COMPUTATIONAL AND EXPERIMENTAL ANALYSIS OF PARAMETERS IN CENTRIFUGAL FORCE ASSISTED ABRASIVE FLOW MACHINING PROCESS

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CANDIDATE'S DECLERATION

I ANANT BHARDWAJ, Roll No 2K17/PIE/01 students of M. Tech (Production Engineering), hereby declare that the project dissertation titled, "COMPUTATIONAL AND EXPERIMENTAL ANALYSIS OF PARAMETERS IN CENTRIFUGAL FORCE ASSISTED ABRASIVE FLOW MACHINING PROCESS" which is submitted by me to the department of Mechanical Engineering ,Delhi Technological University ,Delhi in partial fulfillment of the requirements for the award of degree of **Master of Technology ,** is original and not copied from any source without proper citation . The work has not previously formed the basis for the award of Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the project Dissertation titled "COMPUTATIONAL AND EXPERIMENTAL ANALYSIS OF PARAMETERS IN CENTRIFUGAL FORCE ASSISTED ABRASIVE FLOW MACHINING PROCESS" which is submitted by Anant Bhardwaj, Roll no 2K17/PIE/01, Mechanical Engineering Department, Delhi Technological university. Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this university or elsewhere.

Place: Delhi K. SRINIVAS

Date: (SUPERVISOR)

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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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ANANT BHARDWAJ

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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.	$\bar{A}_2, \bar{B}_2$	mean values of responses at second level of parameters A&B
7.	CI_{CE}	Confidence Interval
8.	CI_{POP}	Confidence Interval of Population
9.	F α	The F-Ratio at the confidence level of (1- α) against DOF 1
10.	f_e	Error DOF
11.	Ve	Error Variance

ABSTRACT

Centrifugal force assisted abrasive Flow machining has played a vital role in improving the efficiency of the traditional abrasive flow machining process. It has readily kept its stands against the disadvantage of abrasive flow machining and has proven itself as an essential alternative against AFM process. In this works three different rods of different shape (rectangular, triangular and circular) are rotated in the centrifugal force assisted abrasive flow machining setup and the amount of MR (material Removal) and the quality of the surface finish have been observed. ANSYS 15.0 are used for the computational analysis of the centrifugal force assisted AFM process. The three rods are separately modeled and are tested for the same condition and found that pressure on the work piece which is a measure of the material removal is more for the rectangular rod. In order to validate the simulation results, Taguachi optimization technique was used in which the initial reading of material removal was taken by measuring weight and the initial reading of surface Roughness was taken by Taylor Hobson tally surf. After performing the experiment, it was found that for material removal the optimum value would be 300 RPM of rectangular rod speed, extruded with 6 numbers of cycles. And for the percentage improvement in surface finish the optimum values were 200 RPM of triangular rod in which media is extruded to 9 numbers of cycles. Evidently it was found that both the simulation and the experiment justify the centrifugal-force assisted AFM as the suitable mode for finishing operation with the use of suggested Process parameters.

Chapter 1

INTRODUCTION

The requirement of high-quality material has drastically increased in the modern era. Now a days the aesthetic value of the product is more important along with the functional value of the product. Although there were many Conventional methods available which could be use to provide the proper surface finish like buffing, Honing and lapping but they have their own specific area and specific advantages and disadvantages but AFM is a special finishing process which can do finishing up to the Micro level and when some hybrids are used it can provide finishing up to the Nano level as well. [1]. The process is simple and includes the reciprocation of media, which is a mixture of polymer-jell for binding the abrasives which are used for abrasion of the workpiece material, from the lower media cylinder to the upper media cylinder and vice-versa thus making a cycle. It has been reported that the range of simple AFM process is up to 0.05 micron but it reaches up to Nano level when different hybridisation of AFM comes into picture. The process finds its application in machining hard to reach cavities, Complex shape and hollow surface with less internal Diameter. It also finds its application in micromachining of Keyways and finishing of gears moreover it is used to remove the thermal recast layer formed after machining of EDM process. AFM has a limitation of low material removal to overcome this Centrifugal force assisted AFM is taken into consideration which had improved the material removal as well as the surface finish.

1.1 NON-CONVENTIONAL MANUFACTURING PROCESSES

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

Merchant [2] studied the trends and needs of future of manufacturing technology by interrelating the present and past manufacturing activities to the future requirements. He suggested 3 needs of future manufacturing technology are:

- Versatility of automation
- Sustained productivity in face of rising strength barrier

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

AFM is a unique un-conventional Finishing process which results in higher dimensional accuracy, provides better Finishing surface and optimal removal of materials. Although it has a limitation of material removal initially but it can be overcome by proper hybridization, proper selection of media and proper fixturing conditions and design.

1.2 AFM Process

Extrudes Hones Corporation (A USA based Firm) has developed AFM process in 1960. The process finds its application in manufacturing industry in finishing of small gears, complex shapes, in automobile part in hard to reach surfaces of miniaturized parts, it is used in the medical field for the Nano finishing of biomedical tools. Due to the absence of physical tool and extrusion of fluid very complex hollow geometry can be machined also polymer media consist of the bonding properties which binds the abrasive (silicon particles, alumina and iron particles). These abrasives have a multiple cutting edge which results in the abrasion of the material from the surface of the workpiece. The important point about the Fluid is that it should have proper viscosity and better fluidity so that the cutting tool abrasive have better flexibity. There are various finishing process like lapping, honing and Grinding but they possess certain limitations like development of microcracks which reduces the strength and reliability of the workpiece due to the heat generated by the contact surfaces moreover the complex shape cannot be machined economically using this conventional techniques so to overcome this AFM process is taken into considerations.

1.3 BASIC PRINCIPLE OF AFM

The principle of AFM involves the reciprocation of media which is a mixture of polymer and abrasives and other bonding materials through a constrained path which results in the pressure increase and thus making suitable conditions for the material removal. In Abrasive flow machining the polishing process along with deburring occurs simultaneously which results in the desirable surface finish and thus it is a preferred finishing operation for finishing the internal diameter of the hollow workpiece. The centrifugal force assisted abrasive flow machining is a hybrid of Abrasive flow machining in which centrifugal force is produced due to the rotation of rod which is aligned parallel to the axis of workpiece making it suitable for material removal and provides better surface finish to the workpiece.

1.4 CLASSIFICATION OF AFM MACHINES

There are three categories of AFM according to the working and configuration which are One-Way, Two-Way and orbital AFM.

1.5 TYPES OF AFM

As mentioned above on the basis of configuration 3 configuration of AFM are available out of which two-way AFM is commercially used.

1.5.1 ONE WAY AFM

One-way AFM process was coined by Extrude Hone Cooperation in 1960 (Fig.1.1) includes a piston which is hydraulically actuated and an extrusion medium chamber having ability to receive and pressurize the medium towards the specific direction machining workpiece internally. The flow is directed from the extrusion media chamber to internal passage of the workpiece and it is done by the fixture. Medium collector collects the extruded media which comes out from the internal passage.

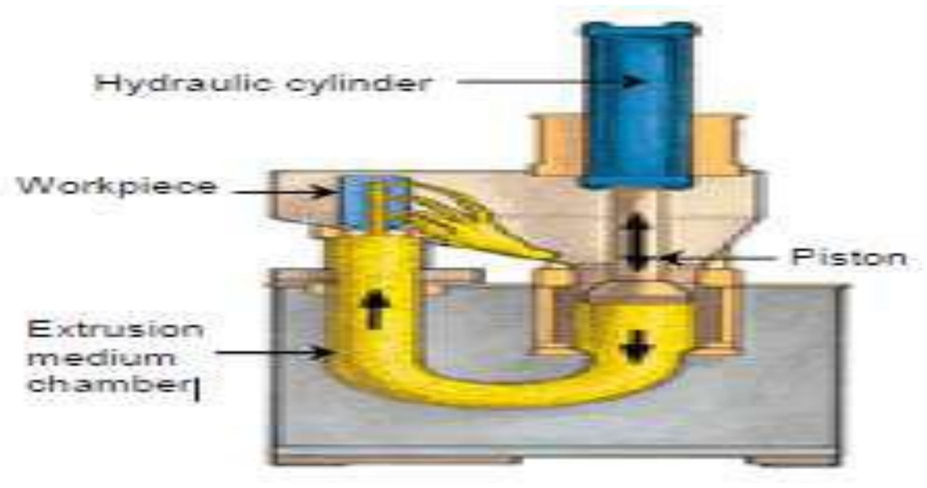


Figure 1.1 One-way AFM [1]

The advantages of one-way AFM process are as Follows:

- Processing cycles are Rapid
- The system is Sterile and cleaning is rapid.
- There is a Regulation in Temperature of Media.
- Larger Part handling is available
- tooling and part change-over is not complex and does not required specific skills.

The limitations of the above configuration are as Follows:

- The regulation of the Process is poor.

- Results in the creation of Curves.

1.5.2 TWO WAY AFM PROCESS

Two-way AFM process was developed by Extrudes Hones Corporation in 1960. In this process, it contains a pair of hydraulic cylinder and media cylinders (3). The Hydraulic pressure applied by the media cylinder results in the reciprocation of the media through small passage which is due to the shape of the workpiece fixture and tooling. This reciprocation of media results in the abrasion process which further results in the removal material from the surface of the workpiece. The piston aids the medium flowing in the required direction based on the differences in pressure created in the hydraulic cylinders. Since the aim of the process is the material removal which is done by the abrasion process so produce in the workpiece which is aligned co axially with fixture.

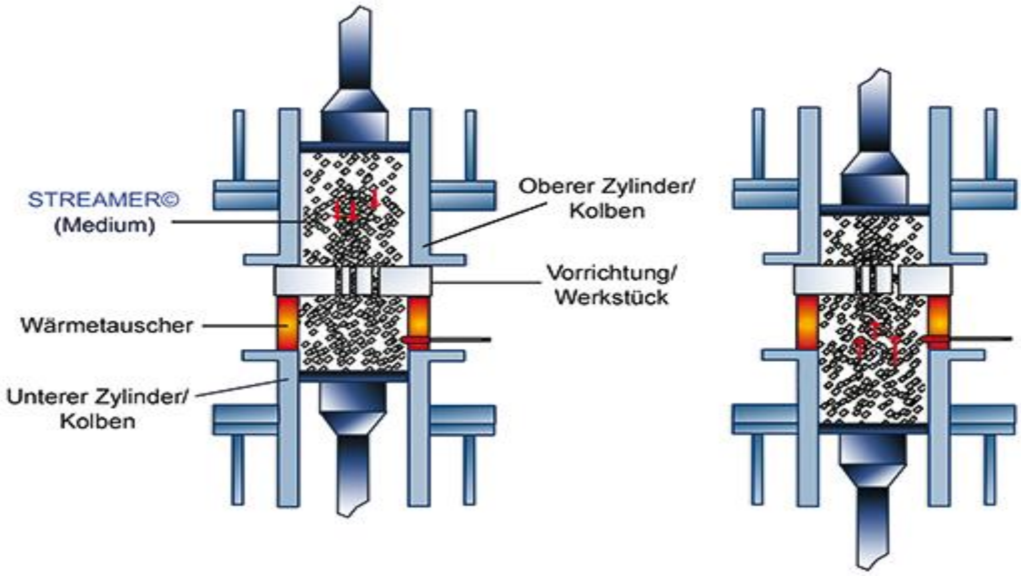


Fig 1.2. Two-way AFM [1]

1.5.3 ORBITAL AFM

The process is characterized by the low amplitude vibrations to the workpiece. It consists of a Displacer, a pair of pistons and a setup for providing orbital vibration to the workpiece. Actually, a very low vibration is given to the workpiece in the direction along the media flow the vibration of the workpiece gets transfer to the media which results in the proper mixing of abrasives to the media and also it increases the contact length so that the machining takes place effectively.

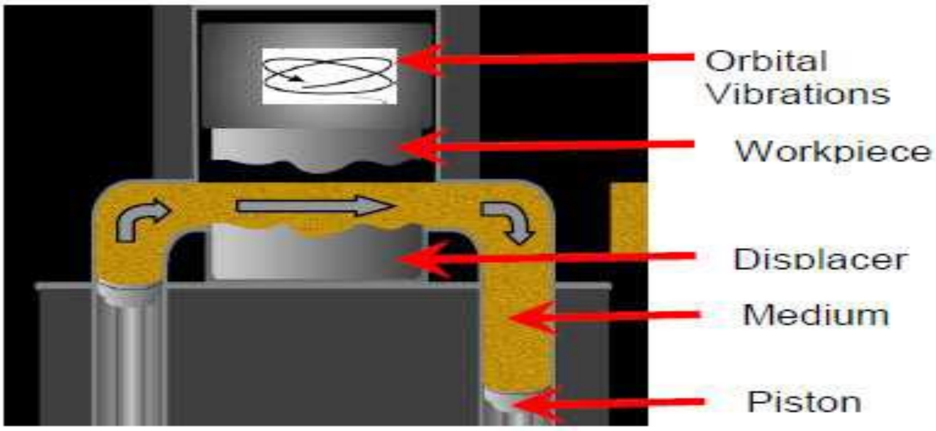


Figure.1.3. Orbital AFM [1]

Mechanical vibrations result in both flow and Detour motion in working zone. The operations which can be performed by this process are as follows

- polishing precisely over the target surface with 3D effect.
- The Smooth and requisite machining of the edges.
- Machining and reaching typical counters of multifaceted shapes.

1.6 AFM ELEMENTS

The major elements of the equipment required to perform AFM are as follows: -

- The machine – Decides the extent of Abrasion
- Tooling and Fixtures -Decides the Exact location of Abrasion
- Abrasive laden media- Decides the Kind of Abrasion occurs

1.6.1 MACHINE

All AFM machines used are positively displacement hydraulic systems, where workpiece clamps among two media cylinder which are placed in opposite direction to each other. The media is extruded from one cylinder to the other by creating the pressure difference.

AFM systems consists of following controls which are as follows: -

- Hydraulic system pressure,
- Clamping and unclamping of fixtures
- Advance and retract of pistons.

1.6.2 FIXTURE OR TOOLING

Fixtures and tooling play an important role in AFM process. The functions of the fixture are as follow:

- Holding the parts in the proper position between the two opposed media cylinders.
- It provides constraint media flow path 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.
- Ensure abrasion free movement of media from edges and surfaces.

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

1.6.3 MEDIA

A liquid polymer which does not follow Newtonian law is used in AFM process. It consists of Following parts which are as follows: -

- Aluminum oxide, Silicon carbide, Boron carbide, Boron nitride, Boron carbide or diamond
- Grinding medium
- Additives.

The additives modify the base polymer for flowability and rheological characteristics of media.

1.7 Advantages of Abrasives Flow Machining

- It provides Fuel Economy
- It reduces imperfections
- It Reduces Frictions
- single workpiece can be entirely machined
- Economic machining of complex geometries.

1.8 Limitations of Abrasive Flow Machining

- Unable to remove major surface irregularities
- Unable to correct tapering and oval shape

- Low Material Removal

1.9 AFM APPLICATIONS

As mentioned above various parts of the single workpiece can be machined simultaneously in the AFM process. Since equal material is removed from all parts so it is unable to remove Large surface irregularities like deep scratches or large bumps.

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

- Air inlet manifold of I.C Engines.
- 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).
- Providing the mirror like appearance to the surface.
- For process industry (Finishing impellers, Integrally bladed rotor, compressor wheels and gears).
- It can also be employed for removing left or light machining marks.
- It plays a vital role in the removal of thermal recast layers due to EDM, or LBM machining process.
- Automobile industry (Finishing of two stroke cylinder and four stroke engine head, splines, valve and fitting).

