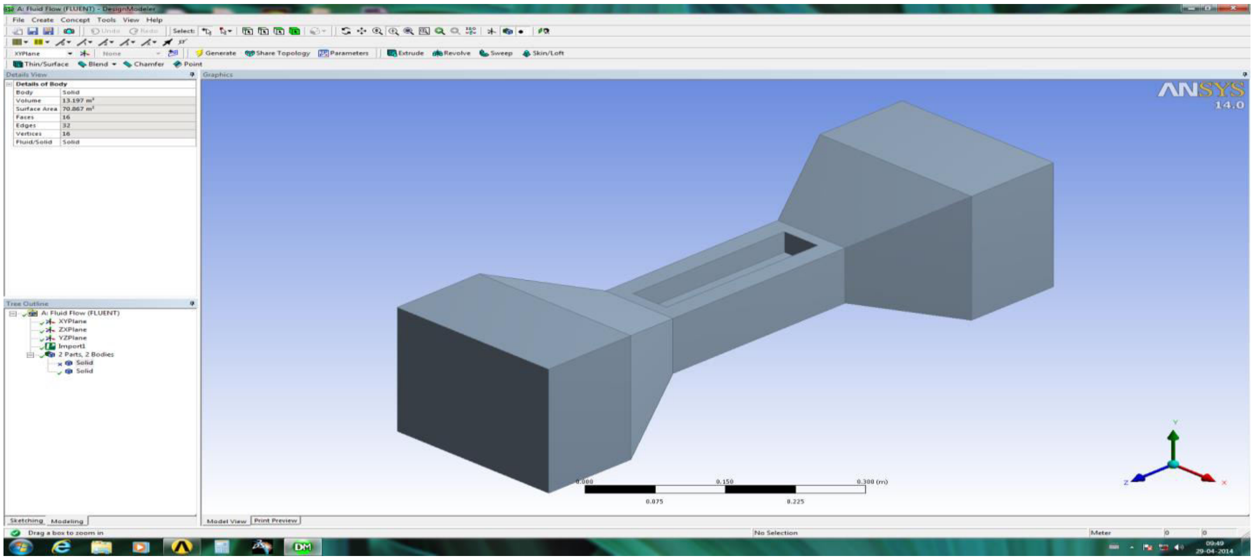

Figure 18. Fluid body of abrasive media path flow in AFM

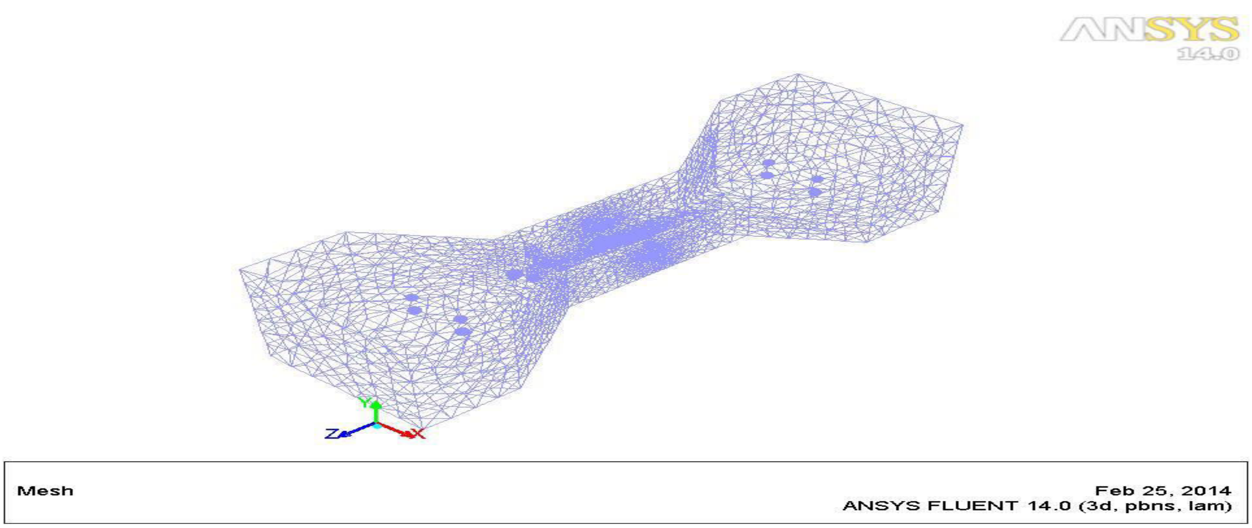

Fig 19. Meshing of abrasive media flow path in Fluent

In this media was taken as the mixture of polyborosiloxane and alumina abrasive. It is assumed that the flow is a turbulent flow and applied pressure is 40 MPa on the inlet side and at the outlet side pressure is 20 MPa because the flow in the abrasive flow machining is due to pressure difference between the upper and lower cylinder. For the movement from the upper to lower side, upper cylinder is maintained at high pressure and lower cylinder is maintained at low pressure.

The results of abrasive media flow path in AFM using Ansys 14 are–

In Figure 6.1(e) we can see that the Z –velocity, by which the fluid is entering, is continuously decreasing which is similar to the literature [38].

