M.TECH PROJECT

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STUDY ON ABRASIVE FLOW MACHINING OF CAST IRON

Submitted in Partial Fulfillment for the Award of the Degree of

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Submitted By

PRADEEP KUMAR

(Roll No.: 2k11 / PIE / 12)

Under the supervision of

Dr. QASIM MURTAZA (Associate Professor)

Dr. R.S WALIA (Associate Professor)

DEPARTMENT OF MECHANICAL ENGINEERING,

DELHI TECHNOLOGICAL UNIVERSITY, DELHI

(FORMERLY DELHI COLLEGE OF ENGINEERING)

(Session 2011-13)

CERTIFICATE

Date:__________

This is to certify that report entitled **"STUDY OF ABRASIVE FLOW MACHINING ON CAST IRON"** by **Mr. PRADEEP KUMAR,** is the requirement of the partial fulfillment for the award of Degree of **Master of Technology (M. Tech.)** in **Production Engineering** at **Delhi Technological University**. This work was completed under our supervision and guidance. He has completed his work with utmost sincerity and diligence. The work embodied in this project has not been submitted for the award of any other degree to the best of my knowledge.

(Supervisor)
Dr. QASIM MURTAZA
(ASSOCIATE PROFESSOR)

(Co- Supervisor)
Dr. R.S WALIA
(ASSOCIATE PROFESSOR)

Department Of Mechanical Engineering,
Delhi Technological University, Formerly Delhi College Of Engineering, Delhi -110042
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Pradeep Kumar
(2k11/PIE/012)

ABSTRACT

In AFM process there is a mixture of abrasive particles and a polymer based carrier in a typical proportion which is extruded under pressure through or across the surface to be machined. The media acts as a flexible brush which is responsible for carrying out the cutting action. AFM is very effective for internal and complicated surfaces. A number of improved versions of AFM have been developed to enhance the material removal rate during machining, to machine the intricate shape and for faster reduction of surface roughness.

In the present study, a drill bit assisted AFM process is used. In this process a stationary drill bit of a particular shape is held inside the work piece. Drill bit performs two functions; firstly it increases the pressure of media and secondly it provides a particular kind of flow. A particular kind of flow is the combination of three flows (straight reciprocating motion, flute flow along the profile of the drill bit and scooping flow), self-deformability of the medium leading to intermixing of abrasives in the finishing region and the presence of an additional force on the abrasives that result in more material removal rate and high surface finish.

In the present investigation, three profiles of drill bit - a spline, two-start and three- start helical profile have been used for experiments and to study the effect of these profiles on various response parameters such as reduction of surface roughness and material removal of workpiece (Cast Iron). L9 orthogonal array based on the Taguchi method has been used to study the effect of the drill bit and other main AFM process parameters. The main parameters are shape of the drill bit rod (H), number of cycles (n) and extrusion pressure (p) that have been selected at three levels considering no interaction among them. All the three process parameters have significant effect on the material removal rate and the result shows type of drill bit has maximum contribution. For reduction of surface roughness, the process parameters extrusion pressure and number of cycle are significant with the latter having maximum contribution whereas type of drill bit has been found to be insignificant. The experimental results show the maximum improvement in surface finish is 28.12% on the inner cylindrical surface of the cast iron work piece with the initial roughness 6.2 micron and the final value being 4.45 micron.

ORGANISATIONS OF THESIS

Chapter 1 contains the introduction of non conventional manufacturing process along with the detail description of AFM Technology and Drill bit assisted AFM.

Chapter 2 Contains with literature review along with status of current research in this field, and objectives of proposed research work to be carried out.

Chapter 3 contains the schematic of Drill bit assisted AFM process and development of Drill bit assisted AFM.

Chapter 4 contains TAGUCHI'S EXPERIMENTAL design and analysis.

Chapter 5 contains selection of process parameters and their range and response characteristics.

Chapter 6 Contains analysis and result discussion.

Chapter 7 contains conclusion and scope for future work.

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ACRONYMS

AFM	Abrasive flow machining
AJM	Abrasive jet machining
ANOVA	Analysis of variance
CBN	Cubic boron nitride
DOF	Degree of freedom
CFAAFM	Centrifugal force assisted abrasive flow machining
CFG	Centrifugal
MR	Material removal
MRR	Material removal rate
MSD	Mean square deviation
NCM	Non-conventional machining
OA	Orthogonal Array
PGR	Polymer gel ratio
R	Sample size of confirmation experiment
ΔR_a	Percentage improvement in surface roughness
WZM	Water jet machining
USM	Ultrasonic machining

CHAPTER 1
INTRODUCTION

Abrasive flow machining (AFM) is a purely mechanical process. A chemically inactive and non-corrosive media, similar to soft clay, is used to improve surface finish and edge conditions. The abrasive particles in the media grind away the material rather than shearing off. The same type of media can be used on different metals. In many cases, the same batch of media can be used on different metals without transferring removed material between work pieces. AFM is used for surface or edge conditioning of internal, external, and otherwise inaccessible holes, slots, and edges. It is highly efficient and accurate, and can be used in one-way or two-way applications. The most abrasive action occurs during AFM if a hole changes size or direction. The need for high- accuracy finishing of material is making the application of abrasive finishing technologies increasingly important. In order to cater to these requirement abrasive flow machining gaining importance day by day. AFM is a controllable machining process. You can control the media flow rate and pressure, volume and type of media, media temperature, and, consequently, the amount of material that is removed for any given application, surface finish improvement, radius generation and/or stock removal, a "cutting" rate per unit of volume can be determined and monitored to ensure repeatability. Two American companies independently developed abrasive flow machining in the 60s. Initially, the process was applied in aerospace to machine high-alloy components with inaccessible and complex inner shapes. Abrasive flow machining was initially applied for deburring and polishing operations which until then had to be carried out manually and hence were extremely time-consuming. Another drawback of manual machining was that even if altering the work piece shape was possible it could not be done reproducibly. A large field of application of abrasive flow machining is finishing in mold and die making. Typical components machined by abrasive flow machining include extrusion molding dies for aluminum profiles as well as crimping and stamping tools.

1. NON-TRADITIONAL MANUFACTURING PROCESSES

Since beginning of the human race, people have evolved tools and energy sources to power these tools to meet the requirements for making the life easier and enjoyable. In 1the early stage of mankind, tools were made of stone for the item being made. When iron tools were invented, desirable metals and more sophisticated articles could be produced. In twentieth century products were made from the most durable and consequently, the most unmachinable materials. In an effort to meet the manufacturing challenges created by these materials, tools have now evolved to include materials such as alloy steel, carbide, diamond and ceramics. A similar evolution has taken place with the methods used to power our tools. Initially, tools were powered by muscles; either human or animal. However as the powers of water, wind, steam and electricity were harnessed, mankind was able to further extend manufacturing capabilities with new machines, greater accuracy and faster machining rates. The conventional manufacturing processes in use today for material removal primarily rely on electric motors and hard tool materials to perform tasks such as sawing, drilling and broaching. Conventional forming operations are performed with the energy from electric motors, hydraulics and gravity. Likewise, material joining is conventionally accomplished with thermal energy sources such as burning gases and electric arcs. In contrast, non-traditional manufacturing processes harness energy sources considered unconventional by yesterday's standards. Material removal can now be accomplished with electrochemical reaction, high temperature plasmas and high-velocity jets of liquids and abrasives. Materials that in the past have been extremely difficult to form, are now formed with magnetic fields, explosives and the shock waves from powerful electric sparks. Material-joining capabilities have been expanded with the use of high-frequency sound waves and beams of electrons and coherent light. During the last 55 years, over 20 different non-traditional manufacturing processes have been invented and successfully implemented into production. The non-conventional manufacturing processes are not affected by hardness, toughness or brittleness of material and can produce any intricate shape on any work piece material by suitable control over the various physical parameters of the processes. The non-conventional manufacturing processes may be classified on the basis of type of energy namely, mechanical, electrical, chemical, thermal or magnetic, apply to the work piece directly and have the desired shape transformation or material removal from the work surface by using different scientific mechanism. Thus, these non-conventional processes can be classified into various groups according to the basic requirements which are as follows:

(i) Type of energy required, namely, mechanical, electrical, chemical etc.

(ii) Basic mechanism involved in the processes, like erosion, ionic dissolution, Vaporization etc.

(iii) Source of immediate energy required for material removal, namely, hydrostatic Pressure, high current density, high voltage, ionized material, etc.

(iv) Medium for transfer of those energies, like high velocity particles, electrolyte, Electron, hot gases, etc. On the basis of above requirements

(a) Ultrasonic Machining[1] Ultrasonic Machining is a non-traditional process, in which abrasives contained in slurry are driven against the work by a tool oscillating at low amplitude (25-100 µm) and high frequency (15-30 KHz). The process was first developed in 1950s and was originally used for finishing EDM surfaces. The basic process is that a ductile and tough tool is pushed against the work with a constant force. A constant stream of abrasive slurry passes between the tool and the work (gap is 25-40 µm) to provide abrasives and carry away chips. The majority of the cutting action comes from an ultrasonic (cyclic) force applied. The basic components to the cutting action are believed to be, brittle fracture caused by impact of abrasive grains due to the tool vibration; cavitations induced erosion; chemical erosion caused by slurry.

(b) Jet Machining In jet machining, high-velocity stream of water (Water Jet Cutting) or water mixed with abrasive materials (Abrasive Water Jet Cutting) is directed to the work piece to cut the material[2]. If a mixture of gas and abrasive particles is used, process is referred to as Abrasive Jet Machining and is used not to cut the work but for finishing operations like deburring, cleaning, polishing.

(c) Water Jet Cutting Water Jet Cutting (WJC) uses a fine, high-pressure, high velocity (faster than speed of sound) stream of water directed at the work surface to cause slotting of the material: Water is the most common fluid used, but additives such as alcohols, oil products and glycerol are added when they can be dissolved in water to improve the fluid characteristics. The fluid is pressurized at 150-1000 MPa to produce jet velocities of 540-1400 m/s. The fluid flow rate is typically from 0.5 to 2.5 l/min. The jet has a well behaved central region surrounded by a fine mist.

(d) Abrasive Water Jet Cutting (AWJC) [3]In Abrasive Water Jet Cutting, a narrow, focused, water jet is mixed with abrasive particles. This jet is sprayed with very high pressures resulting in high velocities that cut through all materials. The presence of abrasive particles in the water jet reduces cutting forces and enables cutting of thick and hard materials (steel plates over 80-mm thick can be cut). The velocity of the stream is up to 90 m/s, about 2.5 times the speed of sound Abrasive Water Jet Cutting process was developed in 1960s to cut materials that cannot stand high temperatures for stress distortion or metallurgical reasons such as wood and composites, and traditionally difficult-to-cut materials, e.g. ceramics, glass, stones, titanium alloys. The common types of abrasive materials used are quartz sand, silicon carbide, and corundum (Al2O3), at grit sizes ranging between 60 and 120

(e) Abrasive Jet Machining (AJM)[4] In Abrasive Jet Machining, fine abrasive particles (typically ~0.025mm) are accelerated in a gas stream (commonly air) towards the work surface. As the particles impact the work surface, they cause small fractures, and the gas stream carries both the abrasive particles and the fractured (wear) particles away. The jet velocity is in the range of 150-300 m/s and pressure is from two to ten times atmospheric pressure. The preferred abrasive materials involve aluminum oxide (corundum) and silicon carbide at small grit sizes. The grains should have sharp edges and should not be reused as the sharp edges are worn down and smaller particles can clog nozzle. Abrasive Jet Machining is used for debarring, etching, and cleaning of hard and brittle metals, alloys, and nonmetallic materials (e.g., germanium, silicon, glass, ceramics, and mica).

(f) Electric Discharge Machining[5] this is one of the most widely used nontraditional processes. A formed electrode tool produces the shape of the finished work surface. The sparks occur across a small gap between tool and work surface. The EDM process must take place in the presence of a dielectric fluid, which creates a path for each discharge as the fluid becomes ionized in the gap. The fluid, quite often kerosene-based oil is also used to carry away debris. The discharges are generated by a pulsating direct-current power supply connected to the work and the tool. Electrode materials are high temperature, but easy to machine, thus allowing easy manufacture of complex shapes. Typical electrode materials include copper, tungsten, and graphite. The process is based on melting temperature, not hardness, so some very hard materials can be machined this way

(g) Wire Electric Discharge Machining [6]Wire Electric Discharge Machining (Wire EDM) is a special form of EDM that uses a small diameter wire as the electrode to cut narrow kerfs in the work. The work piece is fed continuously and slowly past the wire in order to achieve the desired cutting path. Numerical control is used to control the work-part motions during cutting. As it cuts, the wire is continuously advanced between a supply spool and a take-up spool to present a fresh electrode of constant diameter to the work. This helps to maintain a constant kerfs width during cutting. As in EDM, wire EDM must be carried out in the presence of a dielectric. This is applied by nozzles directed at the tool-work interface as in the figure, or the work part is submerged in a dielectric bath. Wire diameters range from 0.08 to 0.30 mm, depending on required kerfs width. Materials used for the wire include brass, copper, tungsten, and molybdenum. Dielectric fluids include demonized water or oil. As in EDM, an overcut in the range from 0.02 to 0.05 mm exists in wire EDM that makes the kerfs larger than the wire diameter.