Chapter 2

LITERATURE REVIEW AND PROBLEM IDENTIFICATION

Abrasive Flow machining is non-traditional process of machining in which reciprocation of media takes place within the internal surface of the workpiece. The media contains the mixture of abrasive particles along with the fluid which bounds the abrasive particles which results in the shearing mechanism thus making a suitable condition for the material removal and thus machining of the process. As discussed earlier that AFM process may be one-way, Two-way and orbital depending upon the flow of media. Various hybrids of AFM are present and may be alter and depending upon the requirement also various abrasives are present which can be used with the suitable combination of bonding media. Many researches have been done in the field of media, fixture design and on the Hybrids. The process found its application in various sectors like manufacturing, Nano and micro finishing and in the field of Defense and Medical [1]. The finishing range of abrasive Flow machining is upto the order of 0.05 micron [2]. Compare to the other finishing process Abrasive Flow machining takes only ten percentage of the finishing time thus it can be inferred that the process is more rapid than the other traditional processes [3]. On the basis of working and configuration, AFM process has three categories (one-way AFM [4], two-way AFM [5] and orbital AFM [2]).Gupta and Chahal [6] conducted there experiment in electrochemical -aided AFM process where they concluded that the contribution of voltage is about 45.35% For material removal .As mentioned above that the major use of AFM is in the removal of the thermal recast layer produced by EDM and LBM , for verifying this fact Tzeng et al. [7] experimented the finishing of wire -EDM cut microchannels using a self- modulating media and claimed that a thermal recast layer is formed along with blow holes and in order to remove it , higher concentration of coarse abrasive particles are required since they have high velocity due to which the surface finish would be improves rapidly. Tzeng et al. [8] concluded that the size of abrasive particle must be 150 microns with 50 percent concentration 6.7 MPa pressure along with thirty minute of machining time will be optimum parameter for machining of micro-slit of width of 0.23 ± 0.02. Wan et al. [9] studied the two different cross-section which were elliptical in shaped and focused the wall shear stress along with variation of slip line velocity against extrusion pressure at different values of extrusion pressure 6, 12MPa .The researchers concluded the use of zero order methodology for lower variation in the cross-section and first order methodology for the significant change in the cross-section . Although most of the work was done experimentally but the use of software was also significant at that time. Many Researchers tried to use software in order to analyse the Abrasive Flow Machining process among them, Jain [10] simulated a model and studied the dynamic abrasive particles used in finishing process up to the Nano level and suggested that as the mesh size of the abrasive increases the density of grains improves thus resulting in the improve of quality of the workpiece. Gorona et al. [11] talked about the cutting forces required in abrasive flow machining, they calculated forces developed on a single grain during material removal with the help of a model the researcher also calculated the axial and the radial forces involved in cutting. It can be concluded that cutting force is most important parameter of material removal in the abrasive flow machining process as it gives the quantitative analysis of material removal from the workpiece. Kenda et al. [12] studied the effects of surface roughness and residual stresses on steel AISI D2 which was discharged electrically and was a pre-machined hardened tool. After the successful experimentation the authors concluded that the Abrasive Flow Machining is the best method which could be used for machining in such conditions. Jain et al. [13] experimented to enquire about the relationship between extrusion pressure of Abrasive Flow Machining and the surface roughness of the workpiece and found that the surface roughness is reduced on increasing the extrusion pressure. Rhoades [14] stated that media flow is an insignificant parameter in consideration with material removal. Walia et al. [15] experimented on the centrifugal force assisted abrasive flow machining process and put forward following conclusions that were inability of AFM process for removing the large irregularities like taper and oval shape. this is primarily because of the fact that the material removal is uniform and equal throughout the workpiece. The researchers also concluded that for removing same amount of material centrifugal force assisted AFM process is more efficient and effective as compare to the traditional AFM process. [16]. When centrifugal force is added in the conventional abrasive flow machining process, dynamic abrasive grains in the media are improved. Walia et al. [17]. Studied the hybrid of centrifugal force assisted abrasive flow machining process and tried to improve it by designing a better fixture for tooling and ensuring the rod rotation and found that the surface finish produce in the case of CFAAFM is much better than compared to the traditional abrasive flow machining process when the particular number of cycle are achieved. [17]. Abrasive flow machining not only works in finishing of metals and the non- metals but it also works in the Metal matrix composites, Sushil et al. [18] used abrasive flow machining for the finishing of Al/SiC MMCs to obtained an optimized parameter. It was found that for material removal, extrusion pressure and material removal are most significant parameters. In continuation with the use of Abrasive flow machining on the MMC, Mali and Manna [19] worked on aluminium-silicon MMC for optimum cutting conditions required for finishing of Al/15wt% SiC MMC the researchers also concluded that for material removal mesh size is significant parameters. In continuation with the modelling many researchers tried to developed the simulation model based on media and its flow, Chen and Cheng [20] modelled the media behaviour in different passageways using CFD-ACE software and found the significance of helical passageway as compare to the polygon passageway. Marzban and Hemmati [21] used the ANN technique of optimization and studied abrasive flow rotary machining process. The authors claimed that providing spin motion along with rotation of the workpiece, the material removal increases, this is because the contact length betwwn the abrasives and the workpiece increases and also the machining takes place effectively. Mohammadian et al. [22] studied the chemical abrasives process and claimed that Ra value reduced by 45 percent. Venkatesh et al. [23] conducted their experiment by studying ultrasonic-assisted abrasive flow machining process and finished the bevel gear and found that asperity peaks of the workpiece is removed in better way in ultrasonic-assisted abrasive flow machining as compared to the traditional ultrasonic abrasive flow machining process. Uhlmann [24] Studied the use of Abrasive Flow Machining process on the automotive industry to finish the complex shape. The researchers made a paramagnetic modelling approach and claimed that as the cutting rate increases, the shear rate and the flow velocity increases but the process is accompanied by the reduction in abrasive holding capacity. Seifu et al. [25] studied the Abrasive Flow Machining process and focused on the media and found that there is twenty percent decrease in the quality of surface and thirty percent reduction in the material removal when the velocity of the media is maximum at the centre.

2.1 Development of Hybrid Abrasive Flow Machining

Abrasive flow machining process is a Nano finishing process but has a major limitations of low material removal. Although many researchers have tried to improve the efficiency of the AFM material through the introduction of the new Media , Improved in tooling and the fixture and by improving the various related parameters. But development of various Hybrids of AFM has emerged as a key factor in the in improvement of efficiency of AFM.

2.1.1 Magnetic Force-Assisted AFM Process

Singh and Shan developed the process in 2002 [26]. This process involves the application of magnetic field along with the reciprocation of the media through the hollow workpiece. the abrasive mixed in the media are sintered with the carbonyl and the iron particles so that they come into the influence of the magnetic field .the applied magnetic field would attract the sintered abrasive carbonyl particles toward the surface of workpiece and the pressure difference applied by the media cylinder would results in the increase in contact length thus resulting in the effective machining of the process. Not only the material removal but the surface finish is improved drastically in the magnetic force assisted abrasive flow machining process as compared to traditional Abrasive flow machining process. This process is more effective on brass workpiece which is accompanied by the lower flow rate of media and the increase in the value magnetic flux density. [26]. From the experiment it was found that the at 0.4 T, MMR was maximum but it decreases when the value of magnetic field rose to 0.6T[26] (Fig. 2.1).

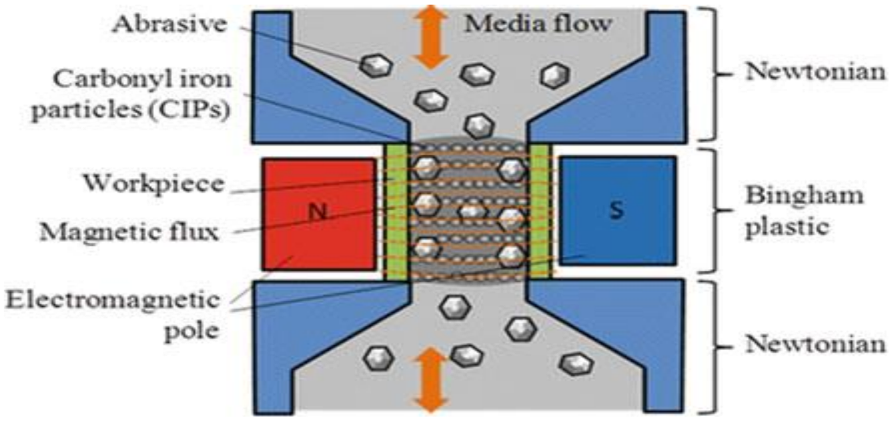


Fig. 2.1 Magnetic force-assisted AFM process [27]

2.1.2 Centrifugal Force-Assisted AFM

Walia et al. [28] coined the concept of centrifugal force assisted abrasive flow machining in 2006. The process involves the use of rod which are placed co axially inside the surface of the workpiece and it is allowed to rotate with certain speed. This rotation of the rod produces a centrifugal motion in the media which directly create a centrifugal force on the abrasives with the help of the centrifugal force the abrasives strike the surface of the workpiece thus resulting in the removal of material. The rotating rod at the centre is called as the CFG Rod. the combined effect of the Centrifugal force along with the reciprocation of the media would increase the contact length and thus results in the increase in the contact length which further results in the effective machining. The mechanism responsible for the material removal is the erosion process and centrifugal force direction is normal to the workpiece axis [30].

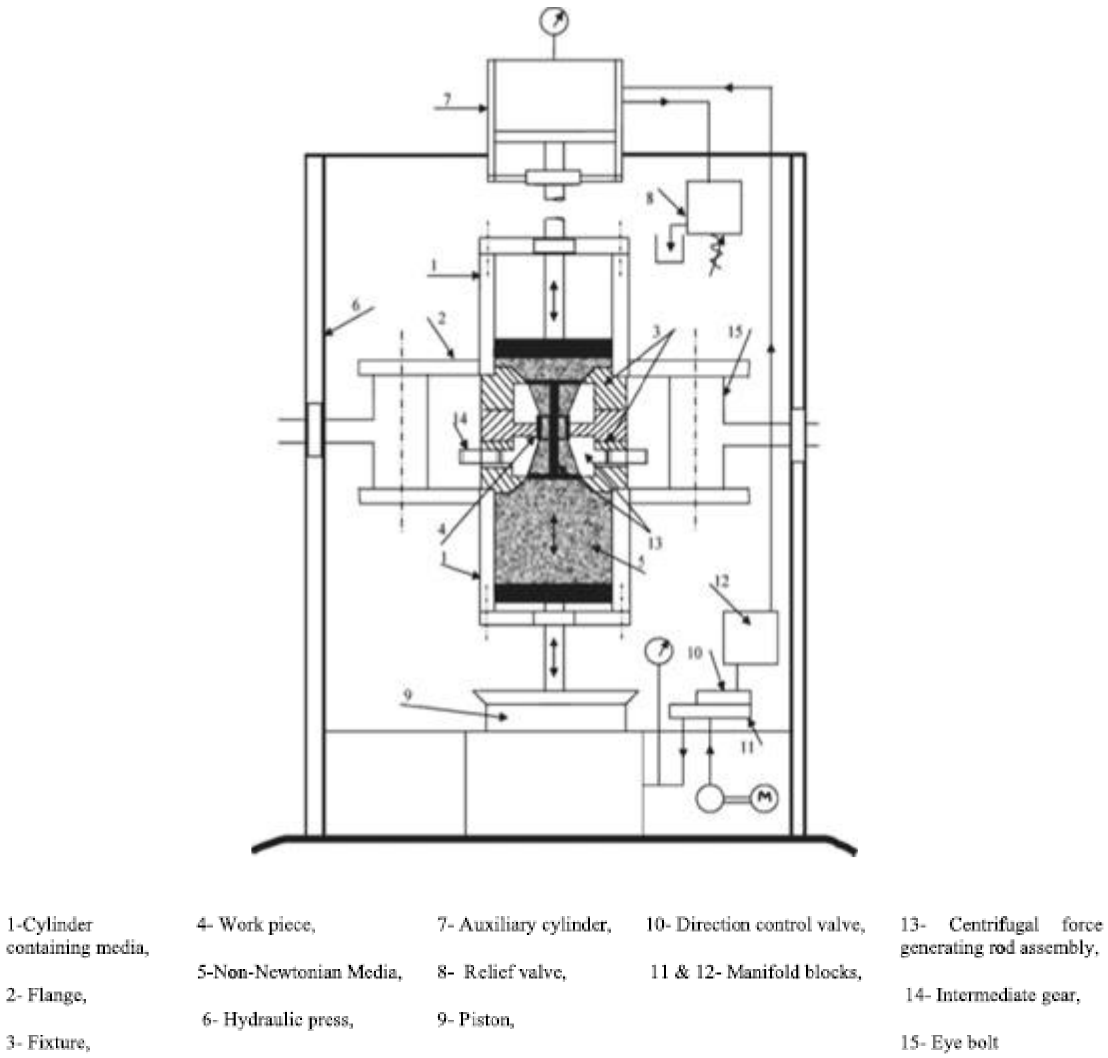


Fig. 2.2 Centrifugal force-assisted AFM process [31]

2.1.3 Ultrasonic AFM

Sharma et al. [32]. Fig (2.3). Coined the process of ultrasonic force assisted abrasive flow machining process. It is a conventional Abrasive flow machining process with little modification that is the workpiece experience vibrations which are of lower amplitude and high frequency. The general range of frequency in this process is 5-20 KHz and the general range of the amplitude is 10 to 50 microns. the important point is that this process is different from the orbital Abrasive Flow Machining process as that was the configuration of AFM and this is the Hybrid of AFM. In this process the vibrations are given in the transverse direction of the flow of media whereas in the orbital AFM the vibrations were given to the workpiece along the direction of flow of media .The mechanism behind the ultrasonic vibration is that the vibration given to the workpiece are transferred to the media which results in the increase in the contact length which results in the effective machining of the process [33].

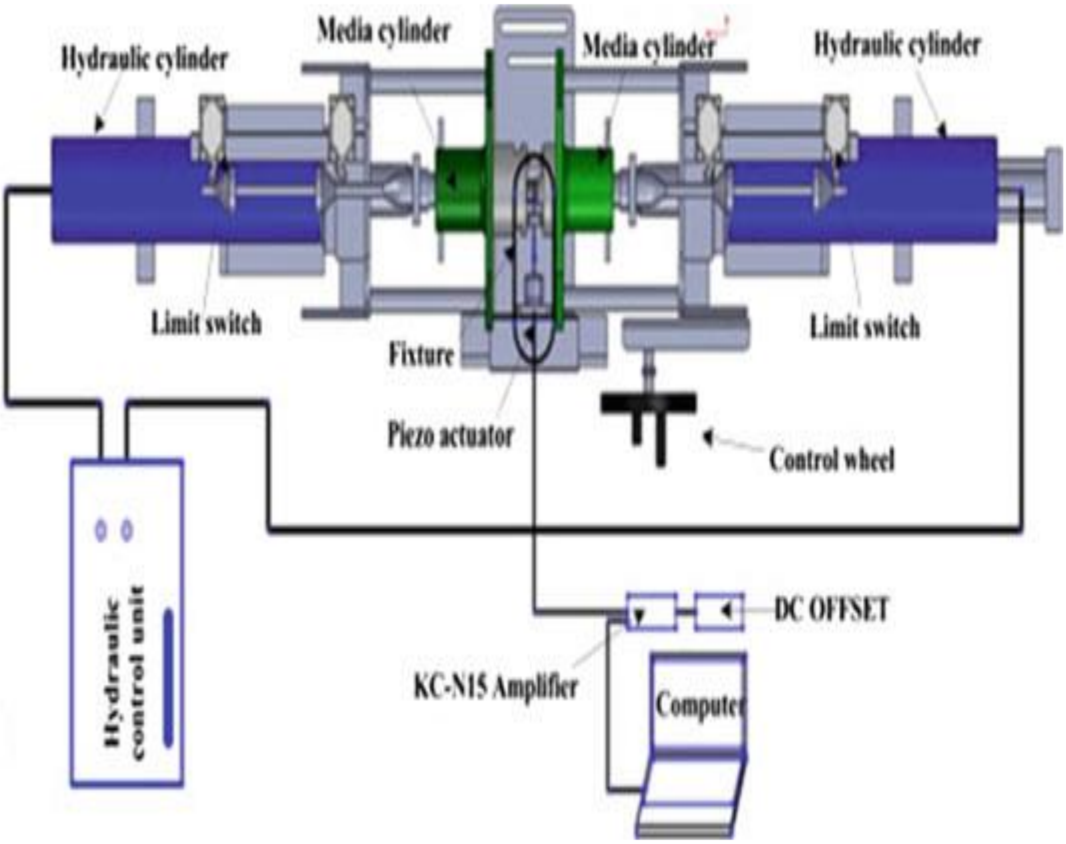


Fig. 2.3 Ultrasonic-assisted AFM process [34]

2.1.4 Drill Bit-Guided AFM

Sankar et al. coined the process in 2009 [35] (Fig. 2.4). The process received its name due to the installation of drill-bit placed co-axially with the workpiece. The machine consists of a Fixture and a fixture plate which is used to guide the abrasive towards the workpiece surface. With the introduction of the drill-bitt, a helical profile is created which results in the intermixing of abrasive and media due to decrease in surface area of flow and increase in the pressure along the material removal zone. Also due to increase in the pressure and low velocity the contact length of the abrasives increases which results in the removal of the material effectively as compared to the traditional Abrasive Flow machining process where the contact length decreases.