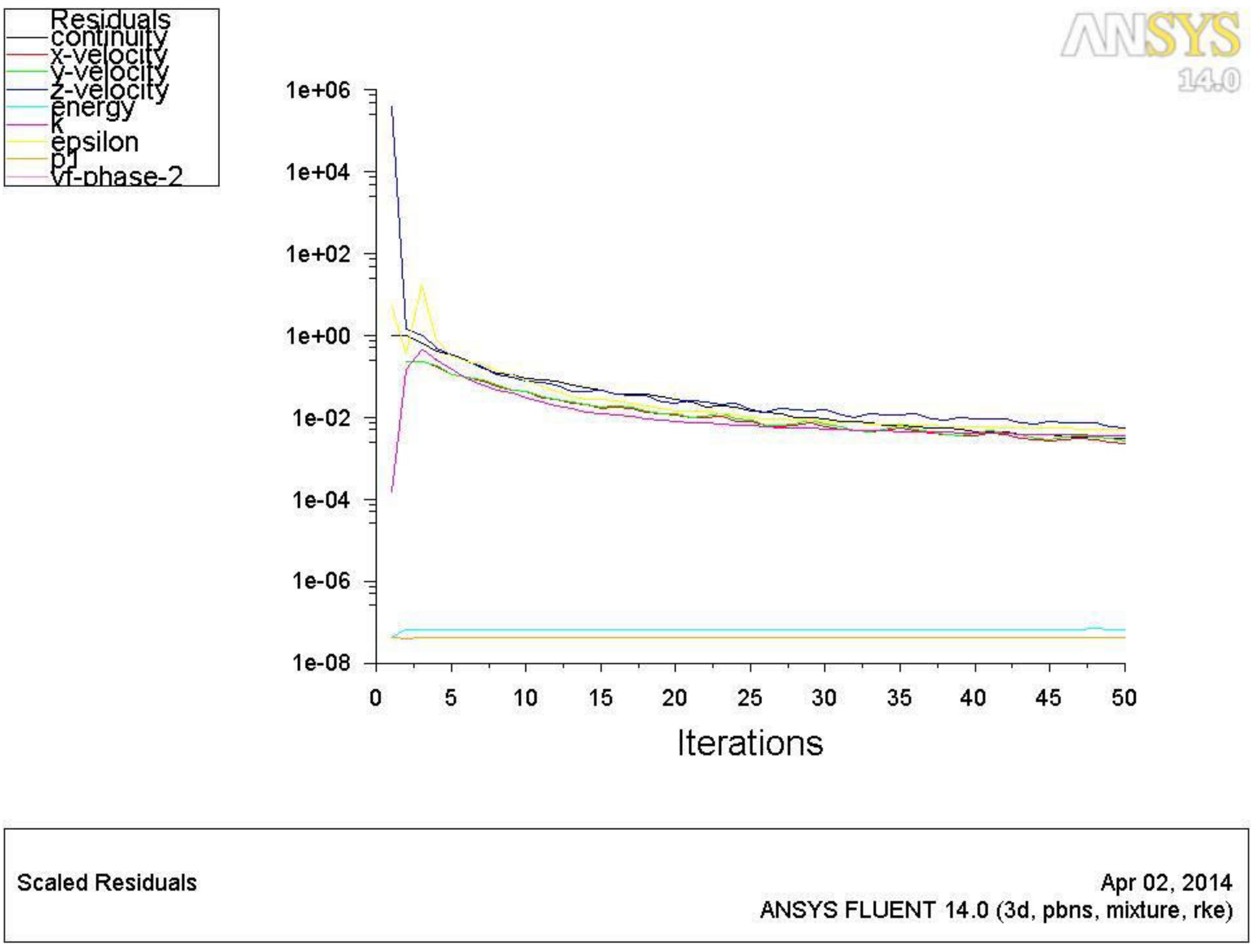

Fig 20. Effect on the velocity and energy

The effects were taken on the plane made from (0,1),(0,0),(0,0) & (0,0),(0,1),(0,0) & (0,1),(0,0),(1,0).

The results obtained in terms of the pressure, velocity, temperature etc are as following-

6.2 Effect on velocity

The result shows that the velocity of the flow decreases after striking on the workpiece. This is already proved from the experiments [38].