(h) Laser beam machining (LBM) [7] Laser beam machining (LBM) uses the light energy from a laser to remove material by vaporization and ablation. The types of lasers used in LBM are basically the carbon dioxide (CO2) gas lasers. Lasers produce collimated monochromatic light with constant wavelength. In the laser beam, all of the light rays are parallel, which allows the light not to diffuse quickly like normal light. The light produced by the laser has significantly less power than a normal white light, but it can be highly focused, thus delivering a significantly higher light intensity and respectively temperature in a very localized area. Lasers are being used for a variety of industrial applications, including heat treatment, welding, and measurement, as well as a number of cutting operations such as drilling, slitting, slotting, and marking operations. Drilling small-diameter holes is possible, down to 0.025 mm. For larger holes, the laser beam is controlled to cut the outline of the hole. The range of work materials that can be machined by LBM is virtually unlimited including metals with high hardness and strength, soft metals, ceramics, glass, plastics, rubber, cloth, and wood. LBM can be used for 2D or 3D workspace. The LBM machines typically have a laser mounted, and the beam is directed to the end of the arm using mirrors. Mirrors are often cooled (water is common) because of high laser powers.

(i) Electron beam machining (EBM) [8] Electron beam machining (EBM) is one of several industrial processes that use electron beams. Electron beam machining uses a high-velocity stream of electrons focused on the work piece surface to remove material by melting and vaporization an electron beam gun generates a continuous stream of electrons that are focused through an electromagnetic lens on the work surface. The electrons are accelerated with voltages of approx. 150,000 V to create velocities over 200000 km/sec. The lens is capable of reducing the area of the beam to a diameter as small as 0.025 mm. On impinging the surface, the kinetic energy of the electrons is converted into thermal energy of extremely high density, which vaporizes the material in a much localized area. EBM must be carried out in a vacuum chamber to eliminate collision of the electrons with gas molecules. Electron beam machining is used for a variety of high-precision cutting applications on any known material. Applications include drilling of extremely small diameter holes, down to 0.05 mm diameter, drilling of holes with very high depth-to-diameter ratios, more than 100:1, and cutting of slots that are only about 0.025 mm wide. Besides machining, other applications of the technology include heat treating and welding. The process is generally limited to thin parts in the range from 0.2 to 6 mm thick. Other limitations of EBM are the need to perform the process in a vacuum, the high energy required, and the expensive equipment.

1.1 BASIC PRINCIPLE OF AFM

In abrasive flow machining, the abrasive fluid flows through the work piece, effectively performing erosion. Abrasive particles in the fluid contact raised features on the surface of the work piece and remove them. The fluid is forced through the work piece by a Hydraulic ram where it acts as a flexible file, or slug, molding itself precisely to the shape of the work piece. The highest amount of material removal occurs in areas where the flow of the fluid is restricted; according to Bernoulli's principle, the flow speed and pressure of the fluid increase in these areas, facilitating a higher material removal rate. The pressure exerted by the fluid on all contacting surfaces also results in a very uniform finish. AFM may be performed once, as a one-way flow process, or repeatedly as a two-way flow process. In the two-way flow process, a reservoir of medium exists at either end of the work piece, and the medium flows back and forth through the work piece from reservoir to reservoir.

1.2CLASSIFICATION OF ABRASIVE FLOW MACHINE

AFM machines are classified into two categories according to the direction of flow of abrasive media i.e. one way AFM and two way AFM.

1.2.1One way AFM process

In one way[11] AFM process the media is extruded inside the work piece only in one direction. For this purpose the setup has a hydraulically actuated reciprocating piston and an extrusion medium chamber adapted to receive and extrude medium unidirectional across the internal surface of the work piece having internal passage formed therein. Piston direct the media through the internal passage of the work piece while a medium collector collects the media as it is extruded out through the work piece. The extrusion media chamber is provided with an access port to periodically receive medium from the collector into extrusion medium chamber. The hydraulically actuated piston intermittently withdraws from its extruding position to open the extrusion medium chamber access port to collect the medium in the extrusion medium chamber. When the extrusion medium chamber is charged with the working medium, the operation is resumed.

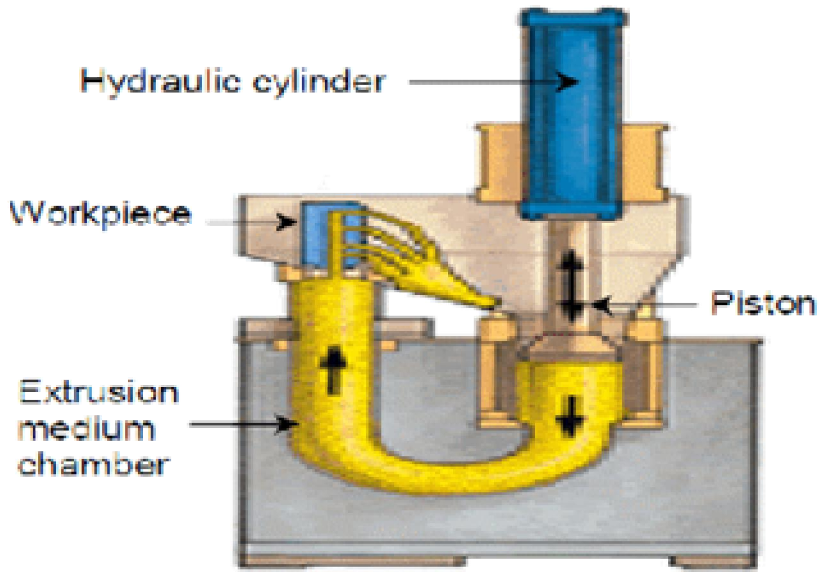

Figure 1.1 Schematic Of one –way AFM [9]

1.2.2. Two-way AFM process

Two ways AFM machine [12] has two hydraulic cylinders and two medium cylinders. The medium is extruded, hydraulically or mechanically, from the filled chamber to the empty chamber via the restricted passageway through or past the work piece surface to be abraded (Fig.1.2). Typically, the medium is extruded back and forth between the chambers for the desired fixed number of cycles. Counter bores, recessed areas and even blind cavities can be finished by using restrictors or mandrels to direct the medium flow along the surfaces to be finished.

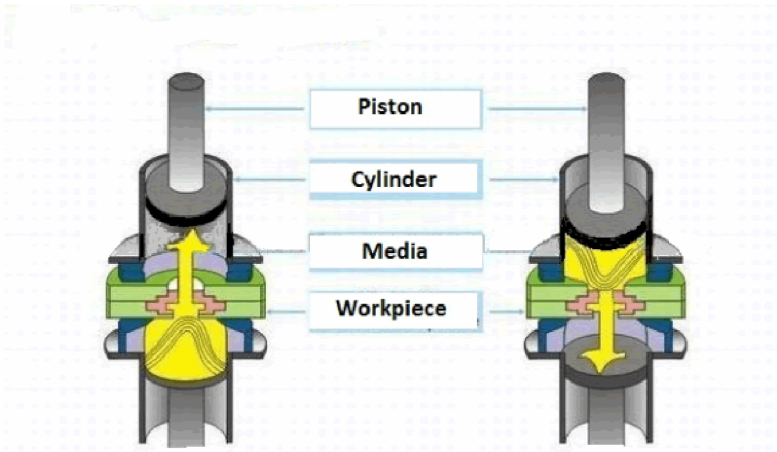

Figure 1.2 Schematic of two way AFM[10]

1.3 PARTS OF ABRASIVE FLOW MACHINING

Abrasive flow machining required some elements to perform the process. The various elements are fixture or tooling, the machine, and abrasive laden media. The abrasive media determines what kinds of abrasion occur, the fixture determines exact location of abrasion, and machine decides the extent of abrasion as the abrasive particles are responsible for direct abrasion action on the surface and fixture is responsible for holding the work piece against the abrasive particles. Pressure, type of drill bit decides the force by which abrasive particles strike the surface.

1.3.1 FIXTURE

Steel, urethanes, aluminum, nylon, Teflon are the material can be used to make fixture. Aluminum and nylon are easily machinable lightweight materials so they are perfect for fixture material. Steel is rarely used and used only for its strength and durability.

Fixture design is often a very important factor in achieving the desired effects from the AFM process as the design of fixture depends on the shape of work piece. In this project the work piece is cylindrical so a proper design of fixture is used which can hold a cylindrical work piece. Basic functions of fixture [13] include:

- holding the work piece in proper position between the media cylinders.
- Directing media flow to and from the areas of the part to be worked on, during the process cycle.
- Protecting edges or surfaces from abrasion due to media flow by acting as a mechanical mask.
- Providing a restriction in the media flow path to control the media action in selected areas.
- Containing the media and completing the closed-loop system required for multiple machine cycle operation without loss of media.

If AFM is used to process external edges or surfaces, the tooling contains the part in the flow passage, restricting the flow between the exterior of the part and the interior of the fixture. Any number of parallel restrictions can be processed simultaneously with uniforms results. To maximize productivity, fixture can be designed for batch production processing of many parts simultaneously if their configuration and size permit.

Figure 1.3 Fixture in three parts

1.3.2 ABRASIVE MEDIA

This technique uses a non-Newtonian liquid polymer containing abrasive particles of aluminum oxide, silicon carbide, boron carbide or diamond as the grinding medium and additives [14]. The viscosity and the concentration of the abrasives can be varied Most widely used carrier is a high viscosity rheopetic fluid. The base materials has enough degree of cohesion and tenacity to drag the abrasive grains along with it through various passages/regions.AL_2O_3 and SiC are most suitable abrasives for many applications but Cubic boron nitride (CBN) and diamond are specifically used for special applications. Abrasive particles to base material ratio can be varying from 2 to 12.Abrasive are available in different mesh sizes. The abrasive have limited life. AS a thumb rule, when the media has machined an amount equal to 10% of its weight, it must be discarded. Machined parts should be properly cleaned before use, by acetone. The additives are used to modify the base polymer to get the desired flowability and rheological characteristic of the media. Hydrocarbon gels are commonly used lubricants in the media. All additives are carefully blended in predetermined qualities to obtain consistent formulation.

1.3.3 MACHINE SETUP

All AFM machines regardless of size are positive displacement hydraulic systems, where work piece is clamped between two vertically opposed media cylinder. By repeatedly extruding media from one cylinder to the other, an abrasive action is produced whenever the media enters and passes through restrictive passage as it travels through or across the work piece.AFM machine controls two crucial parameters for determining the amount of abrasion, the extrusion pressure and the media flow rate. Standard units operate within 10 bar to 200 bar pressure range with flow rates up to 400 liters/min.AFM systems are essentially provided with controls on hydraulic system pressure, clamping and unclamping of fixtures, volume flow rate of abrasive media, and advance and retract of media pistons. Programmable microprocessor control unit can be used to monitor and control additional process parameters at the machine, such as media temperature, media temperature, media viscosity, abrasive wear, and flow speed. Several accessories such as part cleaning stations, automatic flow timers, cycle counters, pressure and temperature compensated flow control valves, automatic media lubricant replenishment, and media heat exchangers units may also be integrated to the conventional AFM systems for production applications[15].