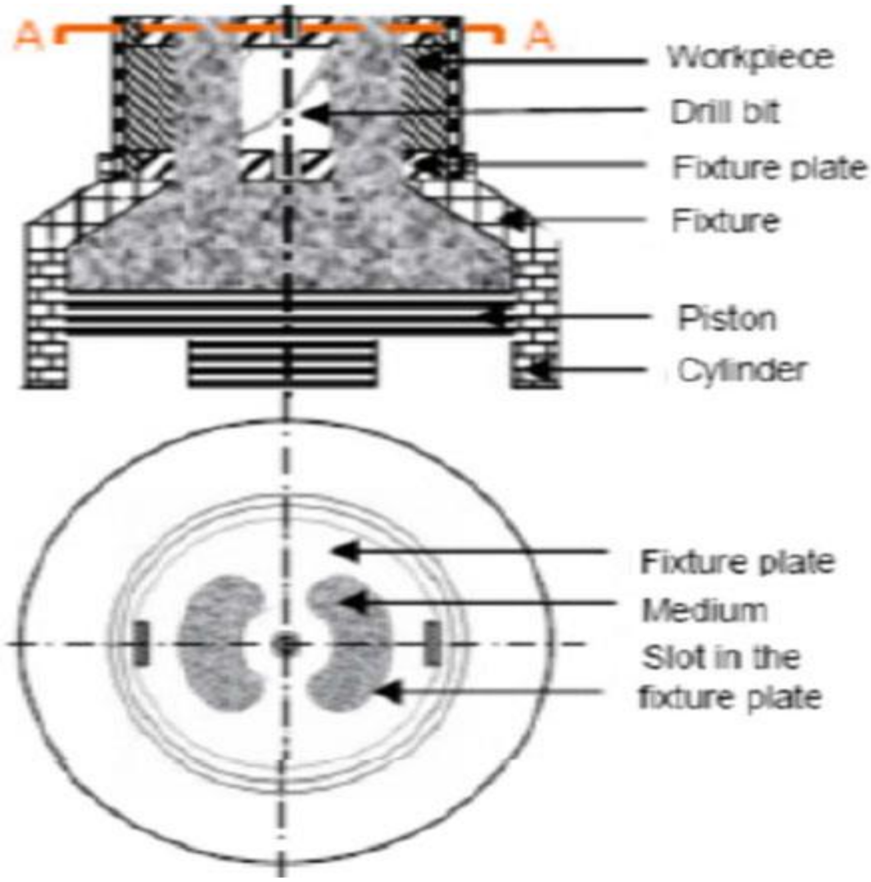


Fig. 2. 4 Cross-sectional front view of tooling in DBG-AFF process [35]

2.1.5 Rotational AFM

Sankar et al. in 2010 [36] coined the process. The process is based upon the idea that the contact area of the abrasive and the workpiece surface must be increased in order to increase the material removal and the efficiency of the traditional Abrasive Flow Machining process. In order to achieve the requite goal the researchers decided to provide the rotation to the workpiece instead of putting A CFG rod and Provide rotation to the media through the centrifugal action. Rotation of the workpiece results in the increase in the contact length and thus helps in the effective machining. conceptually the process finds it similarity with centrifugal force assisted abrasive flow machining but it is different in reality. [37]. Experimentally it was found that forty-four percent more smoothness is achieved as compared with traditional AFM process and moreover the martial removal is enhanced up to 81.8 percent. Figure 2.5 shows the typical setup for the rotational AFM process.

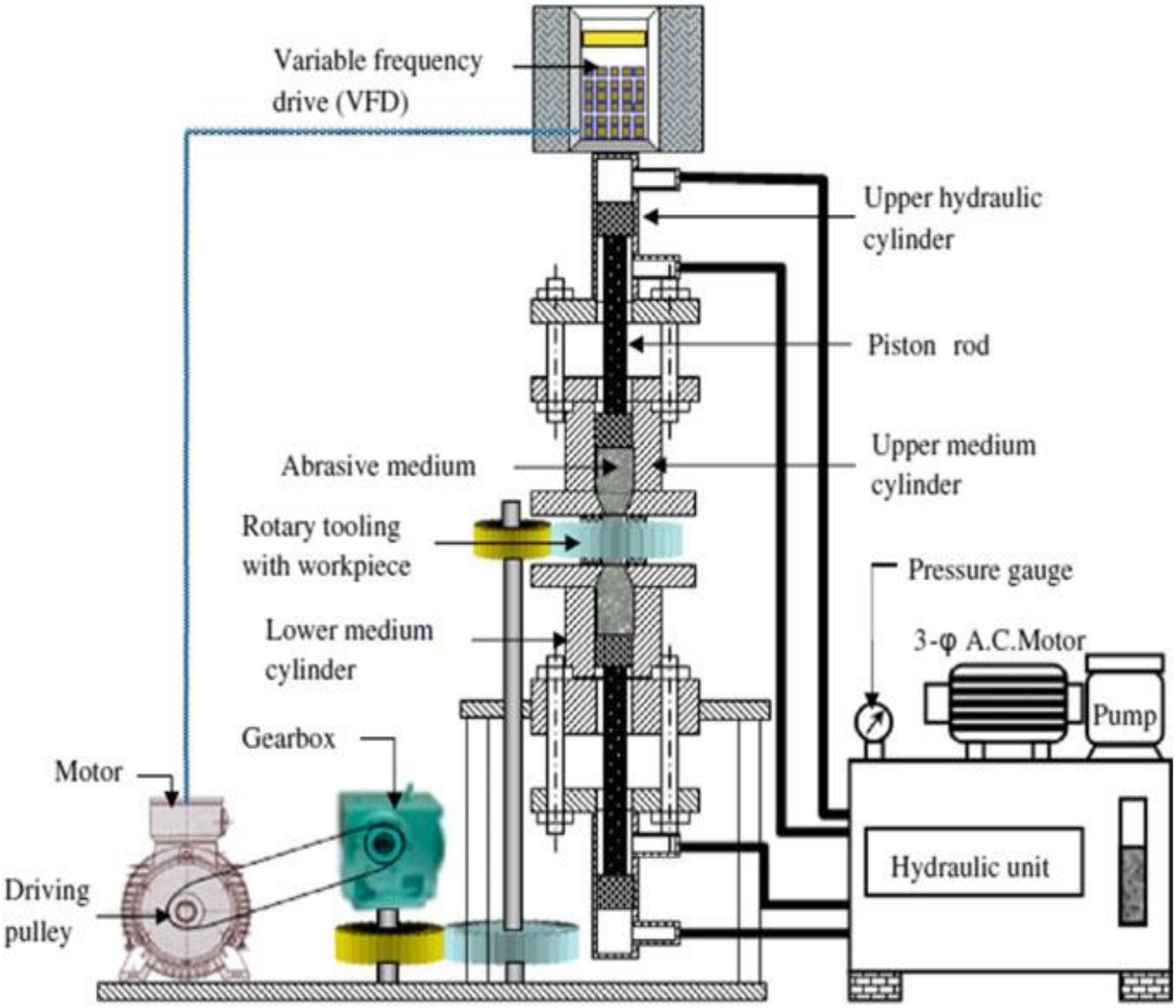


Fig. 2.5 Rotational AFM set-up [36]

2.1.6 Electrochemical-Assisted AFM

Dombrowski in 2011, coined this process for Nano finishing of the surfaces [38, 39,40]. Electrochemical-assisted abrasive flow machining (ECA2FM) it is typically a type of electrochemical machining process. The basic mechanism involves in the electrochemical-assisted AFM is dissolution of the workpiece which is made anodic into its constituents' atom. This process is found its application in the micro-machining and in the Nano machining of the process in the field of Medical, fuel cell and batteries. Although the process has certain disadvantage like roughness of the surface and the development of scratches on the surfaces.it was found that for a brass material, At 10 V, 87.43% improvement in *R*a was observed [40] also there was a significant improvement in Ra from 4.02 to 0.49 Micron (Fig.2.6).

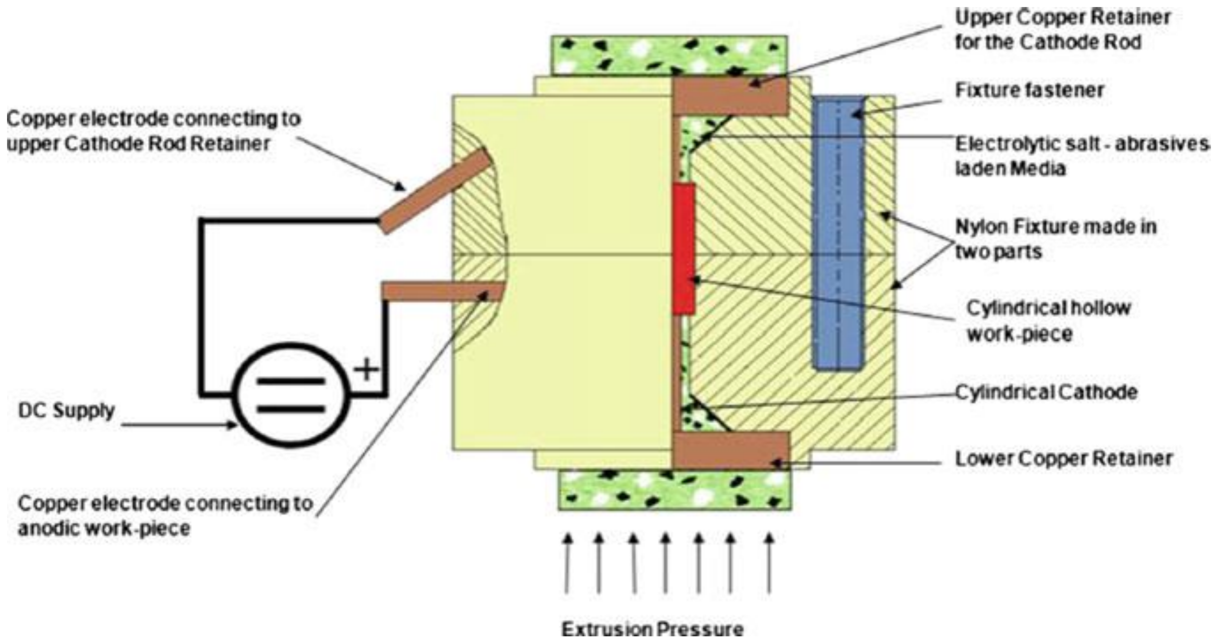


Fig. 2.6 Model of electrochemical-assisted AFM [41]

2.1.7 Helical AFM

Helical AFM was coined by Brar et al. [42] in 2012 and claimed that there is an improvement in surface roughness up to two microns. This hybrid of AFM gives the resultant effect of Centrifugal, axial and radial force. In this type of Hybrid of AFM, a helical profile CFG Rod is placed co -axially with the axis of the workpiece. This is different from the drill-bit guided AFM with the fact that Helical AFM has rotating Helical rod which gives the centrifugal force to abrasives along with the all advantage of drill-bit guided AFM. When the path of the flow is small the pressure at that zone increases which results in the increase in the material removal from that zone, also as stated above that the Hybrids involve the the combination of the three forces hence the contact length increases which also results in the increases in the material removal. The important point is that these combinations of the forces also increases the dynamic grain density. Experimentally it was observed that this hybrid had contributed 78.89 percent and 6.70 percent was the contribution with the number of cycles. Walia et al. [43, 44] also experimented on this hybrid and found that there is 10 to 2.35 times improvement in surface finish when helical rod was rotated as compare to other shape rod in centrifugal force assisted AFM set up. They also claimed that the contribution of helical AFM was about 2.66 times as compared to traditional AFM process. The typical set up of the arrangement is shown in the figure.2. 7.

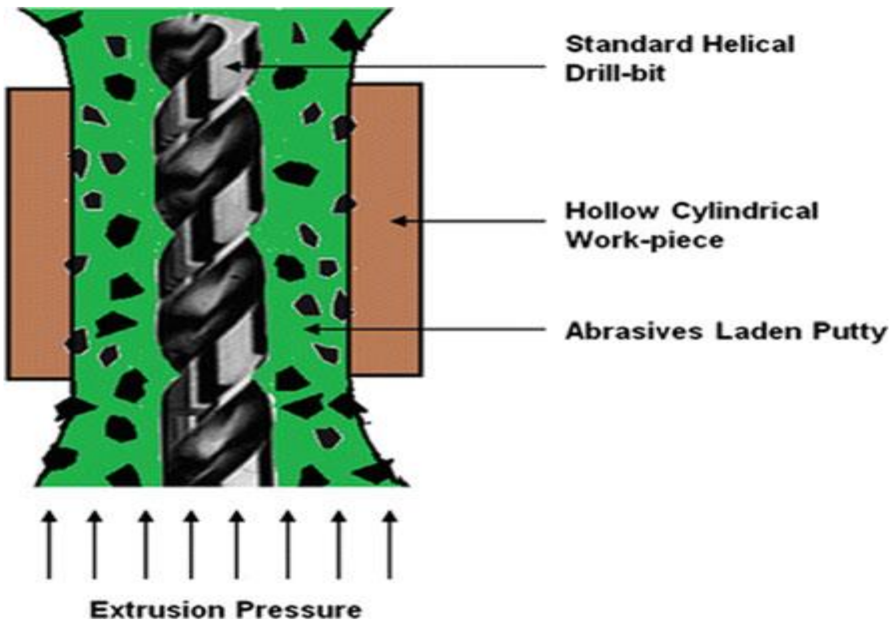


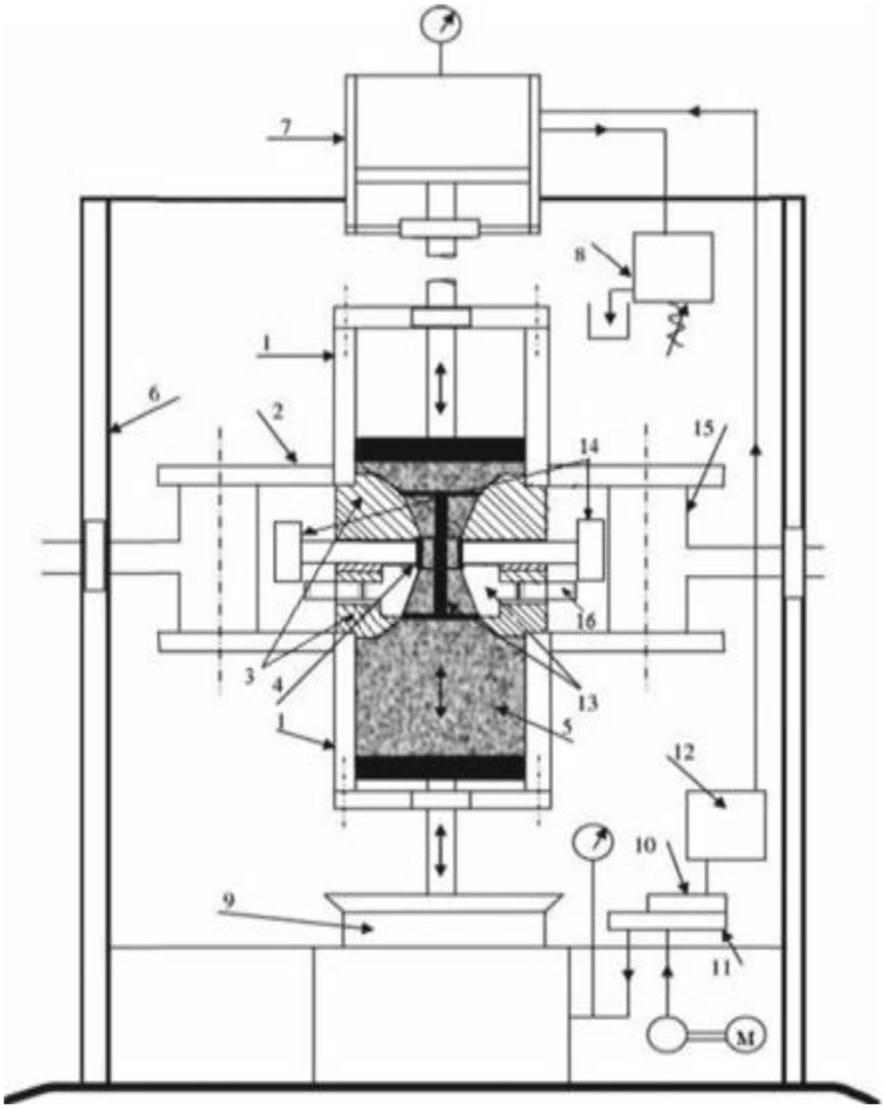
Fig.2. 7 Model of helical AFM [44]