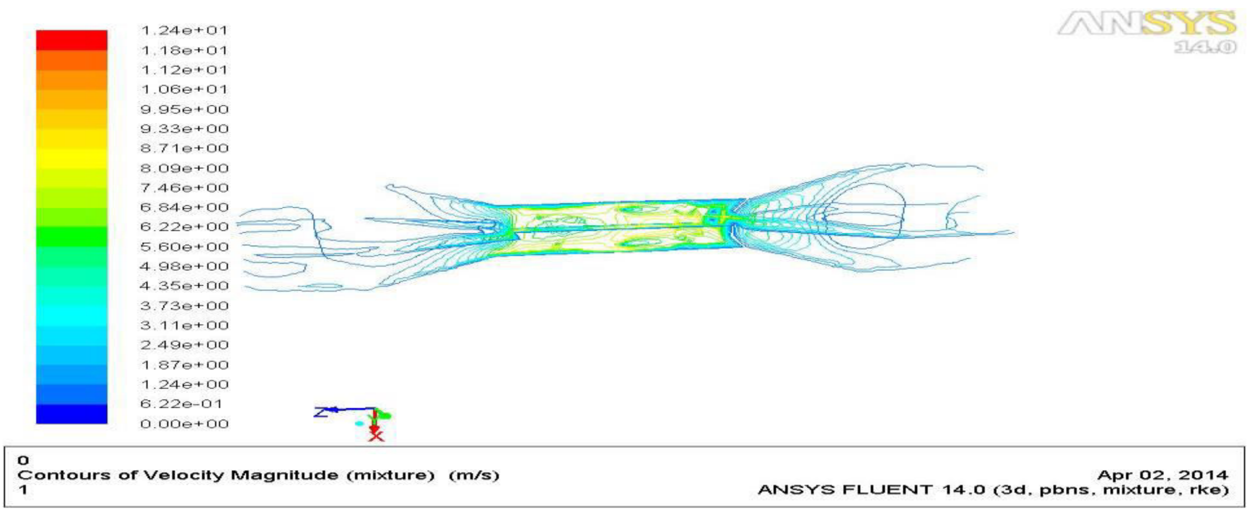

Fig 21. Effect on velocity

6.3 Effect on temperature

The result also shows that as the media will start flowing, continuously there will be increase in the temperature, which is same as the results obtained previously [28].

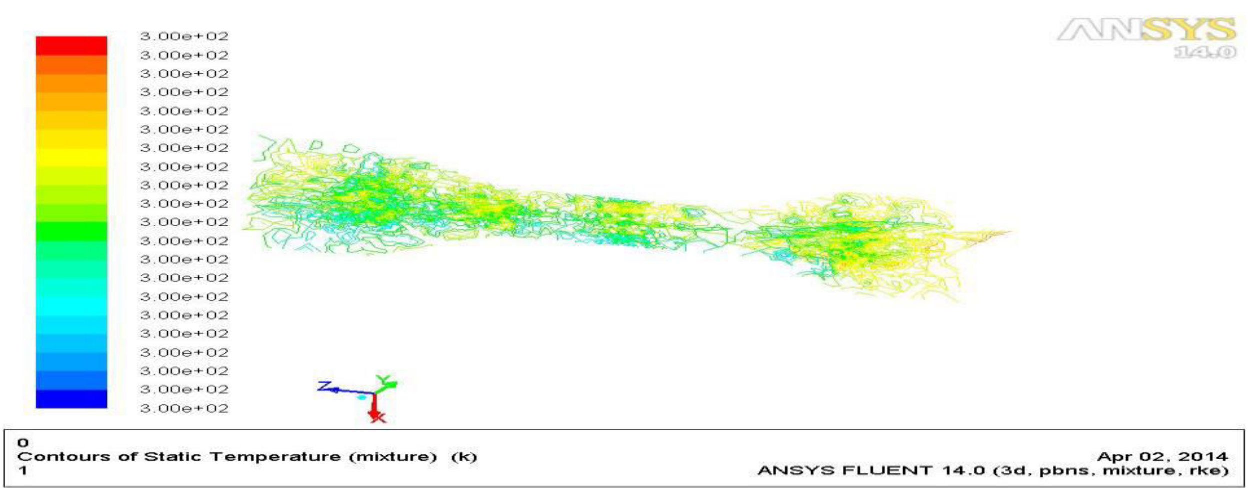

Fig 22. Effect on temperature

6.4 Effect on Pressure

Figure clearly shows the variation of pressure in the machine .The pressure is highest at the starting and it continuously decreases till its outlet.

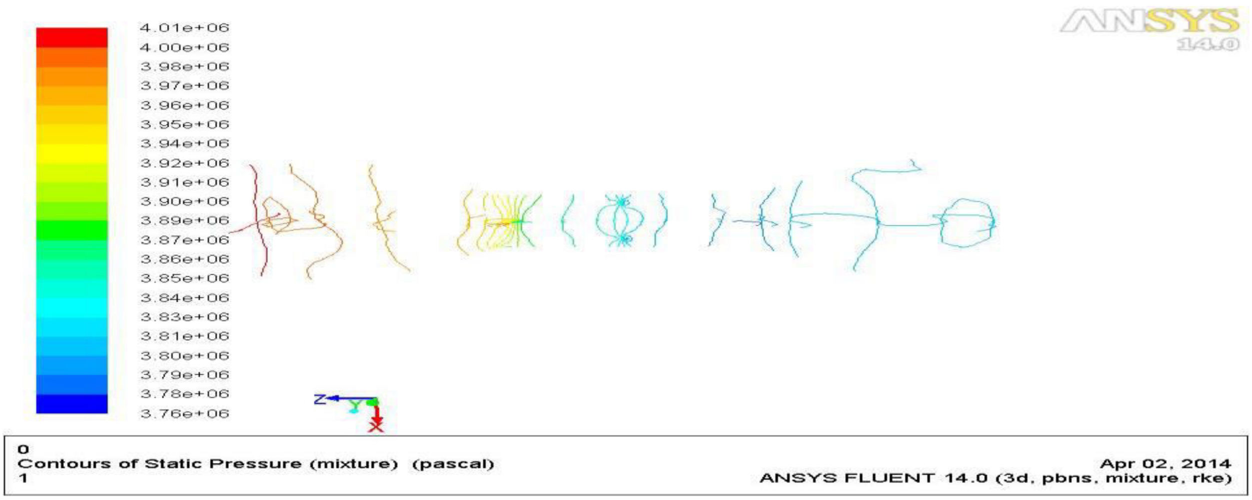

Fig 23. Effect on pressure

6.5 Path Line of the Particles

The figure shows the path followed by the particles during the operation. During the operation particles will cross each other's route and it will cause loss in the pressure, velocity etc.