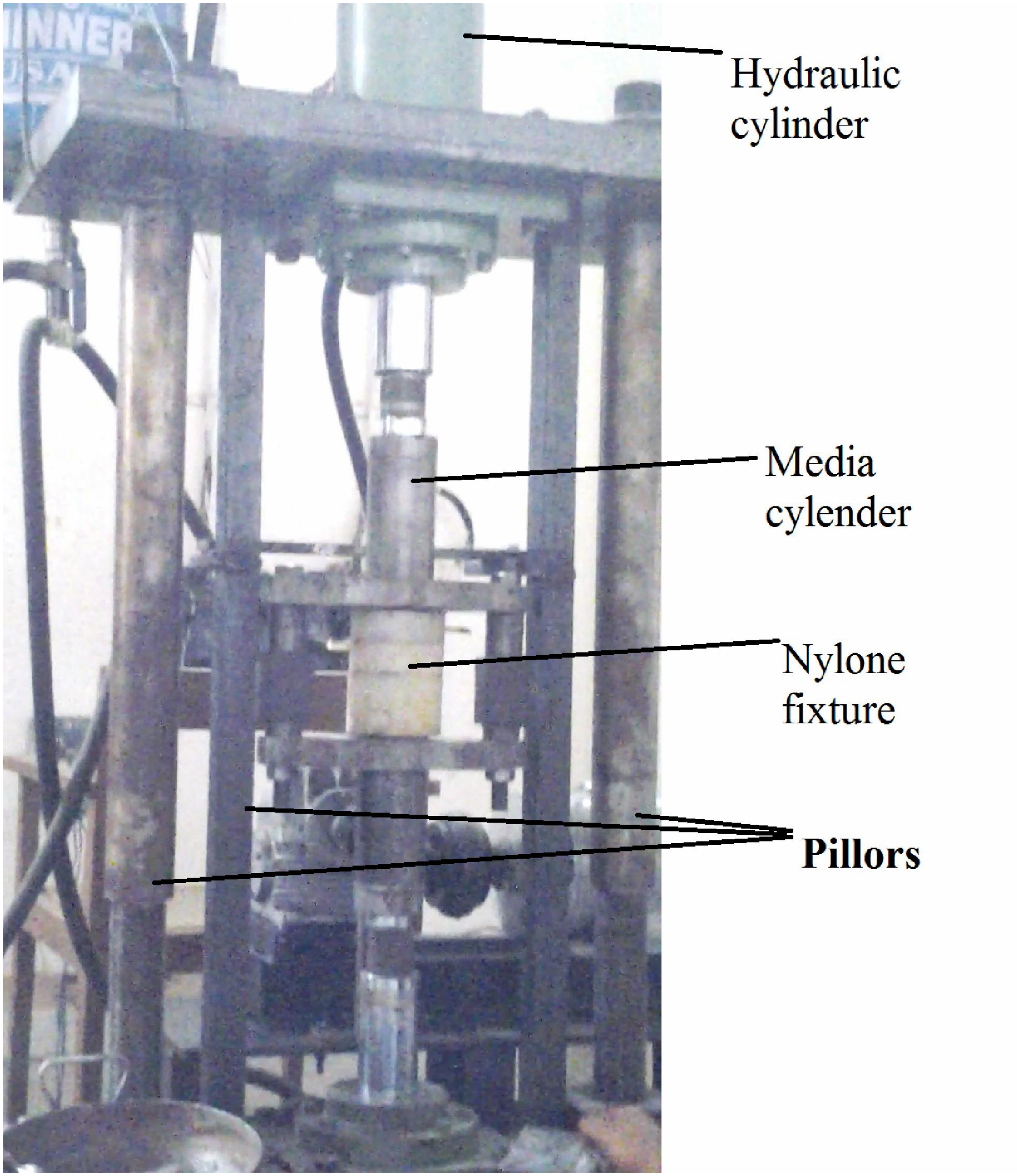

Figure 1.4 AFM machine setup

1.4 DRILL BIT ASSISTED ABRASIVE FLOW MACHINE

There can be two type of motion of abrasive particles while machining depending upon the drill bit used straight and helical. In case of straight-fluted drill bit the shape of the drill bit helps the abrasive particles to move in a straight path. Drill bit in addition of guiding the abrasive particles also increases the presser in machining zone and hence increases the cutting force. The tooling of Helical-AFM setup has fixtures in three parts lower, middle, upper fixtures and in addition of it, it has helical-fluted drill bit. Helical fluted drill bit can be of various types like two start or three start. Drill bit passes through the work piece and held stationary. Lower and upper fixtures are tapered for proper media flow. The major difference between AFM and drill bit assisted machines is its tooling. In AFM machine, circular fixture plate allows the medium to flow as' cylindrical slug. So, the abrasive intermixing (or reshuffling) purely depends on medium self-deformability. The abrasive particles follow the shortest contact length; hence, the material removal is less. In drill bit assisted AFM, abrasive intermixing depends not only on medium self-deformability as in AFM but also on the pressure from the drill bit. When spline drill bit is used than the flow of the media is along the porkpies and motion is reciprocating to and fro type. In Helical-AFM, three types of flows that occur in finishing zone (Figure 1.5(a), (b), (c),) and remixing of medium at exit from the finishing zone (flow along the flute, axial flow, and scooping flow)[16]. Due to the combination of different flows, the work piece-abrasive contact length is no longer a straight line, rather it becomes curved; hence, the number of peaks that can be sheared increases, leading to higher material.

1. **Flow along the flute**

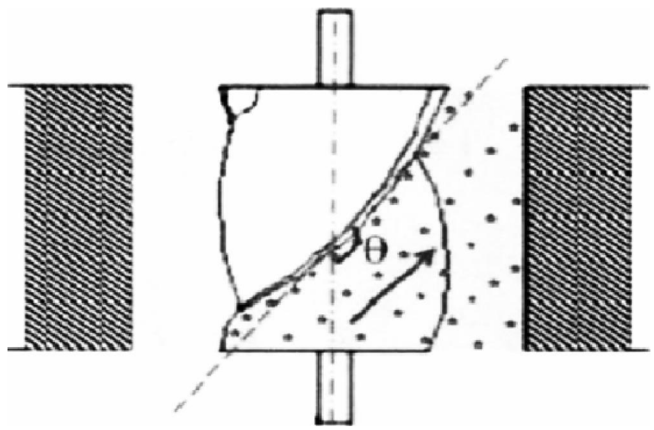

Figure 1.5(a)

2. **Reciprocating axial flow motion**

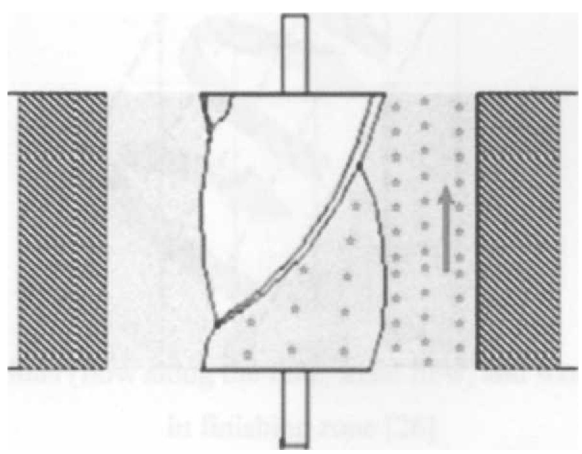

Figure 1.5(b)

3. **Scooping Flow**

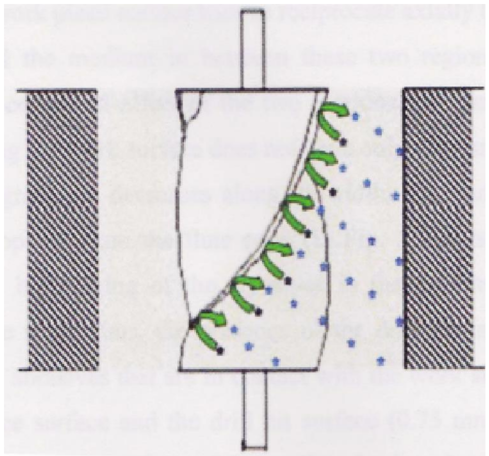

Figure 1.5(C)

4. **Finishing zone in Helical- AFM**

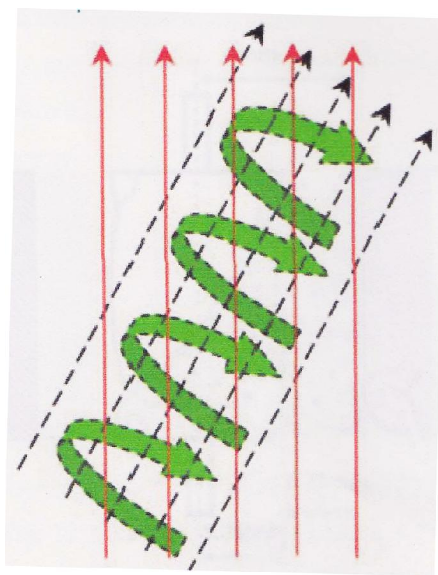

Figure 1.5 (d) three motions (flow along the flute, axial flow, and scooping flow) that can occur in finishing zone

The motion of media in the machining zone is the combinations of three kind of motion. The media near the work piece is straight reciprocating motion and the media near the flute flow along the profile of the drill bit as in case of helical profile media flow in helical path. Since the flute depth gradually decreases along its width, the medium that flows across the flute path tries to scoop out from the flute edge (in Fig. 1.5(c), shown by circular arrows). Scooping flow causes intermixing of the abrasives in the intermediate region and exterior regions of the abrasive slug. Thus, the presence of the drill bit in the finishing zone exerts additional force on the abrasives that are in contact with the work surface due to the small gap between the work piece surface and the drill bit surface (0.75 mm). The combination of all these three flows and self-deformability of the medium leads to intermixing of abrasives in the finishing region (Figure. 1.5(d)). It results in random motion of abrasives (Figure. 1.5(e)), hence more material removal rate and high surface finish. Thus, the presence of the drill bit in the finishing zone exerts additional force on the abrasives that are in contact with the work surface due to the small gap between the work piece surface and the drill bit surface (0.75 mm). The combination of all these three flows and self-deformability of the medium leads to intermixing of abrasives in the finishing region (Figure. 1.5(d)). It results in random motion of abrasives (Figure. 1.4), hence more material removal rate and high surface finish.

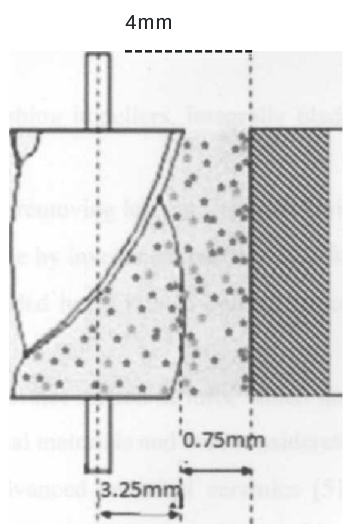

Figure l.5 (e) Intermixing and Random Motion of Abrasives in Finishing Zone

1.5 AFM APPLICATIONS

(A) ULTRA CLEAN

- Food processing
- Semiconductor (front-end) equipment
- Pharmaceutical manufacturers
- Ultra-clean or high purity devices

Polishing surfaces to mirror-like requirements minimizes the amount of microscopic and/or inaccessible areas that enable contamination or entrapment. Ultra-smooth surface finishes greatly diminish the areas of concern for surface absorption, chemical contaminants, foreign particulate and bacteria. Additionally, the AFM process minimizes “flow-retardation” due to machining and/or dies and mold “microgrooves.”

AFM allows for extremely fine finishes on very complex geometry and difficult-to-reach surface configurations often found in prosthetic applications and in a broad range of materials.

(B) INTERNAL EDGE CONTROL

The Abrasive Flow Machining (AFM) process provides a controlled and repeatable method for burr removal and surface finish enhancement at hole intersection(s) and difficult to reach surfaces. Irregular holes, shapes and intersecting surfaces can be deburred or even polished with precision and predictable results in places that are impossible to reach by virtually any other method.**AFM** removes the burrs and enhances the adjacent surfaces by *flowing* the selected abrasive material on the target surface/edge and is typically limited ONLY by hole size coupled with the particulate size of the chosen abrasive.

(C) MOLDS AND DIES

- Metal forming
- Glass forming
- Plastic applications

Critical, forming surfaces may be enhanced as much as (X10) on many applications. EDM's surfaces (all types), milled surfaces and ground surfaces can be consistently and uniformly polished to a very low Ra to further enhance speed, part release, and overall quality and production efficiency while preserving critical tolerances.

(D) AERONAUTICAL COMPONENET MANUFACTURING

- Increased fatigue strength
- Higher performance and efficiency

Abrasive Flow Machining will precisely remove the "recast layers" of material resulting from the thermal characteristics of laser and EDM cutting techniques in many high-strength applications. Improved surface integrity with enhanced eddy current readings results in more reliable and efficient components. Precise and repeatable edge control, regardless of configuration, typically equates to less flow resistance and enhanced cycle fatigue strength

(E) INTERNAL COMBUSTION ENGINE

- Diesel engines
- Automotive

A high-pressure fuel injection system's life cycle can be extended through Abrasive Flow Machining by reducing surface cracks and more uniform surface finishes in critical areas of fatigue failure. Reduction of resistance in fuel and exhaust passages enhances performance and efficiency while maintaining critical tolerance parameters. Smoother intake passages allow for more effective gas/air mixing, higher efficiency and a more powerful engine.