2.1.8 Centrifugal–Magnetic Force-Assisted AFM

Singh et al. in 2015 [45] coined the concept of this Hybridisation. The setup appears to be similar to the centrifugal force assisted AFM with a little difference which is of inclusion of magnetic field in the system. It uses the sintered form of abrasives along with the ferrous particle and are mixed with the polymer gel and thus a media is created which is capable of holding the magnetic field. As the name suggest a CFG rod is placed co-axially with the axis of the workpiece hence the magnetic and centrifugal force increases the contact length which results in the increases in machining as machining takes place effectively. The magnetic field is produced by the DC current supply it is adjusted so that full length of the workpiece is covered for the machining and moreover the design of fixture plays an important role and are made up of three part. The experimental were conducted and it was said that the magnetic field was 0 to 0.6 T and the rotational speed of the rod is 60 RPM. The researchers apply Taguachi optimization techniques and found that 0.3 T magnetic field as the optimum field [45] The typical set up of the Hybrids is shown by the figure 2. 8.

2.1.9 Hybrid Electrochemical and Centrifugal Force-Assisted Abrasive Flow Machining

Vaishya et al. in 2015 [46] coined this process. This Hybrids jointly works on the advantages of CFAAFM and electrochemical process. It consists of a Nylon fixtures which is held between the fastener and the retainer and is made up of three part of fixtures. The experiment results show that the parameters of this process is six megapascal of pressure with maximum voltage up to thirty volt. The experiment also shows that this hybrid when operated at the low extrusion pressure reduces seventy to eighty percent of the machining time also the range is .5 to .6 microns. The typical set up of the hybrids is shown in the figure 2.9.



1- Media Cylinder,	5- Non -Newtonian Media,	9- Piston,	13-Centrifugal force generating rod setup,
2- Flange,	6- Hydraulic press,	10- Directional control valve,	14- Electro-magnet,
3- Work piece holding device,	7- Auxiliary cylinder,	11&12- Manifold blocks,	15- Eye bolt,
4-Test- piece,	8- Relief valve,		16-Intermediate gear

Fig. 2.8 Centrifugal–magnetic force-assisted AFM [45]

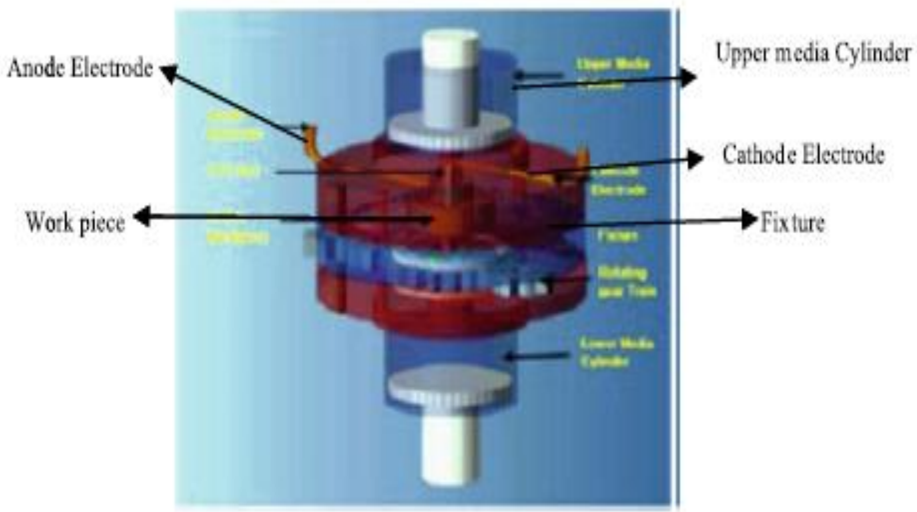


Fig. 2.9 EC2A2FM set-up [46]

In this work the focus is given to the centrifugal force assisted abrasive flow machining process. The reason for choosing the process is to overcome the low efficiency of abrasive flow machining process. Though various hybridizations have improved the process but centrifugal force assisted AFM have played key role. The most important factor is how much force is generated in the process which depends on the shape of the rod. This works focuses on the various shape of the rod and how it affects the pressure and velocity distribution inside the abrasive flow machining and also which rod would be most effective for the MR and the percentage improvement in surface finish. The variation of the pressure explains the material removal from the area and also the streamline also shows the uniform machining through the rod.

2.2 EFFECT OF AFM PROCESS PARAMETERS

Factor influencing MR depends upon:

(1) The flow rate of media

(2) The Viscosity of Media

(3) the size of Abrasive particle

(4) The concentration of Abrasive media

(5) The density of Particle

(6) The Hardness of the particle

The following contents include the brief works done on the abrasive flow machining which are characterized under various headings which are discussed below.

2.2.1 Number of Process Cycles

Media travelling from Upper to lower cylinder and vice-versa is term as a cycle. Particular number of cycles are required to achieve a specific MR and Specific value of Ra on a component. According to the research it is claimed that MR and percentage improvement in Ra requires Specific cycles and then it gets stability. Jain V.K. [47] stated that MR is higher initially but decreases with no. of cycles. Jain and Adsul [48] experimentally reported that surface finish decreases with increase in number of cycles. Mamilla Ravi Sankar et al. [49] stated that increase in no of cycle results in the increase of indentation on the particle which increases the material removal. But on further increasing the number of Cycle, the MR decreases due to shearing of sharp peaks which were formed initially.

2.2.2 Extrusion pressure

There are three factors which are required in proper balance to achieve the requisite surface finish they are extrusion pressure, grain mesh size and abrasive concentration. for Required percentage improvement in Ra there is a requirement of high value of extrusion pressure. The combination of low extrusion pressure with low abrasive concentration and small grain size will decrease the surface finish. When combined with low extrusion pressure and larger grains, uneven distribution occurs which results in the variation in the surface finish of the work pieces. Jain et al. [50] and Jain and Adsul [20] claimed that the surface finish is decreased up to certain value. Przyklenk K., Rhoades L.J., William R.E. et al. [51, 52, 53] reported that Keeping all other factors same high pressure of media would result in faster material removal. Jain [54] reported that higher pressure stabilizes the MR because of localized rolling of abrasion particles.

2.2.3 Media Temperature

Temperature essentially required in the Abrasive Flow Machining process as it is responsible for the process effectiveness. Liang Fang et al. [55] found that temperature proportionally varies with number of cycles which results in less MR.

2.2.4 Media Flow Volume

The volume of the reciprocated medium within the media cylinders is called media flow volume. It controls the amount of abrasion and surface finish on the workpiece.it is a dominant process parameter which controls the abrasion amount by a specific media composition. With all other factor same, the abrasion will increase with the volume. If two passage of different cross-sectional area are given the same media flow volume, smaller passage will abrade more than the larger one. Kohut [56] reported that if all other process parameters are kept constant abrasion will be proportional to media flow volume.

2.2.5 Media Flow Rate

Perry [57] stated that more abrasion is caused when the amount of media flow rate is high. some parameters effect the uniformity of the MR like viscosity of media and pressure. Media flow rate depends upon these factors. Rhoades [52] reported that the media flow rate does not effects MR.

2.2.6 Media viscosity

Viscosity of media affects the Ra value and MR in AFM process. Temperature, Kind of abrasives, amount of abrasive and the grainsize affects the viscosity of media. Media viscosity decreases with the increases in temperature which results in grain settling which effects the flow properties and overall abrasion process. Liang Fang et al. [55] reported that the MR is more with high viscosity in comparing to lower one also the surface roughness is also improved with high viscosity media. Davies and Fletcher [58] experimentally reported that viscosity of the media is affected by temperature. Viscosity of medium decreases very fast even for a slight increase in temperature (2-10 °C). MR capacity of the low and high viscous media varies from each other.

2.2.7 Abrasive Particle Size

The variation of abrasive grit size in AFM changes from 500 grit (tiny hole applications) to 8 grit (roughing and stock removal applications). The abrasives with higher grit size cuts faster on the other-hand smaller size gives improvement in Ra and can machine complex and narrow passages. Davies et al. [58] stated that surface finish is better in small size abrasive and also their scope is larger in complex geometry as compare to the larger size abrasives.

2.2.8 Abrasives Concentration

It is the ratio of weight of abrasive particles to the weight of carrier compound multiplied by 100. Jain V.K. [47] stated that as the abrasive concentration is proportionally dependent on MR while surface roughness value comes down due to increase in number of the active grains.

2.2.9 Initial Surface Condition

Material removal depends upon the hardness of the workpiece and the initial surface finish. Material removal is higher in softer materials. It has a good surface finish as compared to harder material. Loveless et al. [59] concluded the importance of process used for making specimen before AFM and it affects the improvement in Ra value.

2.3 Objectives of using Centrifugal force assisted abrasive flow machining process.

Abrasive flow machining has a major disadvantage of low MR which is a matter of concern , to overcome this issue Centrifugal force assisted Abrasive flow machining is taken into consideration in which 3 shaped rod (Rectangular, Triangular and Circular) rod was rotated to produce a centrifugal effect and with the help of erosion process the material removal tale place and thus the MR is improved and optimal Ra is obtained.

Chapter 3

EXPERIMENTAL DESIGN AND ANALYSIS

Design of experiments (DOE) in simple word may be called as planning through the statically arrangement where variation is present, irrespective of fact that they are in or out of control. However, in statistics, these terms are usually used for controlled. These quantities have the specific importance as the process which are in control corresponds to the specific results which are desirable and confirms the validity of the experiments. Sir Ronald Fisher is the originator of the statistical experimental design he was a British who lived in England in 1920s. Fisher was trying to study the method for improvement in the crop yielding and then he discovered the basic principle of experimental design and the associated data-analysis technique called Analysis of Variance (ANOVA). There were many other researchers like Box and Hunter, Box and Draper, Hicks who came in this field and invented various useful techniques. Taguchi's Method is one of the accurate techniques which uses the Orthogonal arrays on the other hand different matrices are used for experiments to study several decision variables.

3.1 TAGUCHI'S EXPERIMENTAL DESIGN AND ANALYSIS

The Taguachi method came into existence when Genichi Taguachi (Japanese researcher) developed it who was working on the variation of the data. The main aim of the Taguachi method is reduction in variation in the procedures by taking appropriate designee of experiment. the main aim of the Taguachi method is to produce desirable product with high quality at the economic cost to the manufacturer. we know that for any statically data, mean and the variance is the most essential factors which affects the process and these factors decides how much desirable the process is and it how much it can be fruitful. So the experiments developed by Taguachi targets the mean and the variance of the process the aim of the Taguachi designed experiment were the mean and variance of a process are affected by different process parameters .There is a use of orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. One of the special features of the Taguachi method is that it takes pairs of different combinations for testing which gives the optimal factor with appropriate quality and requires least amount of time. The Taguchi method is generally used when the variable is three to fifty with some interactions between the variables and out of which very less number of variables have the significant contribution.

3.2 PHILOSOPHY OF TAGUCHI METHOD

1. Quality is most important parameter of a product which make it relevant for its functional performance and hence it must be designed instead of being inspected into a product. Generally, there are three ways to design the quality which are as follows

a. System design
b. Parameter design
c. Tolerance design.

Among these three systems of design parameter design is used which includes the determination of the parameter which significantly affect the product and thus the specified level of quality is achieved by applying proper sequence of procedures. When we talk about the inspection of quality, we talk about the acceptance sampling in which we select a limit around the mean and anything which is not conforming to the specification is generally not consider.

2. There are various uncontrolled environment factors which are available in the vicinity of the product. The design of product must be in that way that these environment factor may not hamper its quality. In statically language the product quality is generally term as the Signals and uncontrollable factor are called as the noise, and for the better quality the ratio of signal to noise must have a higher value.

3.Product's is not only measured from the product but also it is measured from the system and it is effective if we observe it by taking its economic value or by considering its cost. This quality cost must be estimated as a function of standard deviation and entire losses of the system must be considered. This system is practically applicable in the society as the producers bears the loss. This is the concept of the loss function. As it includes the goodwill loss of the producers also.

3.3 Taguchi Method Designs of Experiments

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

1. The first step in order to apply the Taguchi is to select the process objective which is the requisite target for the measurement of the performance.it may be any parameters say rotational speed of the rod, pressure of the workpiece etc. The target may be to maximize and minimize any of the parameters. Any deviation from the target value is used to define the loss function of the process.

2. The parameters which are could affect the process and the number of levels which are varied through the parameters are determined. For example, different values may be given to the particular parameter which accounts for the different level.

3. orthogonal arrays for the parameter design must be created which must include the details of particular experiment containing number as well as the conditions. the number of parameters and the levels of variation for each parameter are important factor for the selection of the orthogonal arrays.

4. the experiment indicated on the array must be conducted and the data must be collected on the effect on the measure of performance.

5. Data analysis was done to get the requisite results.

3.4 Experimental Design Strategy

Orthogonal arrays arranged in Greco -Latin squares are recommended for carrying out experiments in Taguachi system. For designing an experiment particular orthogonal array is taken which could give the suitable results after the interaction within the columns. The suitable parameters are assigned in the given array also there is involvement of linear graph and triangular which makes the process less complex and handy. the introduction of array helps in the identical experiments. So, in order to optimize any parameter with the help of Taguachi suitable steps are taken among which array selection is the most prominent step.

The important objectives of Taguachi methods are as follows: -

- It gives the best or the optimum results for a process or Products.
- It examines the selected parameters and gives their contribution and interactions.
- It examines the response under the optimum situations.

In Taguachi method the knowledge of main effect of the parameter is an important factor. They give the idea of the general trends which influence the parameters It is the main effect of the parameters only whose study gives the optimum results. Also, it gives idea about distribution of the contribution that is how much each parameter is influencing the results. The knowledge of this contribution helps in deciding the nature of control establish in process. Generally, in order to determine the percentage contribution, the particular parameter against the particular level of confidence, we use ANOVA (analysis of variance) method and thus by studding its table, one could find the which of the parameter needs to be in control.

There are two different approaches which occurs in Taguachi method in order to get the optimize results, one is the standard approach and the other is signal to noise approach. In standard approach the results of the experiment which are taken only once or the average of the experiments which are taken multiple times are analysed with taking main effect and the ANOVA analysis into the consideration in which there is an analysis of the raw data. In signal to noise ratio (which is used for multiple run system according to Taguachi), the loss function is minimized by maximising the ratio. This ratio is associated with the loss function and it is a concurrent quality matrix. Signal to noise ratio gives the most accurate set of operating conditions which are optimum, from the variation within the results. It is considered as the parameter which is responsible for transforming the raw data of the experiment and hence called as the response parameter. Taguachi used outer orthogonal array to introduce the variation of noise (which is given to experiment by intention) into the experiment. The variation of response is mostly influence by noise factor which are present in the process. The important point is that it is not necessary to analyses and identify the control parameters by using S/N ratio. It is important to mention that the present work contains both the use of signal to noise ratio and the raw data analysis. The use of Plots and the main effect based on raw data are considered for the study of centrifugal force assisted AFM Process. The works avoids the use of outer array and used 3 times experiment in place of it moreover with the help of signal to noise ratio, Quality characteristic have been established.