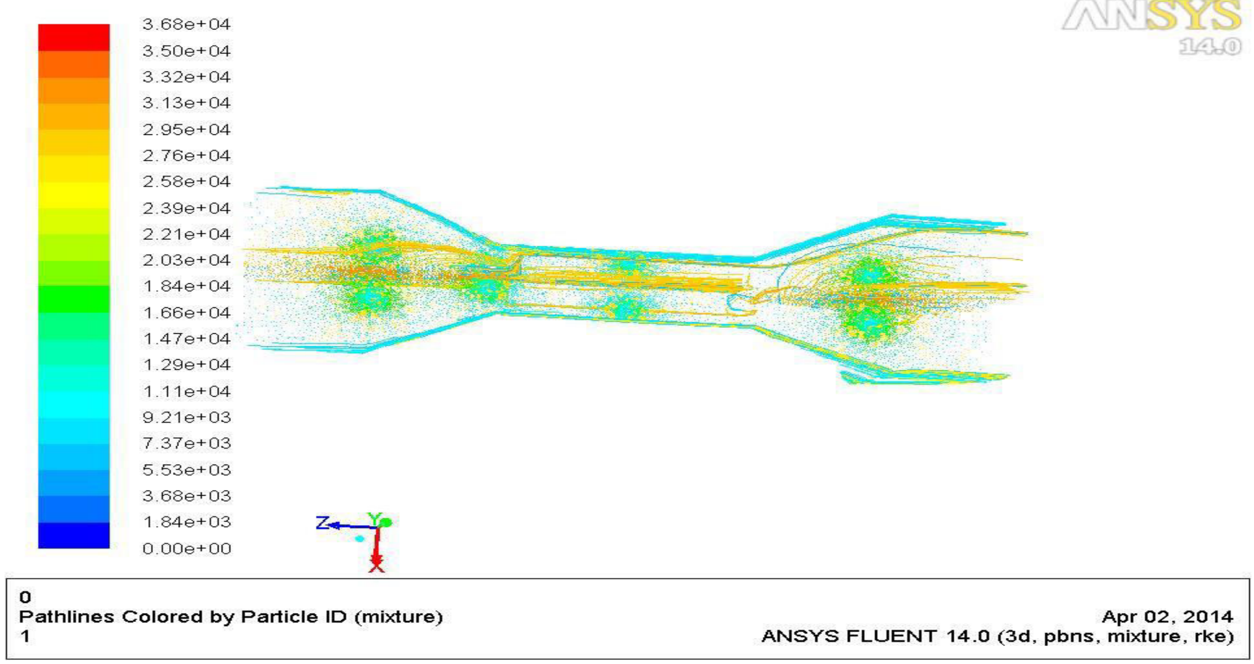

Fig 24. Shows the path line of particles

6.6 Conclusions

The conclusion obtained from the above simulation is that the pressure, velocity continuously decreases with the flow, The result also shows that as the cycle will start the temperature of the flow will start increasing.From this simulation it is observed that we can not operate for a large no. of cycles because with increase in the no. of cycles the temperature of the media increases and due to that the viscosity of the media also varies which effects the material removal.

Chapter 7
ANALYSIS AND DISCUSSION OF RESULT

The chapter contains the analysis and discussion of experimental results.

7.1 ANALYSIS AND DISCUSSION OF RESULTS

The standard procedure suggested by Taguchi was used to analyze the data. The average values and S/N ratio of quality/response characteristics for each parameter at different levels are calculated from the experimental data. The main effects of process parameters both for raw data and S/N ratio are plotted. The analysis of variance (ANOVA) of raw data and S/N ratio is performed to identify the significant parameters and to quantify their effect on the response characteristics.

7.2 EFFECT ON MATERIAL REMOVAL

The average values of material removal (MR) and S/N ratio for each parameter at levels L1, L2 and L3 are calculated and given in table 7.1.

Table 7.1 Average values and Main effects: Material Removal, MR (in mg)

Process Parameter	Level	Pressure(P)		Amount of CNT(C)		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	0.58	-7.06	0.53	-6.44	1.02	-1.79
	L2	1.14	-0.07	0.83	-3.50	0.6	-6.14
	L3	0.72	-3.06	1.08	-0.24	0.82	-2.26
Main Effects(%Ra)	L2-L1	0.56	6.99	0.3	2.94	-0.42	-4.35
	L3-L2	-0.42	-2.99	0.25	3.26	0.22	3.88
Difference (L3-L2)–(L2-L1)		-0.98	-9.98	-0.05	-0.32	0.64	8.23
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							

It can be seen from the figure 25 that up to level 2 of pressure material removal increases and after level 2 the material removal decreases. It is due to initially abrasives cut the peaks of surface and because of that material removal is more. However, when the surface gets smooth, after that it will cause less material removal.