CHAPTER 2

LITERATURE REVIEW AND PROBLEM FORMULATION

Finishing process is a very necessary process for any manufacturing industries. Finishing operation is not only time consuming but also very costly process. In some cases finishing operation is done manually. Some time manual handling causes serious health problem. Some time the mechanical parts are very complex and it is very difficult to finish such part manually by conventional methods. AFM is such process which is the right answer of above problems. This AFM process replaces a lot of manual finishing process leading to more standardization of manufactured part. Further the effectiveness of AFM can be increased by converting it in to Drill bit assisted abrasive flow machining.

2.1 MAJOR AREAS OF AFM RESEARCH

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

2.1.1. Media Flow Volume

Media flow volume is a very prominent parameter which controls the material removal and surface finish. It has been found that if media flow volume is increased than material removal increases. Theoretically it can be understand that as media flow volume is increased more no of abrasive particles come in contact with work piece and more abrasion takes place.

2.1.2. Media Flow Rate

Media viscosity, extrusion pressure, and passage dimension determine the media flow rate (the speed of the abrasive slug passing through the restrictive passage) which affects the uniformity of the material removal and the formation of edge radius. Rhoades [17] has reported that media flow rate is less influential parameter in respect to material removal. Slower slug flow rates are best for uniform material removal and high slug flow rates produce large edge radii [Rhoades 18]. It has been noted by Williams et.al. [19] that if volume of flow is constant. The media flow rate is insignificant with regard to material removal. On the other hand, it has been claimed by Singh [20] and Jain and Jain [21] the media flow rate influences both of the material removal and surface roughness.

2.1.3. Media Viscosity

Williams and Rajurkar [22], and Williams et. al. [23] have reported that viscosity of the media is one of the significant parameters of the AFM process. Keeping all other parameter constant, an increase in viscosity improves both material removal and surface roughness. Przyklenk [23] has observed that the material removal capacity of the least viscous media differs from the most viscous one. This difference could be as much as 300 times. A thumb rules has been suggested by Kohut [24] for the selection of viscosity in relation to work piece passage size. According to this if the passage length is substantially shorter than two times the passage width, a higher viscosity media should be used. On the other hand, if passage length is substantially longer than two times the passage width, a lower viscosity should be preferred. Concentration and abrasive particle size also affect the media viscosity, which may result in settling of particles thereby influencing the flow properties and overall abrasion process [25]. Experiments show that the viscosity of the media increases with the percentage concentration of abrasives and decreases with temperature [26]. It is further indicated that when media viscosity falls below 30 Pa the abrasive particle is less likely to remain in suspension within the media. There is a tendency of particles to sink under gravity to the bottom of the media cylinder.

2.1.4. Type of Drill Bit used

Very prominent effect of the type of rod that we use as a drill bit has been seen over the surface roughness and material removal. Type of rod provides a restricted passage and due to which pressure acting in the area of machining increases which increases the cutting force and hence material removal increases.

2.1.5. Number of Process Cycles

A number of cycles are required to achieve the desired surface finish and material removal. It has been reported in a number of studies that abrasion is more pronounced in some initial cycles after which improvement in the surface finish stabilize or reduce in some cases [27, 28, 19 and 23]. Total number of process cycles range from one to several hundred [29]. Within 1 to 8 cycles, a linear dependence between material removal and surface roughness versus number of cycles was indicated. In AFM the forward and backward extrusion back to the initial stage completes a cycle.

2.1.6 Media Temperature

From the experimental results reported by Weller [30], it can be interpreted that an increase in temperature during processing results in faster cutting of the material, under otherwise constant cutting conditions. Jain and Jain [31] analyzed the heat flow to the work piece and the medium in AFM process. In their study Hull et.al [32] reported the effect of temperature (within the range 30-70 °c) on rheology of media used and stated that the media may sometimes undergo a permanent change in physical properties with increase in temperature.

2.1.7. Extrusion Pressure

It has been found that cutting is faster at an increased extrusion pressure, with all other parameters remaining constant. A part of total pressure is lost within the media due to its internal resistance to flow and rest is imparted to abrasion particles contacting the work piece surface [19, 23, and 18]. Jain and Jain [21] reported that at higher pressure the improvement in material removal just tends to stabilize probably due to localized rolling of abrasion particles.

2.1.8. Abrasive Particle Size

Sizes of abrasive particles used in AFM process range from #8 grit (roughing and stock removal application) to #500 grit (small hole application). Smaller size abrasive gives better surface finish and can reach into complex and narrow passages, while larger one cut faster. According to one thumb rule [33] finer abrasives should be used when the initial roughness of the work surface is less. The reason for a decrease in material removal is that with an increase in mesh size (or decrease in grain size in mm) the depth of penetration as well as width of penetration, decreases.

2.1.9 Abrasives Concentration

McCarty [34] mentions the possibility of using a large range of concentration of abrasive in the media (2 to 12 times weight of carrier media). However, Siwert [13] suggested that abrasive particle to base material ratio (by weight) should vary from 4:1 to 1:4 with 1:1 as the most appropriate ratio. As the concentration of abrasive in the media increase, material removal increases while the surface roughness value decrease. However, its effect is visible only up to a certain percentage of abrasive concentration, beyond which it becomes insignificant. At higher concentration of abrasive particles viscosity of the media increases leading to more material removal [26]. Further, a higher concentration of abrasive particles permits the media to sustain a larger cutting force.

2.1.10 Material and Geometric Feature of Work piece

The nature of surface generated by AFM process is reported by Loveless et.al. [35] to differ significantly from the surfaces produced by other processes. The improvement in surface finish by AFM is also shown to be significantly affected by the type of prior machining process carried out on the work piece. Jain and Adsul [36] in their study mentioned that material removal is governed by initial surface roughness and work piece hardness. Softer material has higher material removal and more improvement in surface finish as compared to harder material. Material and geometrical dimensions of work piece are reported to greatly influence the abrasion process [28, 19,27, 28, and 37].

Generally, work piece with single hole has been taken for processing but an investigation has also been carried on multiple holes specimen [38]. It was observed that for a multiple hole specimen with one centre hole and four outer holes, the central hole experiences 30% more material removal. This has been explained by suggesting a non-uniform velocity distribution of media while flowing through a multiple-hole work piece. Further, it has been reported by Przyklenk [23] that as the media takes the least resistance path, it tends to flow through the major bores even if they are not situated in centre but are staggered.

It was observed that when processing two successive restrictions, equal cross sections receive equal abrasion while with unequal cross sections the smallest passage is abraded more [39]. In case when processing parallel passage, the larger cross section passage receives more abrasion Jain and Jain [21] defined the “Reduction Ratio” as the difference between cross sectional area media cylinder and that of extrusion passage divided by the cross sectional area of media cylinder. For a specified number of cycles, it has been observed that the more the reduction ratio the more will be the material removal from the work piece.

2.2 LATTEST DEVELOPMENT IN AFM

2.2.1. Centrifugal Abrasive Flow Machining

Walia and Shan [40] have shown by their experiments that if a centrifugal force is provided in machining zone than the parameters can be effected positively. They showed that if centrifugal action is provided by rotating the workpiece than both material removal and surface finish increases. It can be seen that addition of centrifugal force with help of external guided arrangements in media increase improvement in surface finish and material removal rate. A rotating Centrifugal Force Generating (CFG) rod was used inside the cylindrical work piece, which provides the centrifugal force to the abrasive particles normal to the axis of work piece.

2.2.2 Magnetic field assisted Abrasive Flow Machining

Jha and Jain [41] analyzed that if the magnetic field is created around the work piece than the force acting on the work piece can be controlled. Magnetic field can be applied around the work piece by using electromagnetic coil or by simply using permanent magnet piece. By varying D.C. electric current flowing in the electromagnet coil or by changing the working gap while using a permanent magnet forces around the work piece can be controlled. A change in the electric current changes magnetic flux density in the working zone due to which the normal force exerted by an abrasive particle on the work piece changes. This change in normal force changes finishing rate ire critical surface finish that can be achieved by the process under the given finishing conditions. This class of processes is capable to produce surface roughness value of 8 nm or lower.

2.2.3 Use of drill bit in abrasive flow machining

Mondal and Jain [42] have given a new concept to increase the material removal and to increase the surface finish. They found that if a drill bit is used which passes through work piece than material removal can be increased and also surface finish can be improved. If a drill bit is used it provides a strict passage for the flow of media and hence increases the pressure in the finishing zone which positively effect the material removal and surface finish. Beside this the shape of the drill bit also effect the material removal and surface finishing. In case if helical drill bit is used than three kind of motion of media takes place which are straight reciprocating motion, scooping motion, and helical motion. The overlapping of different kind of motion increases the material removal rate and surface finish. Introduction of a concept of rotating the media along rotated drill bit axis to achieve higher rate of finishing and material removal. This process is termed as drill bit-guided abrasive flow finishing (DBG-AFF) process. In order to provide random motion to the abrasives in the medium and to cause frequent reshuffling of the medium, the medium is pushed through a helical rotated fluted drill, which is placed in the finishing zone. It has been studied by Jain & Sankar [43] that in drill type AFM, abrasive intermixing depends not only on medium self-deformability as in AFM but also on the pressure from the drill bit, three types of flows (flow along the flute, reciprocating axial flow motion, and scooping flow) that occur in finishing zone and remixing of medium at exit from the finishing zone. Due to the combination of different flows, the work piece-abrasive contact length is no longer a straight line, rather it becomes curved; hence, the number of peaks that can be sheared increases, leading to higher material (finishing rate also improves compared to AFM process. The gap between the work piece surface and the drill bit was varied by changing drill bit diameter and geometry. Increase in drill bit diameter provides more surface finish.

2.2.4 Rotating Drill Bit and Stationary Workpiece AFM

In order to enhance the productivity or the process, Mondal and Jain [42] has been introduced a concept of rotating the media along rotated drill bit axis to achieve higher rate of finishing and material removal. This process is termed as drill bit guided abrasive flow finishing (DBG-AFF) process. In order to provide random motion to the abrasives in the medium and to cause frequent reshuffling of the medium, the medium is pushed through the helical rotated fluted drill, which is placed in the finishing zone.

2.3 PROBLEM FORMULATION

Drill bit assisted abrasive flow machining is a non-conventional finishing operation. Before the advent of drill bit assisted abrasive flow machining simple abrasive flow machining was used. In simple abrasive flow machining media is simply move up and down through the work piece. In drill bit assisted abrasive flow machining a drill bit is used which passes through the work piece which helps to define the path of media responsible for finishing operation. In the present work three types of drill bits are used straight, two star helical and three star helical. In straight fluted drill bit the media is forced to move in a straight path to and fro along the work piece. Helical Abrasive Flow Machining is a non-conventional finishing process that deburrs and polishes by forcing an abrasive media (elastic/viscoelastic polymer) across the work piece surface. If helical drill bit is used than provides a helical path for the movement of the media. In helical drill bit three types of motion occur straight reciprocating motion scooping motion and helical motion. Helical drill bit can be further used in two type two star and three star. Abrasion occurs only where the media flow is restricted; other areas remain unaffected. The process embraces a wide range of feasible applications from critical aerospace and medical components to high-production volumes of parts. One serious limitation of this process is its low productivity in terms of rate of improvement in surface roughness. Efforts have hitherto been directed towards enhancing the productivity of this process with regard to better quality of work piece surface. The present research work focuses on the development of a modified Drill Bit assisted AFM setup for better material removal and high surface finish.

2.4. PROPOSED RESEARCH

This research focuses mainly on the following issues related to the development of Drill Bit assisted AFM Setup:

2.4.1. Setup for AFM

A basic AFM setup for a maximum media pressure of 25N/mm^2 is available in the laboratory, AFM setup includes two media cylinder placed vertically up and down of nylon fixture. The media cylinder is used to store the media while up and down motion of media through the work piece. Above and below the media cylinder there are two hydraulic cylinders. Fluid is present inside the cylinder to create pressure by power pack. It is desired to extrude abrasives laden media up and down through the nylon care and work-piece with the help of these cylinders. The media is to be extruded at different flow rate and at different pressures. Once one extrusion stroke is complete the process is to be reversed by maintaining the same pressure combinations with least possible hydraulic controls. There is a provision of removing of nylon fixtures from the machine.