3.5 Loss Function and S/N Ratio

Taguachi defined quality in most appropriate way whose definition was cloudy and unclear in many Respect he stated that quality is that characteristics reduces loss to society, this loss is counted in the monetary unit and may possess quantified characteristic of the products. This loss was defined as loss function by Taguachi. He used the Taylor series expansion and gave a relation between the loss as a function of certain parameters.

In order to study the Taguachi procedure following observation needs to be observed

- Loss is proportionately dependent on the variation of the product’s characteristic from the target value. If the desirable quality is achieved, the value of the loss function becomes zero.

- The loss is a continuous function which means that if the product is within specification, it does not mean it is of good quality.

The general expression of the average loss per unit is given by:

$L(y) = \{k(y_1 - m)^2 + k(y_2 - m)^2 + \ldots\ldots\ldots\ldots + k(y_n - m)^2\}$ Where y_i= characteristics value of unit i and n stand for total units in a given sample and k stands for constant according to the magnitude of characteristic and m is the Target value.

The main success of Taguachi was to transformed the loss function into S/N ratio, which includes both the mean values of the characteristic involved in the quality and variance of this particular mean to single matrix. signal to noise ratio merges various repetitions into a singular value in which minimum 2 data points are needed. Optimum value is achieved when the value of S/N ratio is high. Type of response classify signal to noise ratio into three type which are taken into consideration.

.

1. Larger the better:

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

Where

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

2. Lower the better:

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

Where

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

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

the standard definition of MSD is taken into consideration in order to obtained the best suited characteristic. The target value changes for different type cases for instance if we take the case of 'smaller the better' the target value is taken as zero. If we consider the case of larger the better type, in this type also the target value is taken as zero, the inverse of each large value becomes a small value. And from these values the smallest value is taken. In order to Magnify S/N number the use of ten must be there for each analysis and there is a use of negative sign to set S/N ratio of larger the better in comparison to the square deviation of smaller the better.

3.6 Taguchi Procedure for Experimental Design and Analysis

The stepwise procedure for Taguchi experimental design and analysis are as follows

(A). Selection of OA

The selection of orthogonal array is an important step if one is seeking optimization through the Taguachi method. There are some predefined steps which are to be taken in minds which are

- parameters of process are to be selected.
- selected parameters' levels are considered.

In Taguachi method DOF of an experiment is a function of total number of trials. The DOF of the parameter increases with total number of levels also increase because the DOF of a parameter is one less than the number of parameters. also, on increasing the degree of freedom, number of trials also increases. In Taguachi method Three level is consider when higher order polynomial relationship among the parameters is there and two levels for each parameter are recommended to minimize the size of the experiment. Both the two level and the three level have standard array set which is Two-level arrays: L_4, L_8, L_{12}, L_{16}, L_{32} and Three-level arrays: L_9, L_{18}, L_{27} in this the subscript represents the number the number of trials. As stated earlier (DOF) available in an OA is f_{LN} = N-1 Where f_{LN} stands for total degrees of freedom of an Orthogonal Arrays and the L_N represents the Orthogonal Array designation and N represents number of trials. $f_{LN} \geq$ Total DOF required for parameters and interactions this inequality stands true for selection of the orthogonal arrays.

(B). Assignment of parameters and interactions to OA

A particular orthogonal array contains several columns which involves various parameters and its interactions are assigned. The possible interaction between the parameters and their assessment in the columns of orthogonal array contains the Linear graphs and Triangular tables which are important tools in Taguachi technique. Each ‘OA’ has its particular liner graphs and interaction tables.

(C). Selection of outer array

There are two main group of factors which involve

•Controllable factors- Factor which are easily controlled

• Noise factors- factors which are difficult to control. Responsible for the performance variation of a process. It involves use of orthogonal arrays

(D). Experimentation and data collection

Experimentation is one of the key factors in the computation of optimal parameters in the Taguachi methods. Experiments are performed in the inner array and are then transferred to the outer array. There are conditions wen the outer array are used or not, when the outer array are used than the experiment in the trial condition is repeated and if the outer array is used than the condition are modified according to the outer array itself. The value of bias is the main problem of the system and its value must be reduced so in order to do that the Random values must be taken into consideration in experiment.

(E). Data analysis

In order to analyze the data Taguchi coined many methods which were as follows- observation method,

- Ranking method
- Column effect method
- ANOVA
- S/N ANOVA
- Plot of average responses
- Interaction graphs

The above stated methods are common and are used in the most of the applications which involved the use of the statically observations into consideration. Present works contains, following methods are used.

• Plot of average response curves- To indicate the trends and represents effects pictorially

• ANOVA for raw data- It provides a suitable structure to OA used for the experimentation

• ANOVA for S/N data- Estimates the Variation in trials when noise is present in the system it also identifies significant parameter.

(F). Parameter design strategy

As stated above tat for a structure system of experiment there is requirement of variance analysis of raw data and the analysis of variance for the data indicating te signal to noise ratio, which are helpful in computation of the control factors which could influence the system. These control factors may be further classified in four groups which are -

The group first involves the factors through which both the variation and the effect in the experiment is affected. The group second involves the parameter which influences the variation in the experiments only. Whereas group three includes the parameters by which average is affected only and lastly the parameters which does not affects anything are arranged in group four.

So for any experiment if the strategy is to minimize the variation of the experiment than we use the group two type parameters and if the strategy is to choose particular levels of the parameters we take group 1 into the consideration. If situations arise in which there is a need to modify the average target value than we use group 3 type of parameters. If we have to see the group 4 parameters they are taken into consideration when certain economic factors and cost consideration are taken into consideration.

(G)Prediction of mean

The next step in the consideration of the Taguachi method is the computation of mean of the collected responses at the optimum or the desired situations. It is to be noted that the mean is calculated at the desired conditions only and for the computation of the mean significant parameters (which are selected by ANOVA) are taken into consideration. If we assume that, parameters C and parameter D significant the set of selected parameters and if we consider the second level of both the parameters C and D that is C2D2 is optimal situation, the mean would be given by $\mu = T + (c_2\text{-}t) + (d_2\text{-}t) = C_2\text{+}D_2\text{-}T$, in which T stands for the mean value of the response and C_2B_2 THE average response values at second levels of parameters C and parameters D respectively. This method is not the only method for the prediction of the mean of the response, the situation may occurs that the optimal level you computed may match with any trials present in the array of experiment than in that case the computation of the mean is a simple task and involves the computation of the average of result trials at the specified level.

(H). Determination of confidence intervals

The computation of the optimal condition through Taguachi is completely based on the statically computed steps thus in order to obtained various results some statically quantities like mean is taken into consideration not only the mean but other quantities are also required for the computation of the optimum value of the experiment. The prediction of the range of parameters and its value is one such important quantity. This range is known with some other name in Taguachi approach and is called as the confidence interval which is denoted by CI which is generally classified into two types in order to compute the mean.

•CI_{CE} – This interval is used for the verification of the predictions around the mean values of treatment situations of experiment at the confirmation experiments. The point to be noted is that it is done only for the limited size of groups where the trials are not large.

•CI_{POP} – This interval is calculated in the situation when all the product is under specified conditions. It is called as the Confidence Interval of population computed around the mean value at the optimal condition predicted from the experiment.

The following expressions are used for the computation of the above stated values.

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

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

Where

- F_α (l, f_e) is F-ratio (1-α) confidence-level with 1DOF.
- f_e., f_e = error in Degree of Freedom
- N = Total results
- R = Sample size
- V_e = Error in variance

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

(I). Confirmation experiment

The last step in the analysis is the verification of the conclusion obtained in the previous experiments. The methodology is that firstly the significant parameters are taken into considerations and the test which were selected under optimum conditions are allowed to run in those conditions. Than a comparison is done in the mean value so obtained from the final or the confirmation experiment and the value which is predicted and thus the result is predicted.it is to be noted that the value so obtained in the confirmation experiment must lie within Ninety-five percent confidence level when confidence interval at confirmation experiment is taken into account where as it may or may not lie in ninety-five percent of the confidence interval of population. Thus, it is the most important step and is an essential component of t he Taguachi approach in order to identify the significant parameter effects on the results and also to compute the optimal values and the range of the parameters.

Chapter 4

Description of Abrasive Flow Machine

4.1 AFM COMPONENTS

The two-way AFM pressurizes the abrasive media to flow with in the inner -cylindrical part of the hollow workpiece. The abrasive laden media interacts with the target portion and results in the MR from it. 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 main driving component of the Media. This is the only components which results in the reciprocation of the piston media within the hydraulic cylinder. The hydraulic power pact consists of following part which are listed below-

- Motor
- Reservoir
- Filter
- Hydraulic pump
- Hydraulic circuit.

Fig. 4.1 Photograph of Hydraulic power pack

4.1.2 Hydraulic Cylinders

Hydraulic cylinder consists of two cylinders which are placed parallel to the axis of the machine. These cylinders are responsible for the reciprocation of the media through the movement of the piston from one end to other and the vice-versa due to the change in pressure applied at the ends of the cylinders. The system is closed by cylinder bottom and the gland which are placed at the bottom and the top part of the bore respectively. So more precisely the pistons are driven by the mechanical action of the Hydraulic fluid present in the media which in turn is activated by the pressure difference which initiate the flow in the particular directions.

Fig. 4.2 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 contains following constituents-

- Mixture of the gel
- Polymer
- Abrasive particles

Fig. 4.3 Media Cylinder

4.1.4 Fixture

The fixture is made of Nylon. It holds the work piece and allows the media to flow through the workpiece. The material of fixture is generally chosen in such a way that it possesses good holding as a well as wear properties, and one such material is Nylon, which is generally used in the process.

Fig.4.4 Photograph of Fixture

4.1.5 Machine Frame

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

Fig.4.5 Machine Frame

Fig 4.6 Machine Photograph

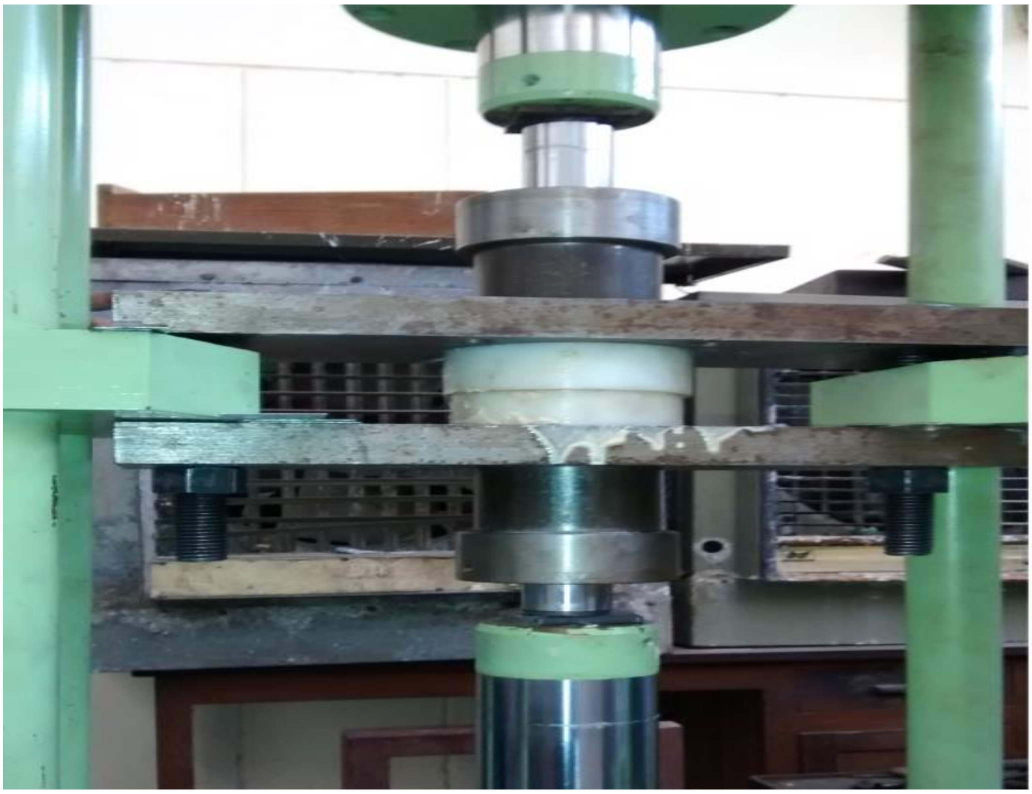


Fig 4.7. Photograph of developed AFM set up

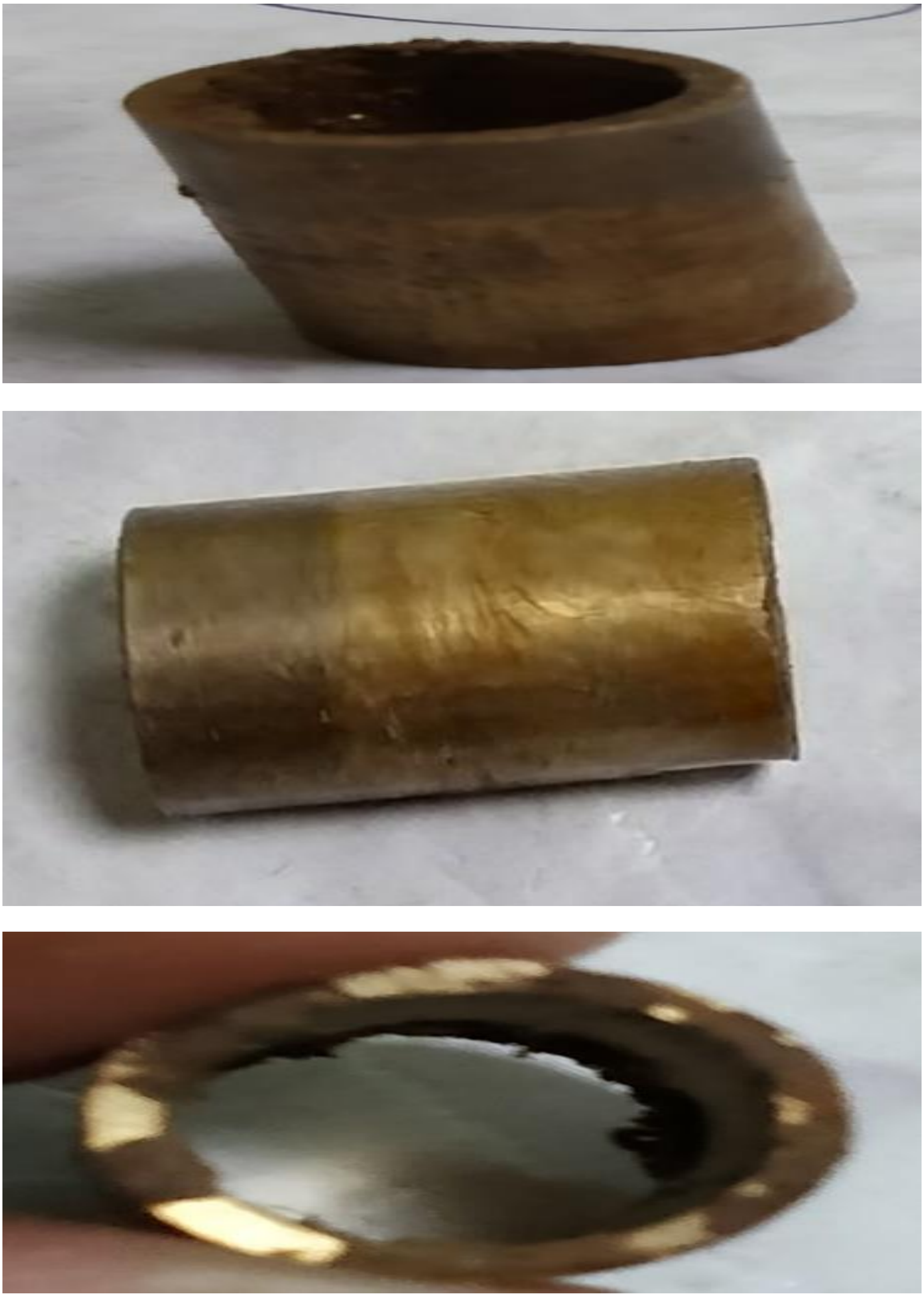


Fig 4.8 Photograph of the workpiece used

Chapter 5

PROCESS PARAMETER SELECTION AND EXPERIMENTATION

The technique used in this investigation is the Taguachi method which involves the use of statically data and the computation of the optimum conditions and the significant parameters. AFM is a major tool for controlling the surface finish and shaping the product into its desired industrial requirement. It looks after the wide range of the parameters which should be taken into consideration while designing the requisite results.