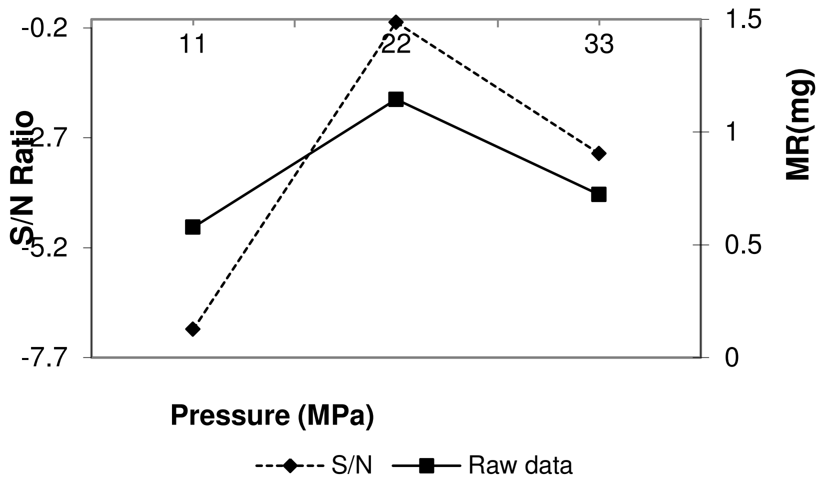

Fig 25. Effect of Pressure on the S/N Ratio and MR

From Fig 26 it was found that as the amount of CNT particles increased material removal was increased. CNT particles are harder compare to the aluminium oxide. CNT has very sharp cutting edges. When the Extrusion pressure is applied it easily cuts the peak of the roughness and causes more material removal and better surface finishing.

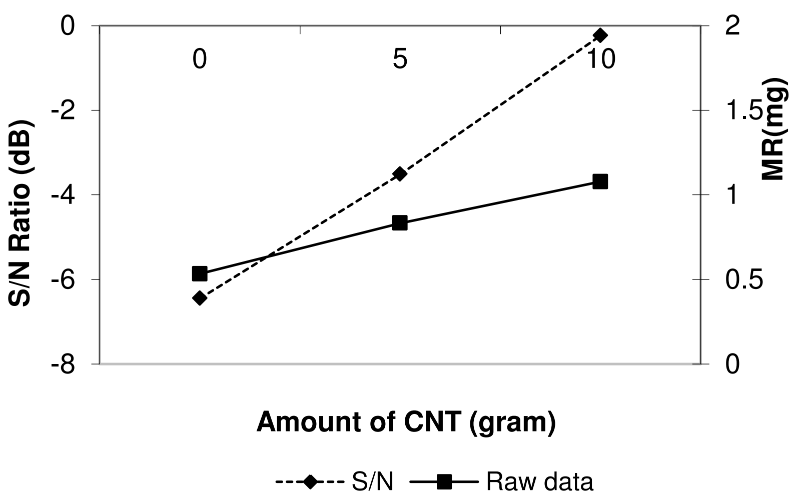

Fig 26. Effect of CNT particles on the S/N Ratio and MR

From Figure 27 it was found that as the number of cycle is increased initially the material removal decreases but after sometime as the number of cycle increases material removal also increases.

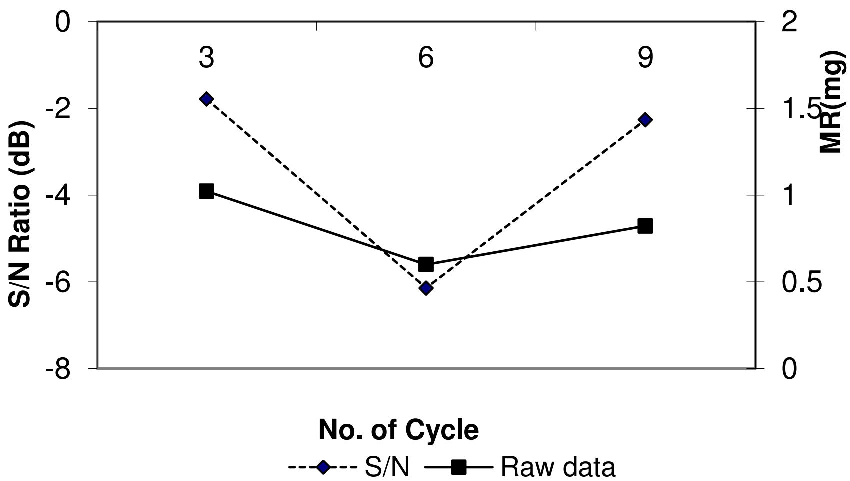

Fig 27. Effect of No. of Cycle on the S/N Ratio and MR

7.3 SELECTION OF OPTIMUM LEVELS

In order to study the significance of the process parameters towards the MR, analysis of variance (ANOVA) was performed. The pooled versions of ANOVA of the raw data and the S/N ratio for MR are given in Tables 7.2 &7.3. From these tables, it is clear that the parameters Pressure, Amount of CNT and No. of Cycle significantly affect both the mean and the variation in MR values.