The basic AFM setup has been modified for the Drill Bit assisted AFM by designing new fixture holding a drill bit stationary inside the hollow cylindrical work piece.

2.4.2 Performance Improvement and Testing of developed setup

Though AFM is a metal finishing technique, material removal and surface finish play significant roles in providing the final surface finish to the component. In the Helical-AFM a combination of axial, radial, centrifugal forces and media movements take place. This results in more material removal and better surface finish. Use of different kind of drill bit has produced different results.

2.5 OBJECTIVE OF THE PRESENT INVESTIGATION

In light of the above-mentioned proposal, the present investigation aims to explore the following objective:

- Experimental study of the effect of various process parameters which are extrusion pressure, no of cycle and type of drill bit on the performance characteristics and to optimize the important process parameters for the internal finishing of cast iron specimens.

CHAPTER-3

DRILL BIT ASSISTED AFM SETUP

Two-way AFM setup is already available in the institute laboratory. As mentioned above two hydraulic and two media cylinder are placed vertically whose purpose is to force the media up and down through the work piece. Work piece is hold in position with the help of nylon fixture. In the Two-way AFM process, there are two hydraulic and two media cylinders to be placed vertically. It is desired to tide abrasives laden media up and down through the nylon fixture and work-piece with the help of these media and hydraulic cylinders.

3.1 SCHEMATIC OF DRILL BIT ASSISTED AFM PROCESS

The pressurized media passes through drill bit causes a braiding of the work piece. Due to stationary drill bit, three types of flows (axial flow, reciprocating flow and scooping flow) and forces (axial, radial and centrifugal forces) that occur in finishing zone and remixing of medium at exit from the finishing zone [16] in Helical-AFM process. Due to the combination of different flow and forces, the work piece-abrasive contact length is no longer a straight line, rather it becomes curved; hence, the number of peaks that can be sheared increases, leading to higher material. In Helical- AFM process rolling, ploughing and indentation of the abrasive grains is me to motions and forces as shown in figure 3.1.

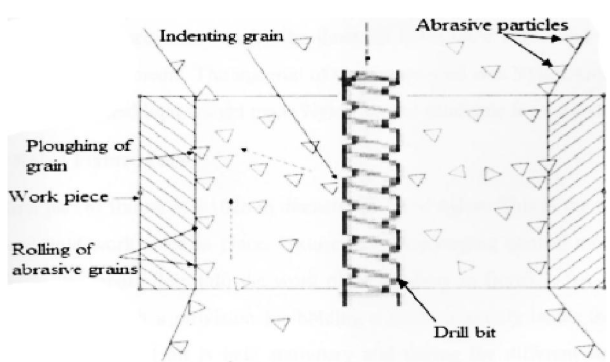

Figure3.1 Schematic of Helical-AFM Process

3.2 DEVELOPMENT OF DRILL BIT ASSISTED AFM

Helical-AFM can be divided into two elements:

- Abrasive laden media
- Development of drill bit assisted abrasive flow machining

The media is to be extruded at different pressures, at different number of cycles and through different drill bit. Two hydraulic cylinder with outer dia 130 mm, inner dia 63 mm and volume 290 mm3 are required to operate the system with as without stationary drill bit. The hydraulic drive is capable of reversing the process, once one extrusion stroke is complete by maintaining the same pressure combinations with least possible hydraulic controls. An appropriate frame and housing is available to accommodate the system.

3.2.1 Development of Improved Fixturing for drill bit assisted AFM

The design of fixture is completely depends on the type of work piece. In the present case the work piece is of hollow cylinder. The fixture is made in three parts. The work-piece is held between first and second, at the interface of two parts and the fixtures plates are clamped together with the help of three countersunk screws allowing the passage (in the work-piece) itself to form the greatest restriction in the media flow path. The threaded holes were kept blind to avoid the possible ingress of abrasive media. The material of the fixture used was Nylon. Good shearing strength, ear resistance, and light weight made Nylon a good candidate for the fixture material.

(A) Nylon Fixture Part-1

The first part of fixture is a 102mm diameter piece of nylon. This is the topmost nylon fixture part and hold work piece in place. Fixture has a converging conical mouth at the top which facilitates the media flow into the work piece as show in fiure3.2. An improved fixture has been developed with a provision for holding a drill bit axially inside the hollow cylindrical work piece. The drill bit is held stationary and during the different strokes will randomly: rented itself inside the work piece.

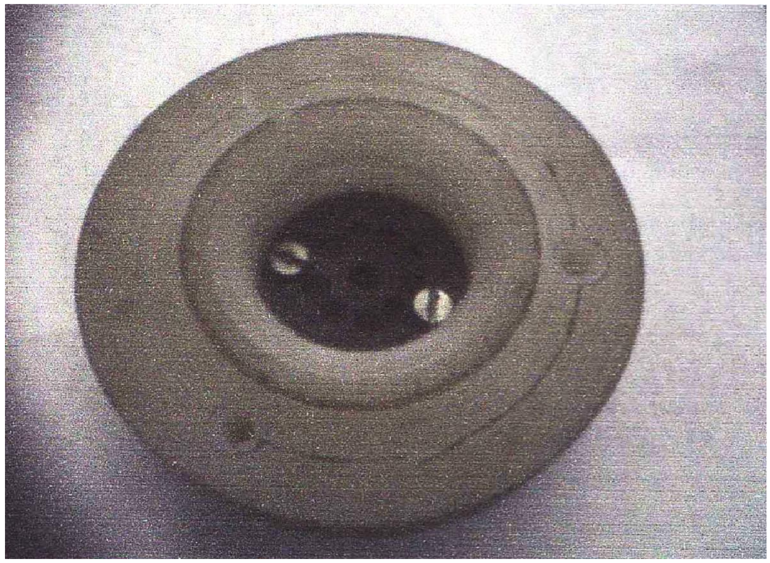

Figure 3.2 Nylon fixture part 1

(B). Nylon Fixture Part-2

Second part of fixture is also a 102 mm diameter piece of nylon. It holds the work piece at top along with Nylon Fixture Part-1 and has a passage for the flow of media as shown in figure 5.3. On the bottom side it is attached to Nylon Fixture Part-3. The drill bit is held axially mostly inside this part and to this HLX-AFM Part-3 which is a M.S. disc with holes for drill and media is fixed.

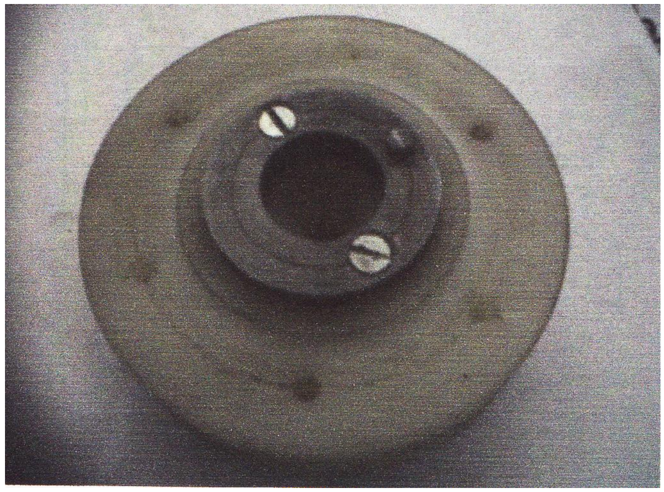

Figure 3.3 Nylon Fixture Part-2

(C). Nylon Fixture Part-3

Third part of the fixture is also made of nylon. Its diameter is 120 mm. this is the bottom most part with a cylindrical bore inside it (figure 3.4). Inside the cylindrical bore the drill bit assembly can slide freely. It also has a component AFM Part-5 attached at the bottom of cylindrical bore stop the drill bit at any random orientation. At the bottom it, a converging conical mouth similar to the first part at top.

Figure 3.4 Nylon Fixture Part 3

(D). Drill-Bit Axial Restraining Disc

This is mild steel disc of 40 mm diameter, 4 mm width (Figure 3.5). It is tightly fitted in the first part of the fixture with the help of screws. Its key function is to hold the drill bit at centre of the work piece during the flow of media. It contains holes at centre and circumference required to keep drill axially and for the flow of media.

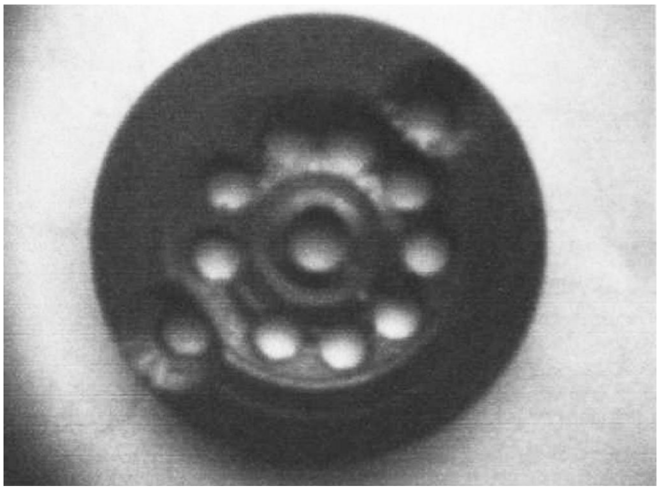

Figure 3.5 Drill-Bit Axial restraining Disc

(E). Mild Steel disc (2 Numbers)

Disc-2 is a Mild Steel disc with 48 mm outer diameter, 25 mm inner diameter and a width of 10 mm (figure3.6). It is fixed in the second part of the fixture with the help of two screws. It is fitted with a tight fit cylindrical key. When media flows upwards, it fits into one of the holes drilled in the outer periphery of the drill disc (disc on which drill bit is mounted) as a result of which the drill stays in place and the flow of media remains uniform when the media is flowing upwards this disc is attached at the bottom of cylindrical bore inside nylon part-3.

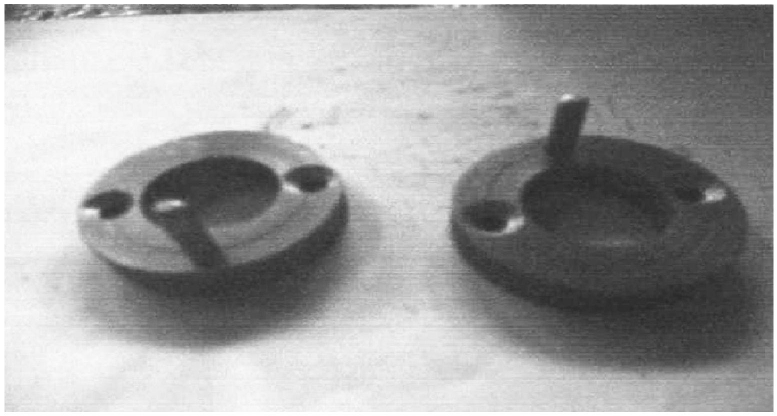

Figure 3.6 Mild Steel Discs

(F). Two start Helical Drill Bit with an attached Disc

The diameter of the disc attached to the drill bit is 48mm and width 15mm.this disc is movable and can move up and down. This is slide fit inside the cylinder bore and can rotate freely. It is a mild steel disc. Unlike other three discs, this disc is movable. At its centre a drill bit of length 95mm, diameter 6.5 mm and Flute length 65 mm is welded (Figure 3.7). There is a possibility of damaging the internal surface of work piece by the flute so in order to avoid it the cutting edges of the flute are grounded.

At its outer periphery there are holes which fit into one of the keys when the media is flowing, in order to stabilize itself and hold drill bit in place. At inner periphery holes are drilled to allow the flow of working media through the disc.