5.1 SELECTION OF WORKPIECE

For this investigation the most initial requirement was the preparation of the work piece for that the study of Kohut was taken into consideration in which e suggested the optimum value of the length to diameter ratio. The steps involved in the preparation of the work piece are as follows: -

- Selection of material which is aluminum
- Preparation of cavity of specified size by Drilling
- Determination of no of cycles for finishing particular component by AFM.
- Cleaning the work piece with Acetone for further measurement.

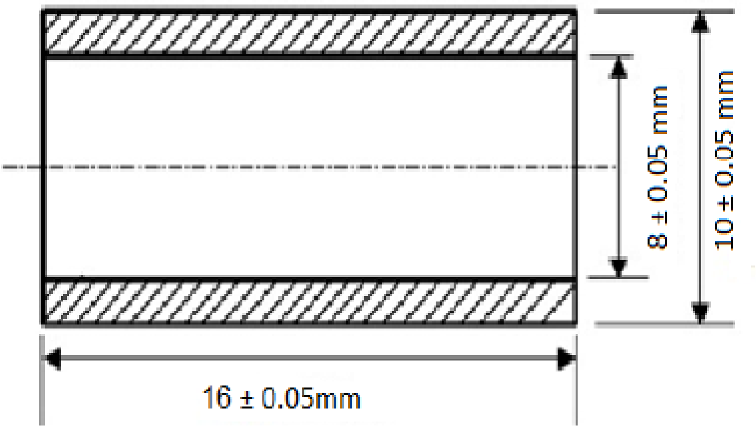


Fig. 5.1. Test Piece

5.2 SELECTION OF PROCESS PARAMETER AND THEIR RANGES

The process parameters along with their range are firstly the Type of Press which is taken as the fabricated Design specifically two pillars type. The next is the Capacity which varies from – 25 ton to + 25 Ton. The stroke length of the machine was ninety-six mm and the diameter of the bore is about 130 mm. the stroke length of the hydraulic cylinder is ninety millimeters with the value of working pressure as 210 kg/Cm^2but the maximum pressure is thirty-five mega Pascal note that the cylinder is driven by the piston whose stroke length is three hundred millimeters with the extrusion pressure ranges from five to thirty-five mega Pascal. The volume of the media is 290 cubic centimeters with the temperature ranges from thirty to thirty-four degree centigrade. The total number of Cycle varies from one to nine in AFM.

5.3 RESPONSE CHARACTERISTICS

In the present investigation the Taguachi method was applied to know the response of following characteristic which were-

1. Δ Ra- improvement in surface roughness
2. Material Removal (MR)

5.4 PERCENTAGE IMPROVEMENT IN SURFACE FINISHING

The surface roughness was measured at certain points which were randomly taken on internal cylindrical portion of the aluminum workpiece. The mean value was taken of the random values of roughness. Then the percentage improvement in surface finishing was given by following expression.

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

5.5 Material removal (MR)

Material removal signifies the amount of material removed from the specimen in a specified number of process cycle. MR was given from the expression MR= (weight of the workpiece before machining – weight of workpiece after machining).

5.6 SCHEME OF EXPERIMENTS

Taguachi method was adapted to designee the experiments which could highlight the effect of significant AFM parameters on the response characteristic of AFM. For that task the previously discussed methodology was adopted and a relevant orthogonal array was made with L9 array having 8 DOF. The three levels were listed in the table below.

Table 5.1 Process Parameters and their values at different levels

Symbol	Process Parameters	Unit	Frist level	Second level	Third level
S	Rotational Speed	Rpm	100	200	300
P	Shape of Rod	-	Rectangular	Triangular	Circular
N	Number Of Cycles	-	3	6	9

- Gel and polymers are mixed in the media in the ratio 1:1
- The material for work piece is taken as Brass
- Abrasive used is alumina
- The Mesh Size of the abrasives are 300
- The value of the Extrusion Pressure taken for the system is 15
- The volume of Media Flow is 290cm3
- The Temperature is taken as 32 ± 2 °C
- The value for the Initial surface roughness: 1.1 - 2.96 microns

Table 5.2 The $L_9(3^4)$ OA (Parameters Assigned) with Response

Exp. Number	Order of run	Trial Conditions for Parameters			Raw Data for the response			Signal to noise Ratio (db)
		S	P	N	R1	R2	R3	
		1	2	3				
1	1	1	1	1	Y_{11}	Y_{12}	Y_{13}	S/N(1)
2	4	1	2	2	Y_{21}	Y_{22}	Y_{23}	S/N(2)
3	7	1	3	3	Y_{31}	Y_{32}	Y_{33}	S/N(3)
4	2	2	1	2	Y_{41}	Y_{42}	Y_{43}	S/N(4)
5	5	2	2	3	Y_{51}	Y_{52}	Y_{53}	S/N(5)
6	8	2	3	1	Y_{61}	Y_{62}	Y_{63}	S/N(6)
7	3	3	1	3	Y_{71}	Y_{72}	Y_{73}	S/N(7)
8	6	3	2	1	Y_{81}	Y_{82}	Y_{83}	S/N(8)
9	9	3	3	2	Y_{91}	Y_{92}	Y_{93}	S/N((9)
Total					Σ	Σ	Σ	

- Each trial is repeated tree times
- R1, R2, R3 - response value.
- 1’s,2’s, and 3’s - levels 1,2,3 of the parameters
- Y_{ij}- quality characteristics (response)

5.7 EXPERIMENTATION

The three process parameters Rotational Speed, Shape of the Rod, 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. The proceeding of the experiments was strictly based on the L9 array which is available in table 5.3. There were in total twenty-seven experiment, this is due to the fact that each experiment was performed tree times in certain trial conditions. In order to satisfy the above conditions, there were selection of twenty-seven work piece which were prepared according to the specified conditions and the surface roughness. The main parameters which were measured in each of the experiment were the value of change in Ra and MR. The data is recorded in Table 5.3.

Table 5.3 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

In order to get the idea of Qualitative and quantitative Material removal, the simulation was done on Ansys Fluent 15.0 in which the pattern of pressure variation was analyzed on 100 RPM rotation. The estimate idea of material removal may be observed with the help of pressure variation and the result were predicted also the plot of streamline of the fluid was also displayed for different shapes of Centrifugal Force assisted abrasive flow machining.

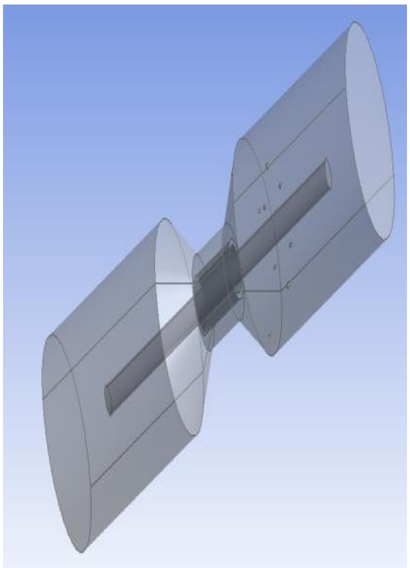


Fig 6.1 Circular Rod Geometry

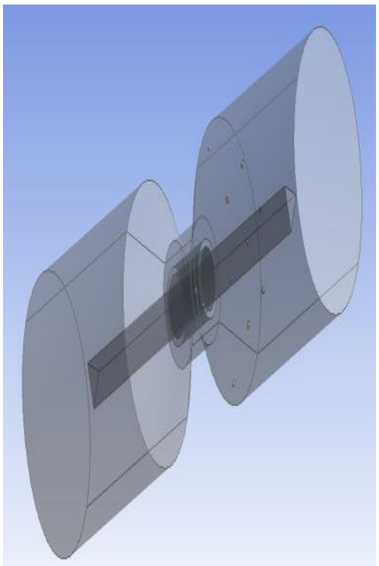


Fig 6.2 Triangular Rod Geometry

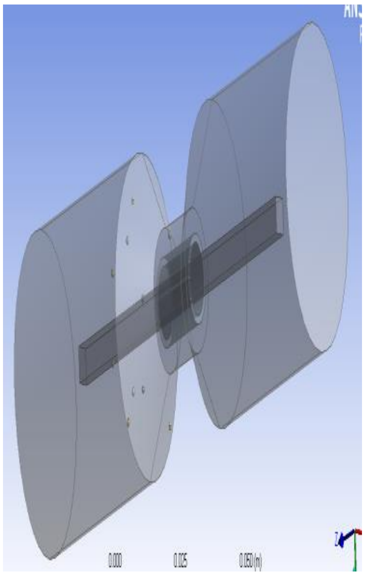
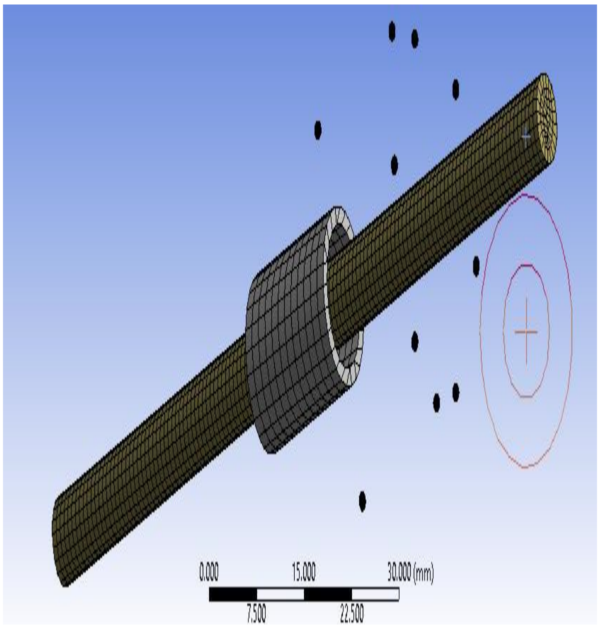


Fig 6.3 Rectangular Rod Geometry

The above figure shows The geomery of abrasive flow machinig which contain a circular,Triangular and rectangular shaped rod inserted in the hollow workpiece of specified size and the surface is fluid containg Polyborosiloxine and the abrasives particles which are reciprocated due to the pressure difference and the rod is given a rotation of 100 RPM. Initially the model was made on CREO 3.0 and was further transported to Ansys Fluent for Simulation.



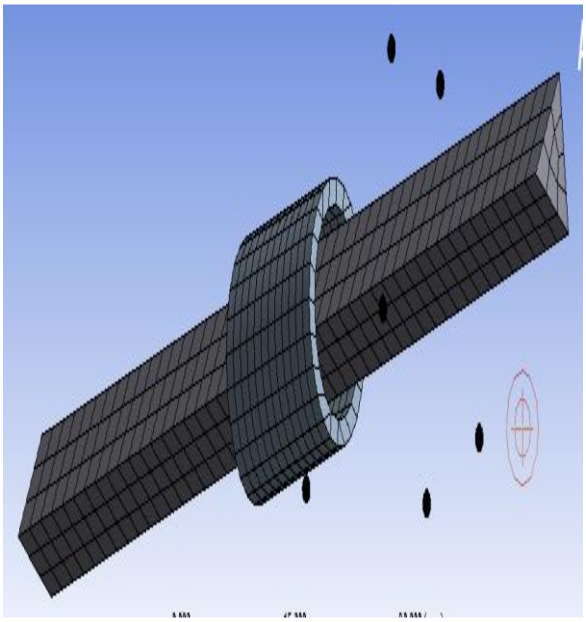
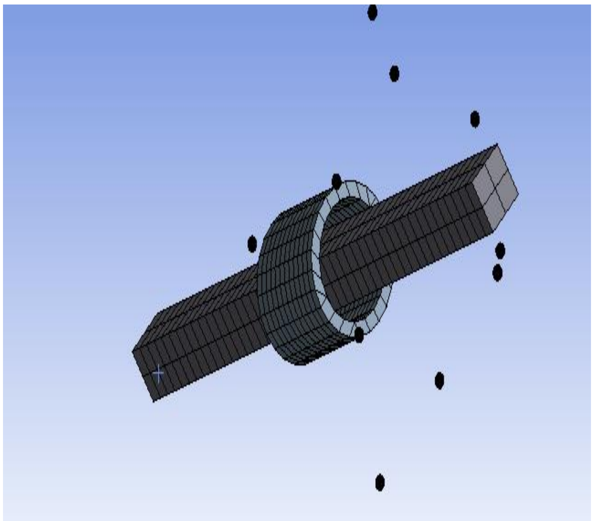


Fig 6.4 Circular Rod Meshing

Fig 6.5 Triangular Rod Meshing



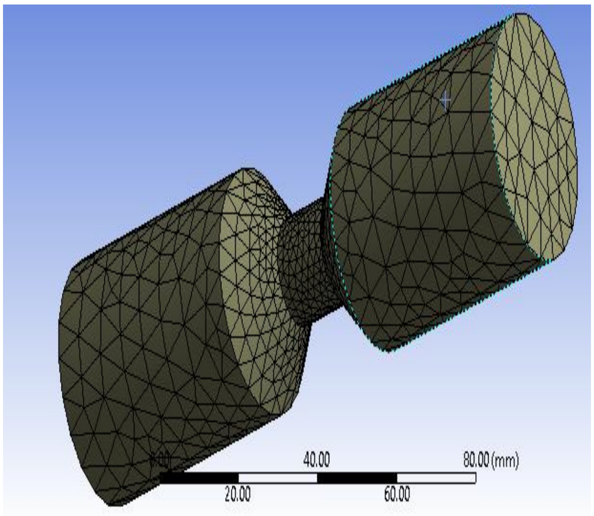
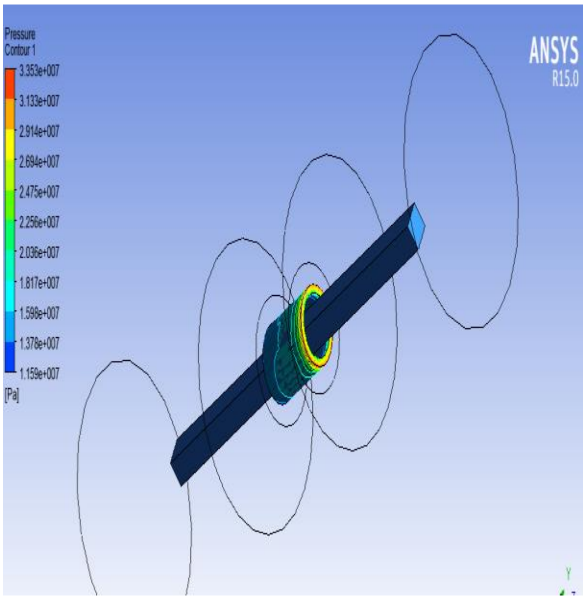


Figure 6.6 Rectangula Rod Meshing

Figure 6.7 Fluid Body Meshing

The above figure 6.4,6.5,6.6,6.7 shows the meshing of circular,triangular,rectangular rod and the fluid body.The shape of the elements were hexagonal and the size of the element is taken as 3x 10^{-6} m. The results obtained were checked on various size and it was found that the results were independent of the mesh size of elements.