Table 7.2 Pooled ANOVA (Raw Data) (MR)

Source	SS	DOF	V	F-Ratio	SS'	P%
Pressure	1.56	2	0.78	17.90*	1.47	32.22
Amount of CNT	1.34	2	0.67	15.35*	1.25	27.36
No. of Cycle	0.80	2	0.40	9.21*	0.72	15.65
e	0.87	20	0.04	------	1.13	24.78
Total (T)	4.57	26	*	-------	4.57	100

*Significant at 95% confidence level, $F_{critical}$ =3.4928(Tabular Value)
SS-Sum of Squares, DOF-Degree of Freedom, V-Variance, SS'-Pure sum of Squares

Table7.3 Pooled ANOVA(S/N Data) (MR)

Source	SS	DOF	V	F-Ratio	SS'	P%
Pressure	73.74	2	36.87	41.40*	71.96	42.93
Amount of CNT	57.85	2	28.92	32.48*	56.07	33.44
No. of Cycle	34.27	2	17.13	19.24*	32.48	19.38
e	1.78	2	0.89	------	7.12	4.25
Total (T)	167.64	8	--------	-------	167.64	100

*Significant at 95% confidence level, $F_{critical}$ =19(Tabular Value)
SS-Sum of Squares, DOF-Degree of Freedom, V-Variance, SS'-Pure sum of Squares

7.4 EFFECT ON PERCENTAGE IMPROVEMENT IN SURFACE ROUGHNESS

The average values of percentage improvement in surface roughness and S/N ratio for each parameter at Level L1, L2 and L3 are calculated and given in Table 7.4.

Table 7.4 Average values and Main Effects: %age improvement in Ra

Process Parameter	Level	Pressure(P)		Amount of CNT(C)		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	13.70	22.24	11.86	20.99	15.48	22.84
	L2	24.14	27.33	20.67	25.77	16.34	24.23
	L3	13.04	22.17	18.36	24.98	19.07	24.68
Main Effects(%Ra)	L2-L1	10.44	5.09	8.81	4.78	0.86	1.39
	L3-L2	-11.10	-5.16	-2.31	-0.79	2.73	0.45
Difference (L3-L2)–(L2-L1)		-21.54	-10.25	-11.12	-5.57	1.87	-.94

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

It can be clearly noticed from the figure 28 that as the pressure increases, initially the surface finishing of the workpiece increases but after level 2 of pressure the value of surface finishing decreases. Initially because of more material removal greater surface finishing is achieved but after the surface gets smooth less material removal is achieved, which also reduce the rate of surface finish.

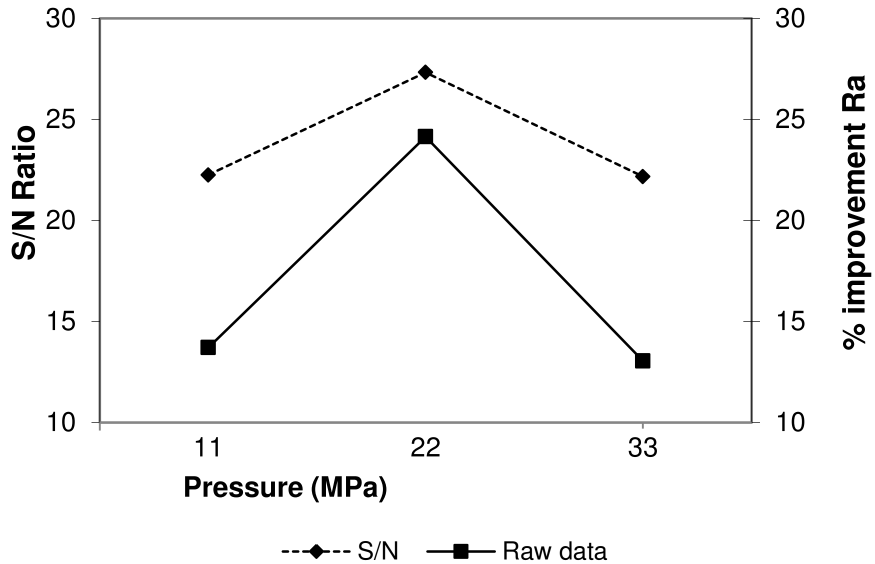

Fig 28. Effect of pressure on S/N ratio and % improvement in Ra

It can be seen from the figure 29 that as the amount of CNT increases the % increase in Ra increases but after level 2, % improvement in Ra starts decreasing at a slow rate. Initially more material removal causes greater surface finish. After certain period of time when abrasives become dull it causes lesser surface finishing.

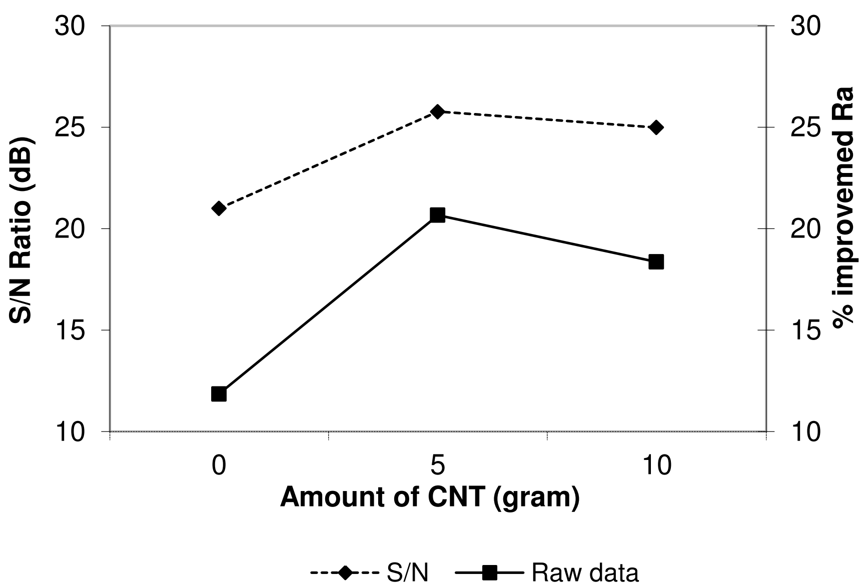

Fig 29. Effect of Amount of CNT on S/N Ratio and % improvement in Ra

From Fig 30 it is defined that as the number of cycle is increased the % surface finish is increased.