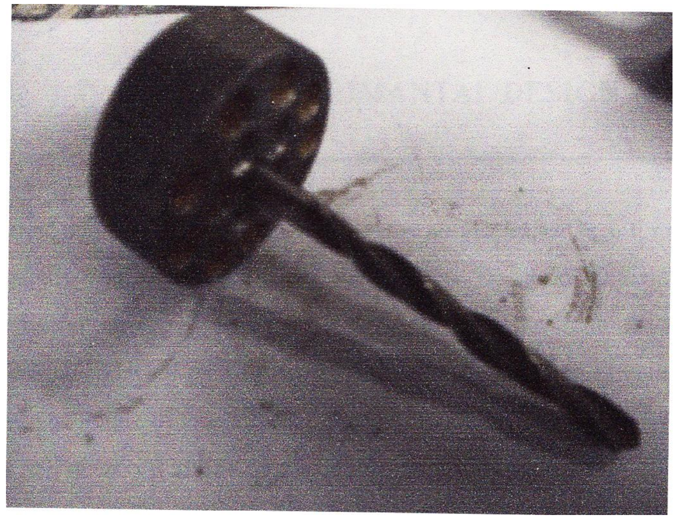

Figure 3.7 Drill Bit with an attached Disc

(G).Three start profile Drill Bit

A three star helical profile is chosen which is made up of steel rod. The length of rod is 95 mm, diameter is 5.8mm, and flute length is 65mm lead is 40 mm. the helical profile is welded to the steel disc. The three star start profile is developed so that whole of the surface have helical grooves so that media is uniformly distributed around the helical rod thus the abrasive laden media makes more surface contact with the inner surface of the work piece.

Figure 3.8Three start Helical Drill Bit

(H). Spline

A rod with length 95mm and diameter 5.8mm have slotted projection over it. The slotted length is 65mm. The no of slot are 6.the rod is welded to the steel disc for axial retainment. The spline have been developed so that the whole surface have the longitudinal grooves, leading to more uniform distribution of media around it, thus the abrasive laden media has more surface contact with the inner surface of the cylindrical work piece.

Figure 3.9 Spline

3.3 ABRASIVE LADEN MEDIA

Media is basically is a mixture of three elements which are abrasive particles, hydrocarbon oil, and silicon based polymer. The size of the abrasive particles which are aluminum oxide is 200 grit. The polymer was prepared by a special technique, for which a patent was granted. The gel was prepared by reacting aluminum striate with hydrocarbon oil. The gel was then mixed into the polymer in a suitable proportion by vigorous kneading. The mixture of the polymer and gel was used as a carrier compound in the media. Aluminum oxide is used for its hardness and strength. It is widely used as an abrasive including as a much less expensive substitute for industrial diamond. Many types of sandpapers use aluminum oxide crystals. In addition, its low heat retention and low specific heat make it widely used in grinding operations, particularly cutoff tools

CHAPTER 4

EXPERIMANTAL DESIGN AND ANALYSIS

In general usage, design of experiments (DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. However, in statistics, these terms are usually used for controlled. A properly planned and executed experiment is of the utmost importance for deriving clear and accurate conclusions from the experimental observations. Design of experiment is considered to be a very useful strategy for accomplishing these tasks. The science of statistical experimental design originated with the work of Sir Ronald Fisher in England in 1920s. Fisher founded the basic principle of experimental design and the associated data-analysis technique called *Analysis of Variance* (ANOVA) during his efforts to improve the yield of agricultural crops [59]. The theory and applications of experimental design and the related technique of *response surface methodology* have been advanced by many statistical researchers as Box and Hunter [61], Box and Draper [62], Hicks [63]. Various types of matrices are used for planning experiments to study several decision variables. Among them, *Taguchi's Method* makes heavy use of orthogonal arrays [45].

4.1 TAGUCHI'S EXPERIMENTAL DESIGN AND ANALYSIS

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. The Taguchi method is best used when there are an intermediate number of variables (3 to 50), few interactions between variables, and when only a few variables contribute significantly.

The Taguchi arrays can be derived or looked up. Small arrays can be drawn out manually; large arrays can be derived from deterministic algorithms. Generally, arrays can be found online. The arrays are selected by the number of parameters (variables) and the number of levels (states). This is further explained later in this article. Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic. The data from the arrays can be analyzed by plotting the data and performing a visual analysis, ANOVA, bin yield and Fisher's exact test, or Chi-squared test to test significance

4.2.PHILOSOPHY OF TAGUCHI METHOD

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

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

3. **The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system wide.** This is the concept of the loss function, or the overall loss incurred upon the customer and society from a product of poor quality. Because the producer is also a member of society and because customer

dissatisfaction will discourage future patronage, this cost to customer and society will come back to the producer.

4.2.1 Taguchi Method Design of Experiments

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

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

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

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

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

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

4.2.2 Experimental Design Strategy

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

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

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

The optimum condition is identified by studying the main effects of each of the parameters. The main effects indicate the general trend of influence of each parameter. The knowledge of contribution of individual parameters is a key in deciding the nature of control to be established on a production process. The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments in determining the percent contribution of each parameter against a stated level of confidence. Study of ANOVA table for a given analysis helps to determine which of the parameters need control [16].

Taguchi suggests two different routes to carry out the complete analysis of the experiments. First the standard approach, where the results of a single run or the average of the repetitive runs are processed through main effect and ANOVA analysis (Raw data analysis). The second approach which Taguchi strongly recommends for multiple runs is to use signal-to-noise (S/N) ratio for the same steps in the analysis. The S/N ratio is a concurrent quality metric linked to the loss function. By maximizing the S/N ratio, the loss associated can be minimized. The S/N ratio determines the most robust set of operating conditions from variation within the results. The S/N ratio is treated as a response parameter (transform of raw data) of the experiment. Taguchi recommends [16] the use of outer OA to force the noise variation into the experiment i.e. the noise is intentionally introduced into the experiment. Generally, processes are subjected to many noise factors that in combination strongly influence the variation of the response. For extremely ‘noisy’ systems, it is not generally necessary to identify controllable parameters and analyze them using an appropriate S/N ratio . In the present investigation, both the analysis: the raw data analysis and S/N data analysis have been performed. The effects of the selected Helical AFM parameters on the selected quality characteristics have been investigated through the plots of the main effects based on raw data. The optimum condition for each of the quality characteristics have been establish through S/N data analysis. No outer array has been used and instead, experiments have been repeated three times at each experimental condition.

4.2.3 Loss Function and S/N Ratio

The heart of Taguchi method is his definition of nebulous and elusive term *'quality'* as the characteristic that avoids loss to the society from the time the product is shipped [60]. Loss is measured in terms of monetary units and is related to quantifiable product characteristics. Taguchi defines quality loss via his 'loss-function'. He unites the financial loss with the functional specification through a quadratic relationship that comes from Taylor series expansion .

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

Where, L = loss in monetary unit

m = value at which the characteristic should be set

y = actual value of the characteristic

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

The traditional and the Taguchi loss function concept have been illustrated in Figure4.l (a) and Figure 4.1(b). The following two observations can be made from Figure 4.1 (a, b) .

- The further the product's characteristic varies from the target value, the greater is the loss. The loss is zero when the quality characteristic of the product meets its target value.

• The loss is a continuous function and not a sudden step as in the case of traditional approach (Figure4.1b).

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

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

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

Where

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

n = number of units in a given sample

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

m= Target value at which characteristic should be set.

Equation (5.1) can be written as:

$L(y) = k\,(MSD)$

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

Taguchi transformed the loss function into a concurrent statistic called S/N ratio, which combines both the mean level of the quality characteristic and variance around this mean into a single metric [35,36]. The S/N ratio consolidates several repetitions (at least two data points are required) into one value. A high value of S/N ratio indicates optimum value of quality with minimum variation. Depending upon the type of response, the following three types of S/N ratio are employed in practice [45].

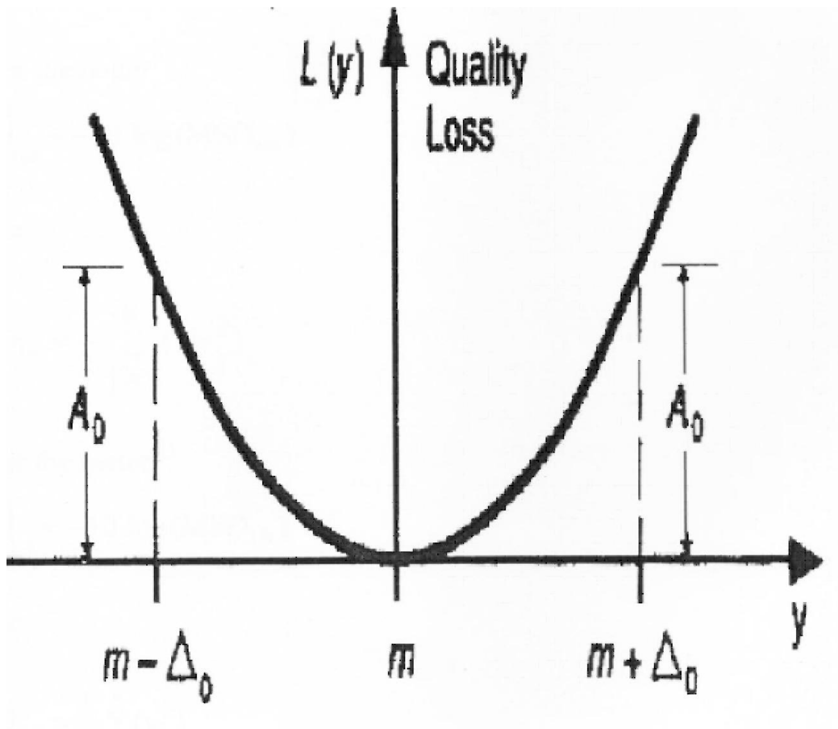

Figure 4.1 (a) Taguchi Loss Function

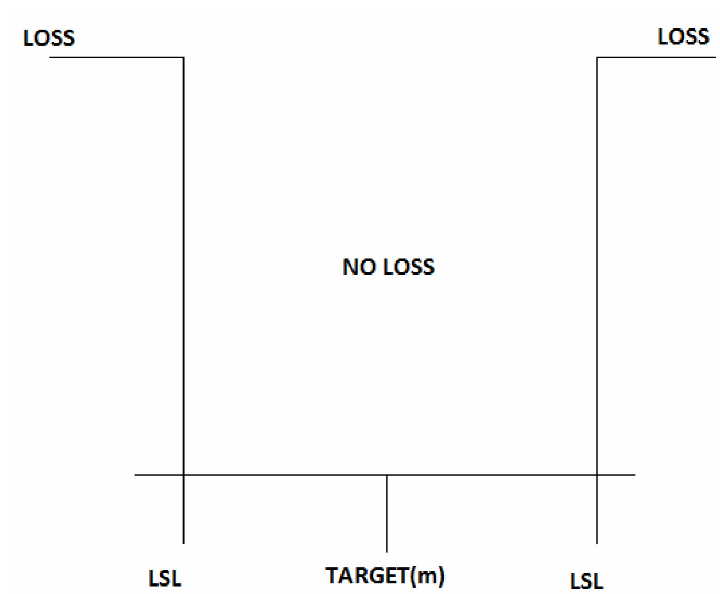

Figure 4.1 (b) Traditional

1. Larger the better :

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

Where

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

2. Lower the better :

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

Where

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

3. Nominal the best :

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

Where

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

R = Number of repetitions

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

4.2.4 Taguchi Procedure for Experimental Design and Analysis

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

(A). Selection of OA

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

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

The determination of parameters to investigate, upon which hinges the product or process performance characteristics or responses of interest [56]. Several methods are suggested by Taguchi for determining which parameters to include in an experiment. These are [56]:

- Brainstorming
- Flow charting
- Cause-effect diagrams

The total degrees of freedom (DOF) of an experiment are a direct function of total number of trials. If the number of levels of a parameter increases, the DOF of the parameter also increase because the DOF of a parameter is the number of levels minus one. Thus, increasing the number of levels for a parameter increases the total degrees of freedom in the experiment which in turn increases the total number of trials. Thus, two levels for each parameter are recommended to minimize the size of the experiment [56]. If curved or higher order polynomial relationship between the parameters under study and the response is expected, at least three levels for each parameter should be considered [50]. The standard two-level and three-level arrays are:

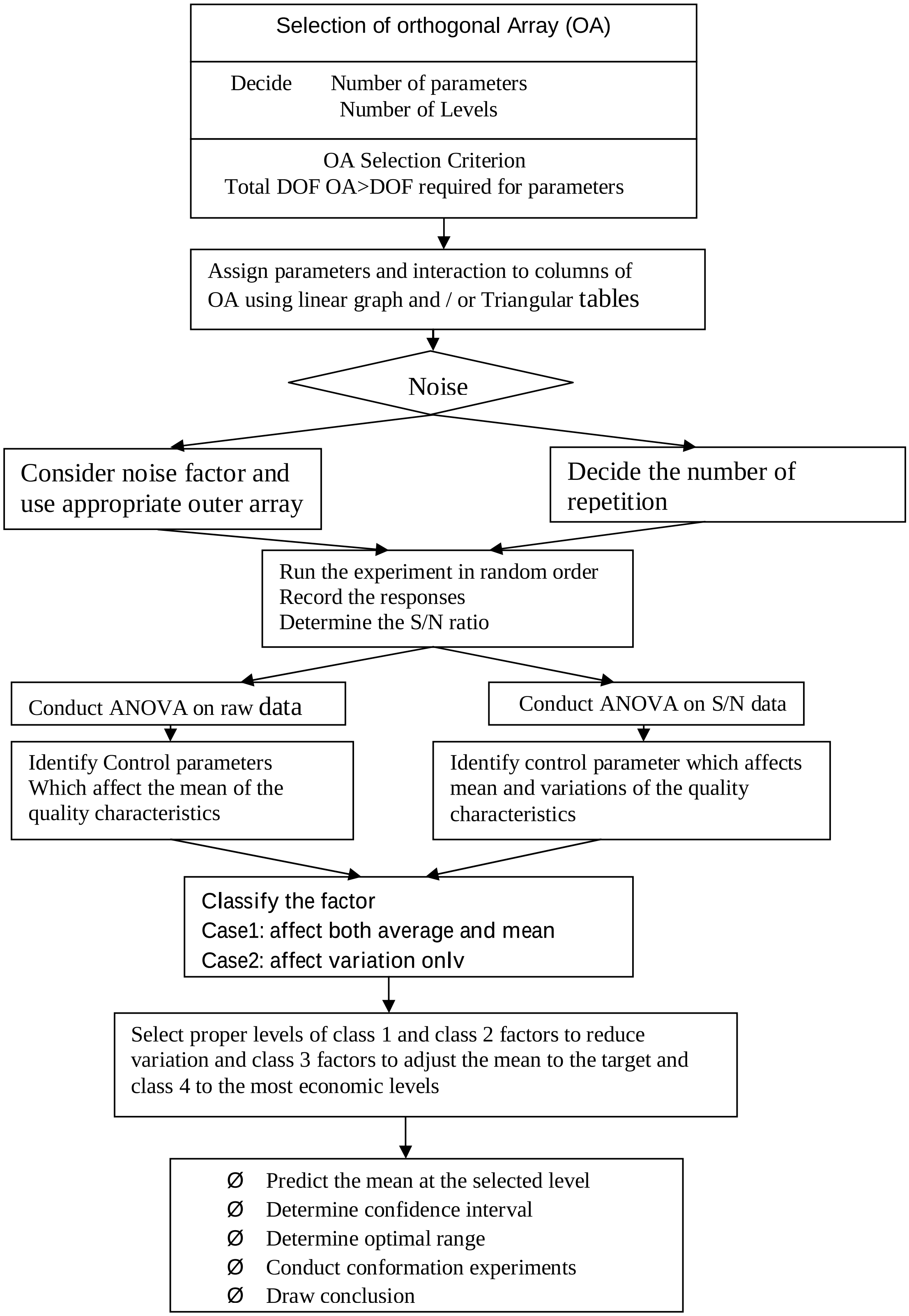

Figure 4.2 Taguchi Experimental Design and Analysis

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

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

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

$f_{LN} = N-1$

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

L_N =OA designation N = number of trials

When a particular OA is selected for an experiment, the following inequality must be satisfied [59]:

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

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

(B). Assignment of parameters and interactions to OA

An 'OA' has several columns to which various parameters and their interactions are assigned. Linear graphs and Triangular tables are two tools, which are useful for deciding the possible interactions between the parameters and their assignment in the columns of 'OA'. Each 'OA' has its particular liner graphs and interaction tables [31].

(C). Selection of outer array

Taguchi separates factors (parameters) into two main groups:

- Controllable factors
- Noise factors

Controllable factors are factors that can easily be controlled. Noise factors, on the other hand, are nuisance variables that are difficult, impossible, or expensive to control [22]. The noise factors are responsible for the performance variation of a process. Taguchi recommends the use of outer array for noise factors and inner array for the controllable factors. If an outer array is used the noise variation is forced into the experiment. However, experiments against the trial condition of the inner array may be repeated and in this case the noise variation is unforced in the experiment [55. 56]. The outer array, if used will have the same assignment considerations.

(D). Experimentation and data collection

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

(E). Data analysis

A number of methods have been suggested by Taguchi for analyzing the data: observation method, ranking method, column effect method, ANOVA, S/N ANOVA, plot of average responses, interaction graphs, etc. [26]. In the present investigation, following methods are used.

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

The plot of average responses at each level of a parameter indicates the trend. It is a pictorial representation of the effect of a parameter on the response. Typically, ANOVA for OA's are conducted in the same manner as other structured experiments [6]. The S/N ratio is treated as a response of the experiment, which is a measure of the variation within a trial when noise tors are present. A standard ANOVA is conducted on S/N ratio, which identified the significant parameters.

(F). Parameter design strategy

Parameter classification and selection of optimal levels

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

Group I : Parameters, which affect both average and variation

Group II : Parameters, which affect variation only

Group III : Parameters, which affect average only

Group IV : Parameters, which affect nothing

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

(G).Prediction of mean

After determination of the optimum condition, the mean of the response (u) at the optimum condition is predicted. This mean is estimated only from the significant parameters. The ANOVA identifies the significant parameters. Suppose, parameters A and B are significant and A2B2 (second level of both A and B) is the optimal treatment condition. Then, the mean at the optimal condition (optimal value of the response characteristic) is estimated [6] as:

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

$$= A_2 + B_2 - T$$

T= overall mean of the response

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

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

(H). Determination of confidence intervals

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

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

- CI_{CE} - Confidence Interval (when confirmation experiments (CE)) around the estimated average of a treatment condition used in confirmation experiment to verify predictions. Get; is for only a small group made under specified conditions.

- CI_{POP} - Confidence Interval of population; around the estimated average of a treatment condition predicted from the experiment. This is for the entire population i.e. all parts made under the specified conditions.

The confidence interval of confirmation experiments (CI_{CE}) and of population (CI_{POP}) is calculated by using the following equations [54]:

$$CI_{CE} = \sqrt{F_{\alpha}(1, f_e) V_e \left[\frac{1}{n_{eff}} + \frac{1}{R}\right]} \quad (4.5)$$

$$CI_{POP} = \sqrt{\frac{F_{\alpha}(1, f_e) V_e}{n_{eff}}} \quad (4.6)$$

Where

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

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

(I). Confirmation experiment

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

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CHAPTER 5

PROCESS PARAMETER SELECTION AND EXPERIMENTATION

In the present chapter, the main process parameters, which may affect the machining characteristics such as material removal and surface finish, are selected. The scheme of experiments is also discussed in this chapter. The experiments were conducted within the ranges of selected process parameters which includes different type of drill bit, no of cycle, and different extrusion pressure. Material removal and surface finish were measured. The measured data are also provided in this chapter.

5.1.SELECTION OF PROCESS PARAMETERS AND THEIR RANGES

In order to obtain high material removal and better quality of surface produced by drill bit assisted AFM, the optimum level of drill bit assisted AFM need to be determined. Based on the critical review of literature, process variables of the drill bit assisted AFM were grouped in the following three categories:

- **The Machine Based Parameters:** media flow rate, media flow volume, extrusion pressure, and number of process cycles.
- **The Media Based Parameters:** Viscosity and temperature of media, abrasive concentration, grain size and shape.
- **The Work-piece/Fixture Based Parameters:** material of work piece, L/D ratio of media flow passage, reduction ratio, and initial surface roughness of work piece and type of drill bit (spline, two star helical, three star helical)

All the above parameters are likely to affect the material removal and surface quality produced by the drill bit assisted AFM

The range of the process parameters was decided on the basis of literature.

5.1.1. Extrusion Pressure

It has been found that cutting is faster at an increased extrusion pressure, with all other parameters remaining constant, at higher pressure the improvement in material removal just tends to stabilize probably due to localized rolling of abrasion particles. The relatively steady rise in *Ra* with increase in the extrusion pressure may be attributed to the increased fractional drag force due to the Non- Newtonian nature of the media which in turn reduces the net abrading force. In the present study the extrusion pressure has been kept in the range of 3-7 N/mm^2. Thought the setup maximum extrusion pressure capacity is 25 N/mm^2.

5.1.2. Number of Process Cycles

It is noticed from the literature that the material removal rapidly increases during the initial cycles and their rate of increase reduces at higher number of cycles. This is due to the fact that higher peaks are removed during the initial process cycles when abrasive particles abrade these peaks; later the peaks become somewhat flatter and the rate of material removal and that of *Ra* reduce. The greater the number and height of the peaks, the more will be the material removal by the process. However, as the surface is subjected to repeated process cycles, the number of peaks and their heights continue to decrease, and hence the material removal rate declines after a few cycles. The range of the number of process cycles have been selected from 2-12.

5.1.3. Type of Drill Bit used

Very prominent effect of the type of rod that we use as a drill bit has been seen over the surface roughness and material removal. Type of rod provides a restricted passage and due to which pressure acting in the area of machining increases which increases the cutting force and hence material removal increases.

5.1.4. Work-piece

In the present investigation, cast iron (pearlite and ferrite with brinell hardness 180) as work-piece material was used. The cavity to be machined in the test specimen was prepared by drilling operation followed by boring to the required size. The size of cylindrical work piece is of length 15 mm, internal and external diameters are 8 and 12.6 mm as shown in figure 5.1. The internal cylindrical surface was finished by Drill bit assisted-AFM process. Each work-piece was machined for a predetermined number of cycles. The work-piece was taken out from the setup and cleaned with acetone before the subsequent measurement.

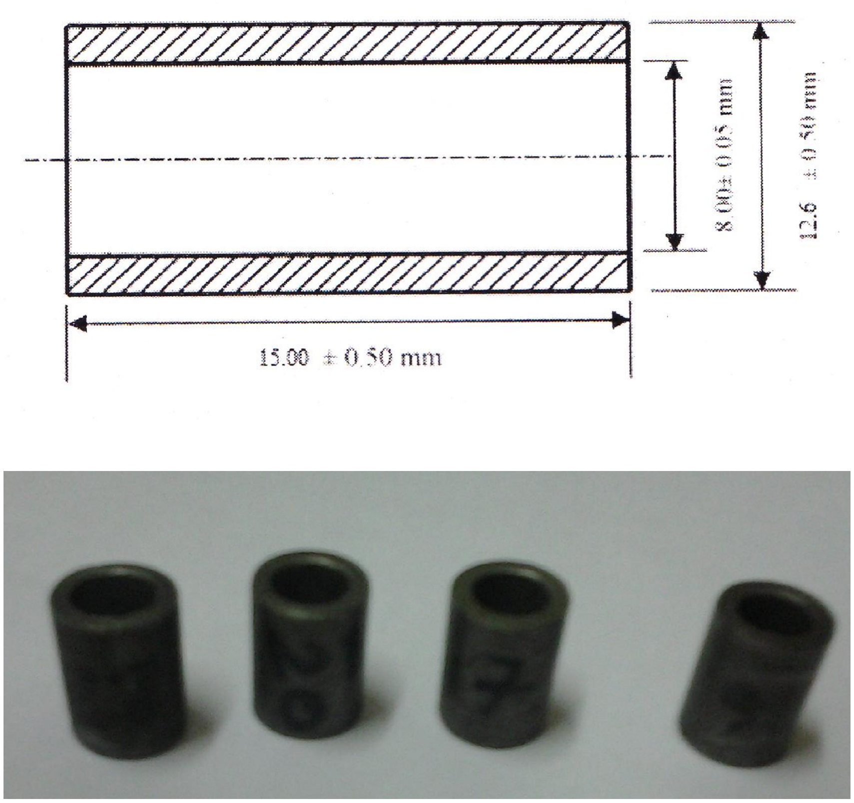

Figure 5.1 Work Piece

5.1.6. Initial Surface Roughness of Work-piece

For each set of experiments, a large number of test specimens, many more than the requirements were prepared. This surface roughness (Ra) and the cavity internal diameter

(ID) were measured and the required number of those specimens whose initial surface roughness of hole was in quite narrow range was chosen from the lot so as to avoid any extraneous effect in response parameters. The range of initial surface roughness of work-piece was selected from 6.2-7.4 microns. The selected parameters and their range for the detailed experiments are shown in Table 5.1.