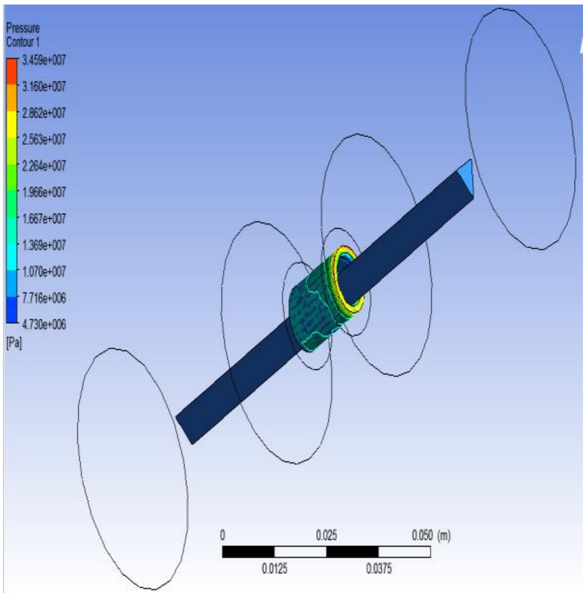


Fig 6.8 Pressure variation in Rectangular Rod

Fig 6.9 Pressure variation in Triangular Rod

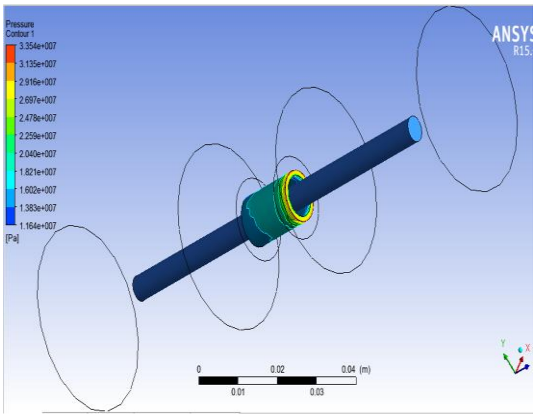
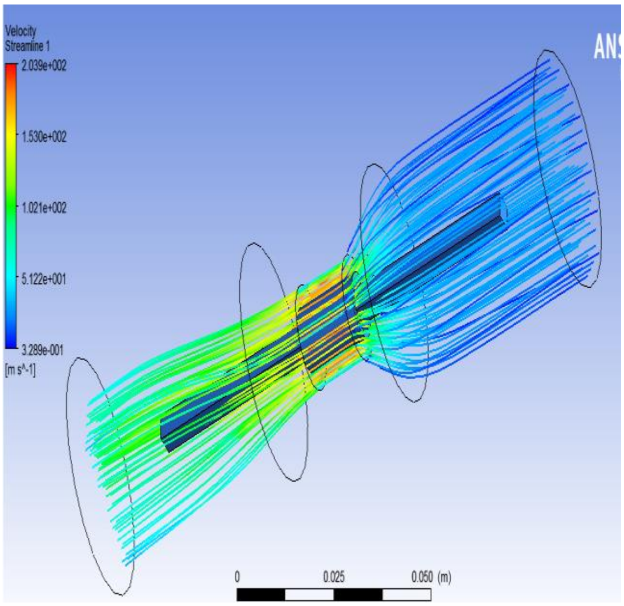


Fig 6.10 Pressure variation in circular-Rod

Figure 6.8 shows the pressure variation on aluminium workpiece when rectangular rod is subjected to 100 rpm and a pressure of 40 MPa is supplied at the inlet and 20 Mpa at the outlet. The similar conditions were given to triangular and the circular shape rod and the result showed the maximum pressure of 33.54 Mpa on the circular rod, 33.59 Mpa on the triangular rod and the pressure of 35.53 Mpa on the Rectangular Rod. So it is evident that the maximum pressure is in rectangular rod which is accordance with the result obtained after following tagauchi optimization technique for material removal. The results are in accordance with the result obtained by Srinivas and Anant [] where the same pressure differene were taken for machining in simple AFM process.The stream line of the particle are also drawn and the curve are plotted which are shown in the subsiquent figure .



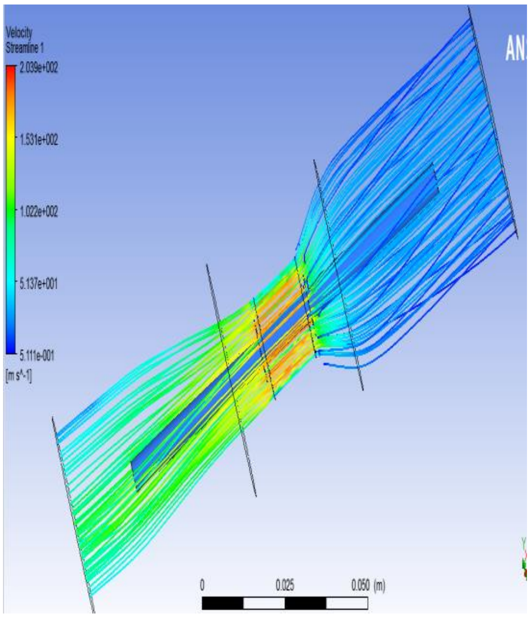


Fig 6.11 Streamline due to rectangular rod rotation

Fig 6.12 Streamline due to Circular rod rotation

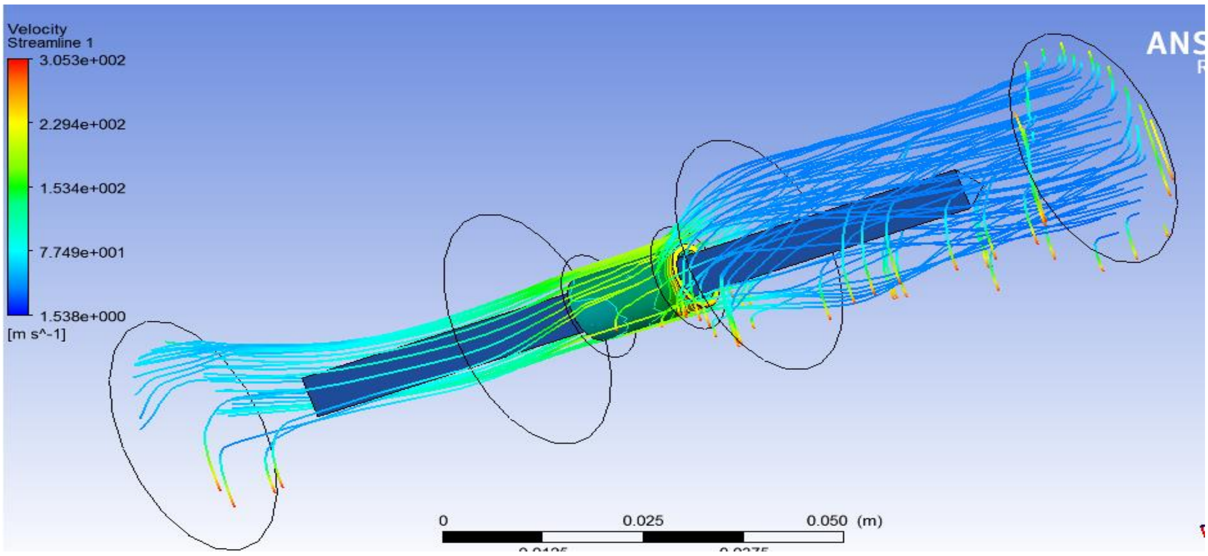


Fig 6.13 Streamline due to rotation of triangular rod

Figure 6.11,6.12 and 6.13 shows the streamline variation of fluid during centrifugal abrasive flow machining The pattern of streamline of fluid (polyborosiloxine and abrasive) is similar due to rotation of rod in circular and triangular shaped rod as equal rotation of 100 rpm is given to the rod and also the shape is symmetrical whereas in triangular shape rod ,the pattern is different due to unsymmetrical shape of the rod, which is evident from figure .13.

Chapter 7
ANALYSIS AND DISCUSSION OF RESULT

The results obtained after the application of the Taguachi methods are discussed and analyzed in this chapter. This includes the data table and graphical explanation of S/N Ratio with each parameter taken separately for MR and Δ Ra.

7.1 ANALYSIS AND DISCUSSION OF RESULTS

The standard procedure suggested by Taguchi was used to analyze the data. The method involves the computation of the average values along with the signal to noise ratio characteristics (generally taken for quality and response) for each parameter and at each level from the specified data of the experiment. The next step was to plot the main effects obtained from the data of S/N ratio and the raw data. In order to identify the significant parameters and the how much it effects the parameters of the process and the response characteristic values, ANOVA (analysis of variance) is taken into accounts.

7.2 EFFECT ON MATERIAL REMOVAL

The table 7.1 gives the values of MR and S/N ratio for each parameter at three different level specified by L followed by the subscript representing the number of levels.

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

Process Parameter	Level	Rotational Speed (S)		Shape of Rod (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	7.68	16.39	11.23	20.61	9.60	19.36
	L2	10.41	19.64	9.04	18.74	10.88	20.18
	L3	10.59	20.27	8.40	16.95	8.20	16.75
Main Effects(%Ra)	L2-L1	2.72	3.25	-2.19	-1.87	1.27	0.82
	L3-L2	0.18	0.62	-0.64	-1.79	-2.67	-3.42
Difference (L3-L2)–(L2-L1)		-2.54	-2.63	-1.54	-0.08	-3.95	-4.24

L_i - levels i of parameter.
(L_j-L_i) is the average main effect
When the corresponding parameter changes from Level i to Level J.

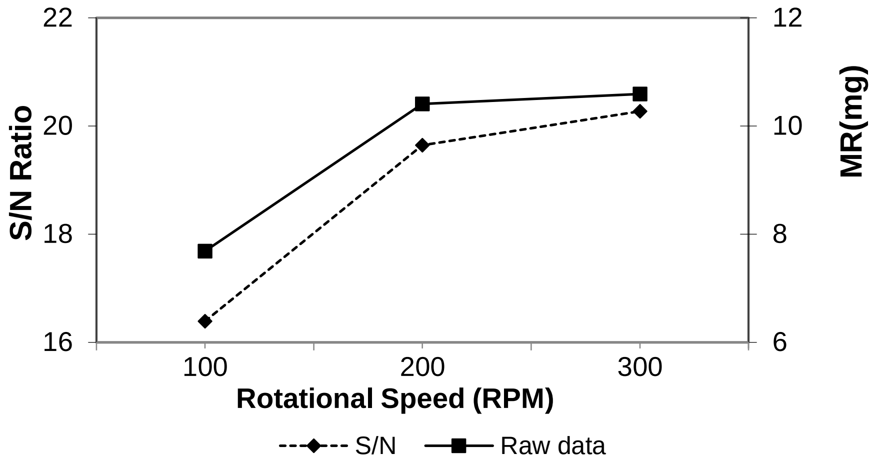


Fig 7.2 (a) Effect of Rotational Speed on Material Removal

Figure 7.2 (a) shows on increasing the rotational speed material removal is initially increasing but after 200 rpm of rotational speed, there is slight decreases in material removal. The reason for the initial increase in material removal may be due to larger resultant force occurs with the higher rotational speed of the Rod. As the rotational speed is increased the abrasive particles are thrown with a larger force towards the inner surface of the workpiece. This causes more material removal. But when the value of rotational speed is increased further, the workpiece surface is subjected to strain hardening due to larger impact force. This may cause decrement in the rate of MR.

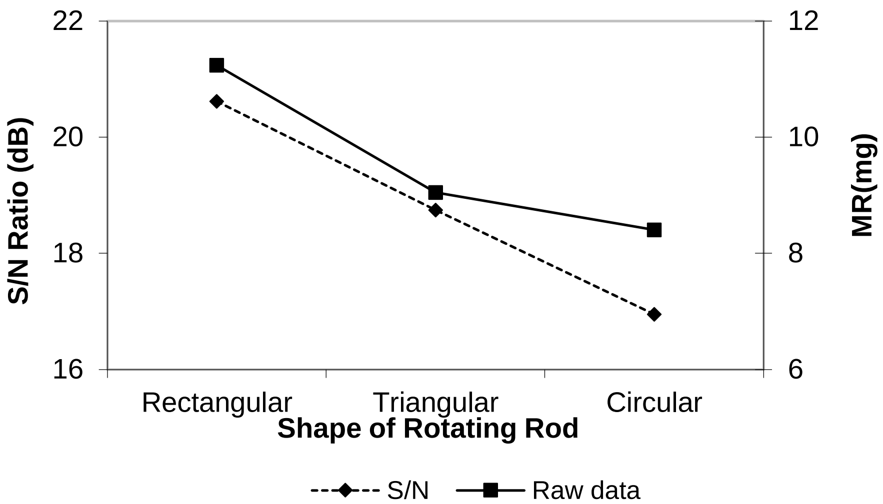


Fig 7.2 (b) Effect of shape of Rotating Rod on material removal

Figure 7.2 (b) shows the shape of Rotating Rod has a significant effect over the centrifugal force generated inside the flowing media. The above figure shows material removal in case of rectangular shape electrode is higher in comparison to triangular and circular shape rod. The shape of rotating electrode shows the throwing ability towards the workpiece surface. Rectangular shape electrode has highest abrasive throwing capability towards the inner surface of the workpiece which increases the resultant force for material removal. This is the reason that rectangular shape electrode gives highest material removal among the circular, triangular and rectangular shape electrode

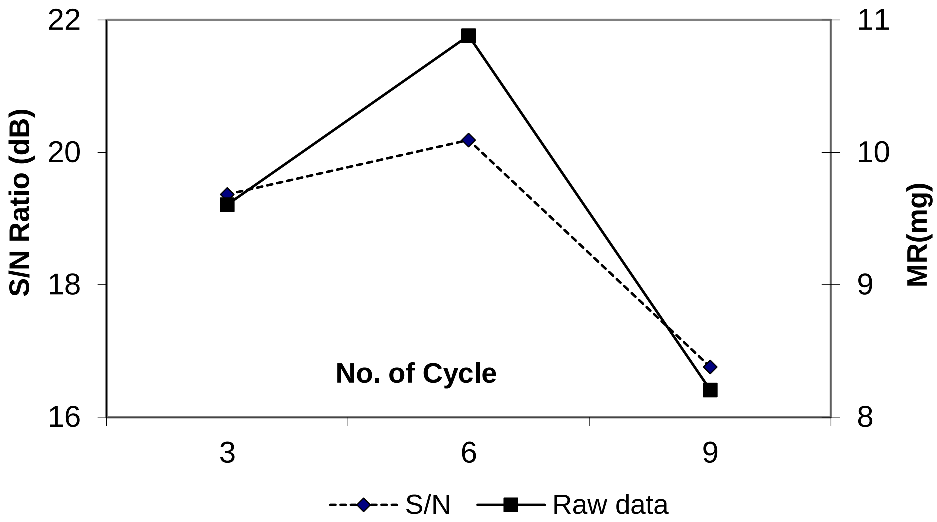


Fig 7.2 (c) Effect of number of cycles on material removal

The figure 7.2 (c) shows on initially the number of cycles MR is increased but after 6 number of cycles MR is decreased. The reason for this may be that on increasing the number of cycles initially dynamic number of abrasive particles are increased which cause more MR. But on further increasing the number of cycles temperature of the flowing media is increased which decrease the viscosity of media. This decrees in viscosity corresponds lower abrasive holding capacity. This causes decrees in material removal.

7.3 SELECTION OF OPTIMUM LEVELS

Analysis of variance (ANOVA) was done to study the effect of significant parameters which affects MR. Tables 7.2 &7.3 shows the data of ANOVA analysis on signal to noise ratio and the raw data. The table clearly shows that the parameters Rotational speed, shape of the electrode and No. of Cycle significantly affect both the mean and MR values.