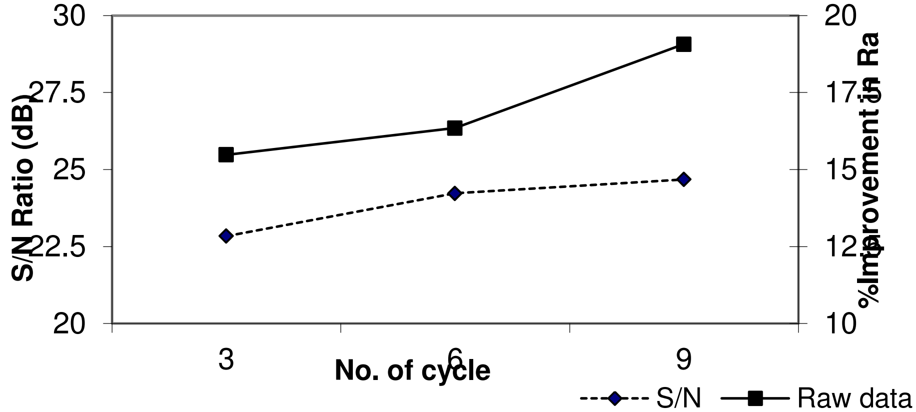

Fig 30. Effect of No. of Cycle on S/N Ratio and % improvement in Ra

7.5 SELECTION OF OPTIMUM LEVELS

In order to study the significance of the process parameters towards the percentage improvement in Ra, analysis of variance (ANOVA) was performed. The pooled versions of ANOVA of the raw data and the S/N data for change in Ra are given in table 7.5 and 7.6.From these tables, it is clear that parameters Pressure, Amount of CNT and No. of Cycle significantly affect both the mean and the variation in the percentage improvement in Ra values.

Table 7.5 Pooled ANOVA (Raw Data)(ΔRa)

Source	SS	DOF	V	F-Ratio	SS'	P%
Pressure	697.78	2	348.89	107.95*	691.32	57.58
Amount of CNT	375.21	2	187.60	58.047*	368.75	30.71
No. of Cycle	63.08	2	31.54	9.76*	56.61	4.72
e	64.64	20	3.23	------	84.03	6.99
Total (T)	1200.70	26	*	-------	1200.70	100
*Significant at 95% confidence level, $F_{critical}$ =3.4928(Tabulated Value) SS-Sum of Squares, DOF-Degree of Freedom, V-Variance, SS'-Pure sum of Squares						

Table 7.6 Pooled ANOVA (S/N Data)(ΔRa)

Source	SS	DOF	V	F-Ratio	SS'	P%
Pressure	52.43	2	26.22	279.77*	52.24	53.61
Amount of CNT	39.30	2	19.65	209.70*	39.11	40.14
No. of Cycle	5.53	2	2.76	29.50*	5.34	5.48
e	0.19	2	0.09	------	0.75	0.77
Total (T)	97.45	8	--------	-------	97.45	100

*Significant at 95% confidence level, $F_{critical}$ =19(Tabulated Value)
SS-Sum of Squares, DOF-Degree of Freedom, V-Variance, SS'-Pure sum of Squares

7.6 Estimation of optimum response characteristics

In this section, 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 of 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 within the 95% confidence level, CI_{CE}. However the average value of quality characteristic obtained from the confirmation experiments may or may not lie within 95% confidence interval, CI_{POP}. As observed the optimum values for the maximum MR are $P_2C_3N_1$ [Ref. Fig 7.2] for both raw data and S/N ratio. For the confirmation experiments on the basis of raw data the optimal settings have been taken as $P_2C_3N_1$. As observed the optimum values for the maximum ΔRa are $P_2C_2N_3$ [Ref. Fig 7.4] for both raw data and S/N data. For the confirmation experiments on the basis of raw data the optimal settings have been taken as $P_2C_2N_3$. Based on the optimal selection of the process the optimum response parameters of the material removal and Percentage improvement in surface roughness have been estimated with the confidence intervals as further.

7.7 Material Removal (MR)

The mean at the optimal MR (optimum values of the response characteristics) is estimated as

$\mu = \bar{P}_2 + \bar{C}_3 + \bar{N}_1 - 2\bar{T}$ ……………………………………………………(Equation No. 1)

$\bar{T}$ = overall mean of the response =0.81 mg [Ref Table 5.3]

$\bar{P}_2$ =Average value of MR at the second level of Pressure

= 1.14mg [Ref Fig 7.2(a)]

$\bar{C}_3$ =Average value of MR at the third level of CNT

= 1.08 mg[Ref Fig 7.2(b)]

$\bar{N}_1$ =Average value of MR at the first level of no. of cycle

= 1.02mg[Ref Fig 7.29(c)]

Substituting these values, Mean MR = 1.62 mg

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

$$CI_{CE} = \sqrt{F_a(1, f_e)V_e\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} \text{ ………………………………………(Equation No. 2)}$$

$$CI_{POP} = \sqrt{\frac{F_a(1, f_e)V_e}{n_{eff}}} \text{ ……………………………………………………(Equation No. 3)}$$

Where F_α (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 =0.04 (Table 6.5)

$$n_{eff} = \frac{N}{1+[\text{DOF associated in the estimate of mean responce}]}$$ ……………………..(Equation No.4)

= 3.86

So, CI_{CE} = ± 0.29

And CI_{POP} = ± 0.19

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

Mean MR – CI_{CE} <MR< MR + CI_{CE}

1.33< MR <1.91

The 95% confirmation interval of the predicted mean is :

Mean MR – CI_{POP} <MR< MR + CI_{POP}

1.43< MR <1.81

7.8 Percentage improvement in R_a

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

$\mu = \bar{P}_2 + \bar{C}_2 + \bar{N}_3 - 2\bar{T}$ ……………………………………………………………………………(Equation No. 5)

$\bar{T}$ = overall mean of the response = 16.96 %

$\bar{P}_2$ = Average value of % age improvement in R_a at the second level of extrusion Pressure = 24.14%

$\bar{C}_2$ = Average value of % age improvement in R_a at the second level of CNT

= 20.67 %

$\bar{N}_3$ = Average value of % age improvement in R_a at the third level of No. of Cycle

=19.07%

Substituting these values, % improvement in R_a = 29.96 %

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

$$CI_{CE} = \sqrt{F_a\,(1, f_e)V_e\,\left[\frac{1}{n_{eff}} + \frac{1}{R}\right]}$$ ……………………………..(Equation No. 2)

$$CI_{POP} = \sqrt{\frac{F_a\,(1, f_e)V_e}{n_{eff}}}$$ ……………………………………………………………(Equation No. 3)

Where F_α (1, f_e) = The F- ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom fe = 3.49 (Tabulated Value)

fe =error DOF = 20

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

R = Sample size for confirmation experiments = 3

Ve = Error variance =3.23

$$n_{eff} = \frac{N}{1+[\text{DOF associated in the estimate of mean responce}]}$$ …………………(Equation No. 4)

= 3.86

So, CI_{CE} = ± 2.58

and CI_{POP} = ± 1.70

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

27.38< %age improvement in ΔR_a <32.54

The 95%age confirmation interval of predicted mean is

28.26<%age improvement in ΔR_a <31.66

7.9 Confirmation Experiments

In order to validate the results obtained, three confirmation experiments have been conducted for each response characteristics i.e MR and %age improvement in surface roughness .For the maximum MR, the optimal levels of the process parameter are $P_2C_3N_1$.Whereas for the maximum %age improvement surface roughness the optimal parameters settings are $P_2C_2N_3$.

P_2 = Extrusion Pressure at second level =22 MPa

C_2 = Amount of CNT at second level =5 gram

C_3 = Amount of CNT at Third level =10 gram

N_1 =No. of Cycle at first level =3

N3 = No. of Cycle at first level =9

The results are given in Table 7.7. 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. Any exploration should be confirmed through additional experiments.

Table 7.7 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	$P_2C_3N_1$	1.62mg	CI_{CE} 1.33<MR<1.91 CI_{POP}:1.43<MR<1.81	1.73 mg
%Improvement ∆Ra	$P_2C_2N_3$	29.96 %	CI_{CE}:27.38<%ΔR_a<32.54 CI_{POP}:28.26<%ΔR_a<31.66	30.93%

CI_{CE} – Confidence interval for the mean of the confirmation experiments

CI_{POP} – Confidence interval for the mean of the population

Chapter 8

CONCLUSION AND SCOPE FOR FUTURE WORK

There is a possibility of improvement in the process of Abrasive Flow Machining by using the CNT as abrasives in the process because it is harder than the conventional abrasives. According to this study, it is clearly defined that after using CNT particles abrasives along with Al_2O_3 abrasives the material removal increases. It is also clearly defined that up to certain value of CNT the surface finish increases and after that it decreases. The important conclusion from this research work is provided in the next subsection.

8.1 CONCLUSIONS

- The study of CNT based abrasive media in AFM on aluminium was done successfully.
- The effects of using CNT were properly analyzed.
- It was seen that as the pressure increases initially the surface finish improves but later it decreases.
- As the amount of CNT increases initially the surface finish improves but later it decreases.
- As the No. of Cycles increases the surface finish increases.
- It was obtained from the experiment that as pressure increases, material removal increases up to certain level after that it decreases.
- As the amount of CNT increases, material removal increases.
- If the No. of cycle is increased up to some cycle material removal decreases and after that it increases.
- AFM process was successfully model to predict media flow pressure and velocity using Ansys Software.

8.2 SCOPE FOR FUTURE WORK

- This process can be improved or automated by using servo control hydraulic units.

- The life of the component increases due to better surface finish.
- The set up can be optimized for many other process parameters like different shapes of work materials, different abrasives, flow rate of media etc.
- Higher order Orthogonal Array (OA) can be considered to incorporate all the possible interactions of the process parameter.

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