Table 7.2 Pooled ANOVA (Raw Data) (MR)

Source	SS	DOF	V	F-Ratio	SS'	P%
Rotational speed	47.67	2	23.83	5.18	691.32	22.53
Shape of Electrode	39.73	2	19.86	30.54	368.75	18.78
No. of Cycle	32.23	2	16.11	9.76	23.04	15.23
e	91.93	20	4.59	------	119.52	43.45
Total (T)	211.58	26	*	-------	211.58	100

- 95% confidence level
- $F_{critical}$ represents the 3.4928
- SS stands for the Sum of Squares
- DOF represents the Degree of Freedom
- V stands for the Variance
- SS' is the Pure sum of Squares

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

Source	SS	DOF	V	F-Ratio	SS'	P%
Rotational speed	26.03	2	13.01	74.64	25.68	39.59
Shape of Electrode	20.15	2	10.07	57.78	19.80	30.64
No. of Cycle	19.21	2	9.60	55.10	18.86	29.22
e	0.34	2	0.17	------	1.39	0.53
Total (T)	65.75	8	--------	-------	65.75	100

- 95% confidence level,
- The value of $F_{critical}$ is 19
- SS stands for the Sum of Squares
- DOF stands for Degree of Freedom
- V stands for the Variance
- SS' represents the Pure sum of Squares

7.4 EFFECT ON PERCENTAGE IMPROVEMENT IN SURFACE ROUGHNESS

The table 7.4 gives the values of Δ Ra and signal to noise ratio for each parameter at three different level specified by L followed by the subscript representing the number of levels.

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

Process Parameter	Level	Rotational speed		Shape of Rod		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	13.78	22.35	11.95	21.10	15.61	22.96
	L2	24.16	27.34	20.75	25.81	16.39	24.25
	L3	13.09	22.19	18.32	24.96	19.03	24.65
Main Effects(%Ra)	L2-L1	10.38	4.98	8.79	4.71	0.78	1.28
	L3-L2	-11.06	-5.13	-2.43	-0.85	2.63	0.40
Difference (L3-L2)–(L2-L1)		-21.44	-10.12	-11.23	-5.56	1.84	-0.40

- L1, L2, L3 –levels at subsequent stage.
- (LJ-Li) - main effect for parameter change from level i to level J
  Where I and J represent subsequent levels

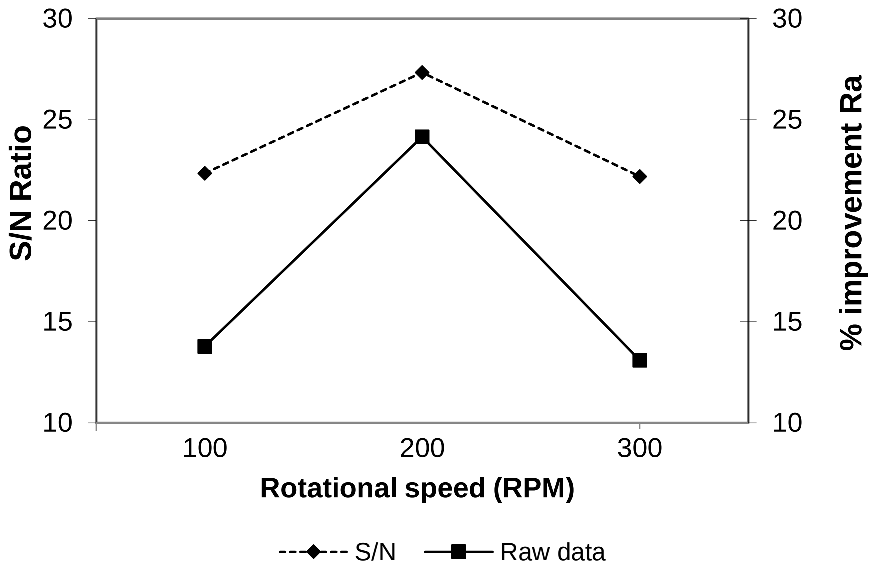


Fig 7.4 (a) Effect of Rotational speed on percentage improvement in surface roughness

Figure 7.4 (a) shows that on raising the rotational speed Δ Ra increases but after further raising the RPM the value of Δ Ra decreases. This is because on raising the RPM the resultant force by which the abrasive particles are impacting on the inner surface of the workpiece is increased. This increase in resultant force increases the material removal which corresponds improvement in surface finish. But on further increasing the rotational speed larger material removal deteriorates the surface quality

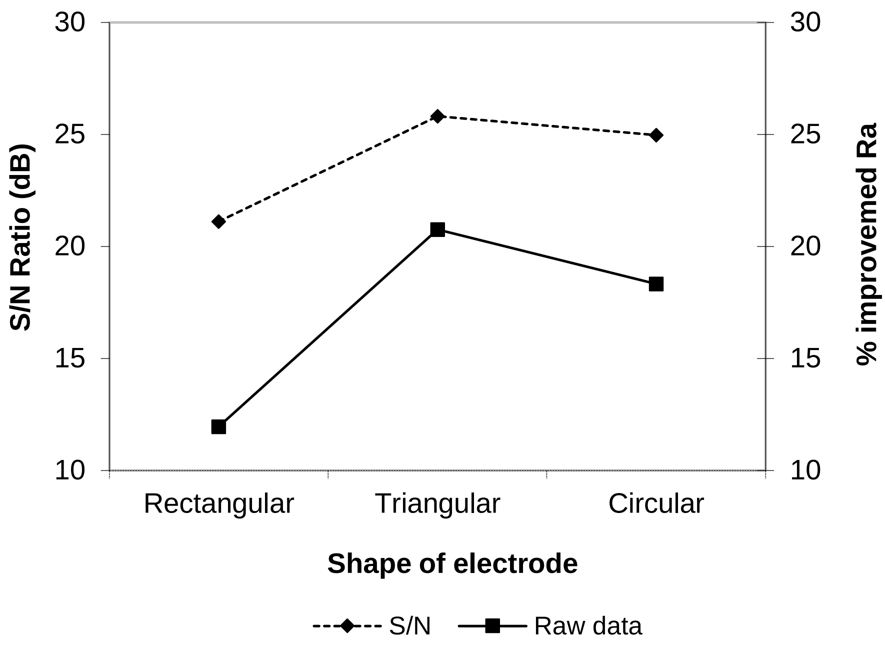


Fig 7.4 (b) Effect of Shape of Rod on percentage improvement in surface roughness

The above figure 7.4 (b) shows that the maximum percentage improvement in surface finish occurs for triangular shaped rod and is minimum for rectangular rod. Material removal in case of rectangular shaped rod is largest among the three different shaped rods. Larger material removal produced by rectangular shaped rod degrades the surface quality due to large increment in centrifugal force. Triangular shaped rod intermixes the abrasive laden media in a better way in comparison to the circular shaped rod. This is the reason why the triangular shaped rod produces better surface finish.

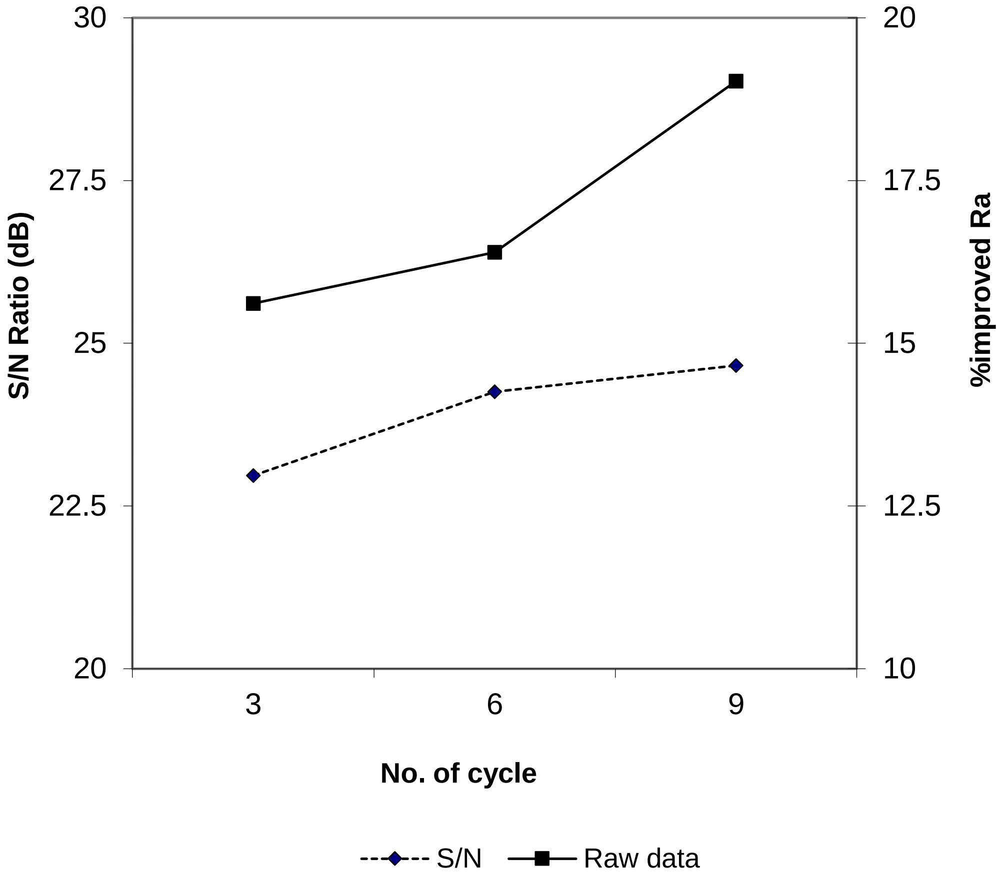


Fig 7.4 (c) Effect of Number of Cycle on percentage improvement in surface roughness

The above Figure 7.4 (C) shows that with the rise in the number of cycles Δ Ra increases. The reason may be that on raising the number of cycles a greater number of abrasive particles are contacting with the inner surface of the workpiece. This corresponds increase in the shear energy required to remove the material from the surface which increases both material removal and surface finish.

Table 7.5 Pooled ANOVA (Raw Data) (Δ Ra)

Source	SS	DOF	V	F-Ratio	SS'	P%
RPM	697.78	2	348.89	107.95	691.32	57.58
Shape of Rod	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

- 95% confidence level,
- The value of $F_{critical}$ is 3.4928
- SS stands for Sum of Squares
- DOF represents the Degree of Freedom
- V represents the Variance
- SS' stands for Pure sum of Squares

Table 7.6 Pooled ANOVA (S/N Data) (Δ Ra)

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

- 95% confidence level
- The value of $F_{critical}$ is taken as 19
- SS stands for Sum of Squares
- DOF stands for Degree of Freedom
- V represents Variance
- SS' stands for Pure sum of Squares

7.5 Estimation of optimum response characteristics

The following steps were taken for in order to predict the optimum response characteristics at respective confidence intervals.

- Firstly, the conformation experiments results were presented for validation of optimal results.
- The optimal level of the process parameters was identified from specific response characteristics.
- The optimal value of each response characteristic is predicted through significant parameters.
- 95% confidence level, CI_{CE} through it may or may not be ninety-five percent for CI_{POP}.

As observed the optimum values for the maximum MR are $S_3P_1N_2$ [Ref. Fig 7.2] for both raw data and S/N data. As observed the optimum values for the maximum % improvement in ΔRa are $S_2P_2N_3$ [Ref. Fig 7.4] for both raw data and S/N data.

7.6 Material Removal (MR)

The following methodology is set to compute the mean value satisfying the optimal condition for material removal.

$$\mu = \bar{S}_3 + \bar{P}_1 + N_2 - 2\bar{T} \quad \ldots\ldots (1)$$

$\bar{T}$= overall response's mean = 9.56 mg

$\bar{S}3$ = MR value of RPM of rod at level 3= 10.59 mg

$\bar{P}1$ = MR value of shape of Rod at level 1= 11.23

$\bar{N}2$ = MR value of no. of cycle at level 1 = 10.88

Putting these values, Mean MR = 13.58 mg

The following equations deals with the computation of bot type confidence level (CI_{CE} and CI_{POP}).

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

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

In which F- ratio corresponding to level of confidence of (1-α) with 1 DOF is represented by F_{α} (1, f_e). The value of the error degree of freedom which is represented by f_e is 3.49.

F_e = 20

N = Total results =27

R = Sample size = 3

V_e = Error in variance =4.59

$$n_{eff} = \frac{N}{1+[\text{DOF associated in the estimate of mean responce}]} = 3.86 \quad \text{(Eq.4)}$$

Therefore, CI_{CE} = ± 3.08

Also, CI_{POP} = ± 4.15

At 95 percent confidence level the value of optimal range may be calculated as: -

average MR – CI_{CE} <MR >MR + CI_{CE}

10.5< MR <16.66

At 95 percent CI of the mean value is -

average MR – CI_{POP} <MR >MR + CI_{POP}

9.43 < MR <17.73

7.7 Percentage improvement in R_a

Steps to compute the mean Ra are as follows: -

$\mu = \bar{S}2 + \bar{P}2 + \bar{N}3 - 2\bar{T}$ ……………………………………………………………………………. (Equation No. 5)

$\bar{T}$ = overall mean of the response = 17.01%

$\bar{S}2$ = Δ R_a value of RPM at level 2 = 24.16%

$\bar{P}_2$= Δ R_a value of shape of Rod at level 2 = 20.75 %

$\bar{N}3$ = Δ R_a value of No of Cycle at level 3 =19.03%

Putting values, % improvement in R_a = 29.92 %

The following equations deals with the computation of bot type confidence level (CI_{CE} and CI_{POP}).

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

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

In which F- ratio corresponding to level of confidence (1-α) with 1 DOF is represented by F_α $(1, f_e)$. The value of the error degree of freedom which is represented by f_e is 3.49

fe =Error in Degree of freedom = 20

N= Total results =27

R = Sample size = 3

V e = Error in variance =3.26

$$n_{eff} = \frac{N}{1+[\text{DOF associated in the estimate of mean responce}]} = 3.86 \ \text{.........} \quad \text{(Equation No.4)}$$

Confidence interval at confirmation experiment = ± 2.59

Confidence interval at mean of the population (CI_{POP}) = ± 2.94

The 95 percent CI,

27.33< %age improvement in Δ R_a <32.51

The 95%age confirmation interval of predicted mean is

26.98<%age improvement in Δ R_a <32.86

7.8 Confirmation Experiments

The results so obtained were validated by conducting three experiments for response characteristic in both MR and Δ Ra. $S_3P_1N_2$ is taken as the optimal values for maximum MR. Whereas for the maximum %age improvement surface roughness the optimal parameters settings are $S_2P_2N_3$.

P2 = Shape of Rod second level = Triangular

P1 = Shape of Rod at level 1 = Rectangular

S3 = RPM of Rod at level 3 = 300 RPM

S_2 = Rotational Speed of Rod at Second level = 200 RPM

N2 =No. of Cycle at first level =6

N3 = No. of Cycle at third level =9

Table 7.7 shows the results so obtained from the analysis. The MR and %age improvement in Ra values so obtained are within 95% of Cl_{CE} of respective response characteristic. So the specified values are within the specified range of process parameters. Additional experiments must be performed in order to confirm the further innovations and requirements.

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 (Average of Confirmation Exp)
MR	$S_3P_1N_2$	13.58mg	CI_{CE} 10.5<MR<16.66 CI_{POP}: 9.43<MR<17.73	15.54 mg
%Improvement ΔRa	$S_2P_2N_3$	29.92 %	CI_{CE}: 27.33<%Δ R_a<32.51 CI_{POP}:26.98<%Δ R_a<32.86	28.97%
CI_{CE} – Confidence interval for the mean of the confirmation experiments CI_{POP} – Confidence interval for the mean of the population				

CAPTER 8

CONCLUSION

After going through the simulation on software and the applying Taguachi optimization method for calculating the optimum value of the significant parameters in calculating the percentage improvement in Surface roughness and maximum Material removal, it was found that experimental analysis justifies the simulation prediction and also the optimum parameters for the Material removal were

- 300 RPM rotation of rod
- Rectangular shape of the rod
- Extruded with 6 numbers of cycles

For the percentage improvement in surface finish the optimum values were

- 200 RPM of rod
- Triangular shape of the rod
- Number of cycles-9

Thus, it is concluded that centrifugal force assisted abrasive flow machining may be consider as the suitable option for the computation of surface finish and a better alternative of the traditional abrasive flow machining process.

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