Table 5.1 Selected Process Parameters and their Range

S.No.	**Process Parameter**	**Range**	**Unit**
1	drill bit	Diameter 6.5	Mm
2	Extrusion Pressure	3-7	N/mm^2
3	Number of cycles	2-6	No.
4	Abrasive particle size	6-8	Micron
5	Media Flow Volume	290	Cm^3
6	Abrasive to media concentration	1.1 to 1:1	% by weight
7	Polymer-to-Gel Ratio	1:1	% by weight
8	Temperature of media	32 ±2	°C
9	Reduction Ratio	0.95	—
10	Initial Surface Roughness	6.2-7.4	μm

5.2 RESPONSE CHARACTERISTICS

The effect of selected process parameters was studied on the following response characteristics of Drill Bit assisted process:

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

5.2.1 Percentage Improvement in Surface Roughness (ΔRa)

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

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

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

Figure 5.2 Taylor Hobson

5.2.2 Material Removal

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

5.3 SCHEME OF EXPERIMENTS

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

Table 5.2 Process parameters and their values at different levels

SYMBOL	PROCESS PARAMETERS	UNITE	LEVEL1	LEVEL2	LEVEL3
H	TYPE OF DRILL BIT		SPLINE	TWO START	THREE START
P	PRESSURE	N/mm^3	3	5	7
N	NUMBER OF CYCLE	N	2	4	6

Polymer to gel ratio:1:1,Workpiece material:Cast iron,Abrasive type:Al_2O_3,Grit size: 200, Media Flow Volume: 290 cm^3, Reduction Ration: 0.95, Temperature: 32 $^+_-$ 2°C, Extrusion Pressure (P): $7N/mm^2$, Flow Rate (F): medium and constant Approximate Pressure difference: 15N/mm), MediaViscosity: 810 Pas

The scheme of experiments based on tagauchi's L9 orthogonal Array (OA) for setting of various parameters is as given in the table5.3

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

Exp no.	Run Order	Parameters Trial Conditions			Response(Raw Data)			S/N ratio(db)
		H	**P**	**N**	**R1**	**R2**	**R3**	
1		**1**	**1**	**1**	X_{11}	X_{12}	X_{13}	**S/N(1)**
2		**1**	**2**	**2**	X_{21}	X_{22}	X_{23}	**S/N(2)**
3		**1**	**3**	**3**	X_{31}	X_{32}	X_{33}	**S/N(3)**
4		**2**	**1**	**2**	X_{41}	X_{42}	X_{43}	**S/N(4)**
5		**2**	**2**	**3**	X_{51}	X_{52}	X_{53}	**S/N(5)**
6		**2**	**3**	**1**	X_{61}	X_{62}	X_{63}	**S/N(6)**
7		**3**	**1**	**3**	X_{71}	X_{72}	X_{73}	**S/N(7)**
8		**3**	**2**	**1**	X_{81}	X_{82}	X_{83}	**S/N(8)**
9		**3**	**3**	**2**	X_{91}	X_{92}	X_{93}	**S/N(9)**
Total								
R1, R2 and R3shows response value for three repetitions of each experiment 1, 2 and 3 represents levels of parameters X_{IJ} represents different measured values of quality characters.								

5.3.1. PRECAUTIONS TAKEN DURING EXPERIMENTATION

While performing various experiments, the following precautionary measures were taken:

1. Each experiment is repeated three times to avoid experimental error.

2. The experiments repeated randomly in order to avoid bias, if any, in the results.

3. As the experiments proceed the cutting edges of abrasive particles wear off and become dull which result in less favorable results are produced in later experiments secondly the particles of work piece material mixed with the media and as the time proceeds the volume of work piece material inside the media increases which deteriorate the finishing action. To avoid this large volume of the media is prepared and after each

experiment the used media is taken out from the cylinder and throughout mixed with the fresh media contained in large container. The media for next trial is taken from this mix. For the limited number of experiments conducted, this would ensure with reasonable reliability that the media used for each of the experiment run contain approximately equal amount of fresh grains(grain with sharp edges)

4. Each set of experiments was performed at room temperature in a narrow range (32 ± 2°C).

5. Before any measurement was taken, the work-piece was cleaned with acetone.

6. The surface roughness was measured in the direction of flow of media and at several random points all over the cavity of the work-piece.

5.3.2 EXPERIMENTATION

The three process parameters viz. type of Drill Bit Status, Extrusion Pressure and Number of Cycles are selected as given in Table 5.7. The parameters which were kept constant are also given in the Table 5.6. The process parameters were varied according to the values as shown in Table 6.3. Experiments were conducted according to the test conditions specified by the L_9OA (Table 6.4). Each experiment was repeated three times in each of the trial conditions. Thus, 27 work-pieces were selected having initial surface in close range of (6.2-7.4). In each of the trial conditions and for every replication, the percentage improvement in surface roughness and material removal were measured. The data is recorded in Table 5.4.

Table 5.4 Experiment Result of Various Response Characterstics

Exp No.	Run Order	%Improvement in Ra			S/N Ratio(db)	Material Removal(mg) MR			S/N Ratio(db)
		R1	R2	R3		R1	R2	R3	
1	2	8.25	5.5	6.09	16.40	1.3	1.3	1.1	1.82
2	1	14.35	23.2	37.79	27.99	2.5	2.6	1.9	7.35
3	3	2.86	9.7	2.1	13.78	3.7	3.6	2.9	10.62
4	4	11.5	32.24	14.2	25.71	2.6	2.8	1.9	7.72
5	7	20.85	3.63	13.1	21.95	3.9	3.2	3.9	11.28
6	5	7.83	5.2	9.2	17.39	3.8	2.7	2.1	9.14
7	8	7.04	8.3	9.2	18.25	3.8	3.9	3.2	11.20
8	6	11.42	20.84	20.9	24.96	3.8	4	2.1	10.37
9	9	23.16	23.65	23.52	27.40	3.9	4.1	4	12.04
Total		107.26	132.26	136.1		29.3	28.2	23.1	
		$T_{\Delta Ra}$ = Overall mean of ΔRa =13.91				T_{MR} = Overall mean of MR =2.98mg			

CHAPTER 6

DISCUSSION OF RESULT

6.1 ANALYSIS AND DISCUSSION OF RESULT

Tagauchi's method was used to plan the experiments. The response characteristic data already have been provided in chapter 5. Tagauchi has shown a standard procedure to analyze the data. The same method has been used here. The average values and S/N ratio of quality/response characteristics for each parameter at different levels are calculated from experimental data. The main effect of process parameter both for raw data and S/N data are plotted. The response curves (main effect) are used for examining the parametric effect of response characteristics. The most favorable condition (optimal setting) of process parameters in term of mean response characteristics by analyzing response curves and the ANOVA tables.

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

6.1.1. Effect on material removal

The average value of material removal (MR) and S/N ratio for each parameter at levels L_1, L_2, L_3 are calculated and given in table 6.1.

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

Process parameter	Level	Shape of Drill Bit(H)		Extrusion pressure		Number Of Cycle(N)	
Type of data		Raw Data(mg)	S/N Ratio	Raw Data(mg)	S/N Ratio	Raw Data(mg)	S/N Ratio
Average value	L1	2.32	6.43	2.43	6.73	2.46	6.45
	L2	2.98	8.97	3.1	9.16	2.92	8.82
	L3	3.64	10.78	3.42	10.30	3.56	10.91
Main Effect	L2-L1	0.66	2.53	0.66	2.43	0.45	2.37
	L3-L2	0.65	1.81	0.32	1.13	0.64	2.087
DIFFERENCE $((L_3-L_2)-(L_2-L_1))$		0.01	-0.72	-0.34	-1.29	0.18	-0.28
L_1, $L_2$and L_3 represent levels 1, 2 and 3 respectively of parameters. L_2-L_1 is the average main effect when the corresponding parameter changes from level1 to level 2. L_3-L_2 is the main effect when the corresponding parameter changes from level 2 to level 3.							

The main effects of different process parameter on the material removal (MR) are plotted as figures 6.1(a,b,c)

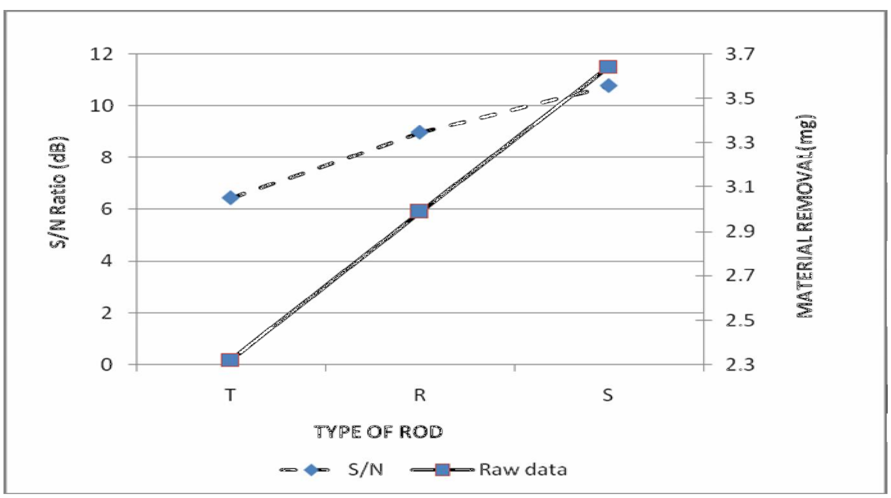

Figure 6.1(a) Effect of shape of dill bit on(MR and S/N Ratio)

Fig 6.1(a) shows that max material removal is at third level(H3). It means that max material removal takes place when three start Helix drill bit is used. Lowest material rate is at first level(H1) i.e. in case of spline. Material removal is more in case of three start helical drill bit because in case of helical Drill bitt the abrasive particles flow in three type of motion. The abrasiv particles near the surface moves in axial direction where the particles moving near the drill bit follow a helical path and particles in between scoop up towards the work surface. The three type of flow that occur in finishing zone (Fig 1.5(a),(b)(c)) makes the workpiece –abrasive contact length is no longer a straight line, rather it become curved; hence the number of peaks that can be sheared increases, leading to higher material.But overall effect of Helix type on material removal is significant as observed in both the ANOVA tables(Table nos 6.2 and 6.3) for raw data and S/N Ratio data.

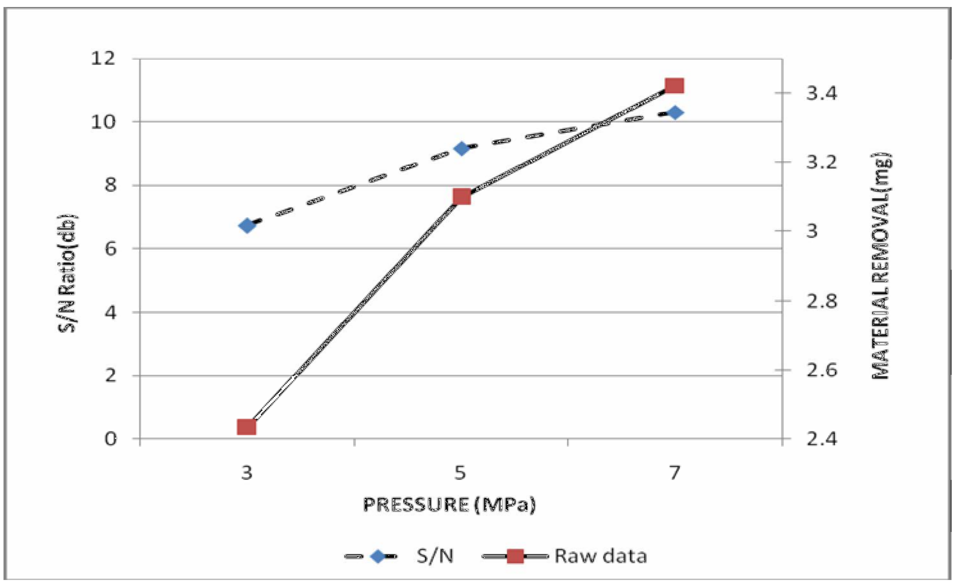

Figure 6.1(b) Effect of Extrusion Pressure on (MR and S/N Ratio)

Figure 6.1(b) show that with the increase of extrusion pressure material removal increase which is max at third level i.e. at 7MP and mini at first level i.e. at 3MP.

This is due to the fact that with increase of pressure the cutting forces involved in cutting action increases. Due to increase of cutting force material removal increase. The rate of material removal is more with initial increase of pressure from 3MP to 5MP but less in later increase of pressure from 5MP to 7MP. This behavior may be due to the fact that with increase of pressure from 5MP to 7MP however cutting force increases but there is lesser rolling of abrasive particles in the media and due to which fresh cutting edges do not comes in contact with work piece. The effect of extrusion pressure is significant in ANOVA table based on Raw Data and S/N ratio (Table 6.2).

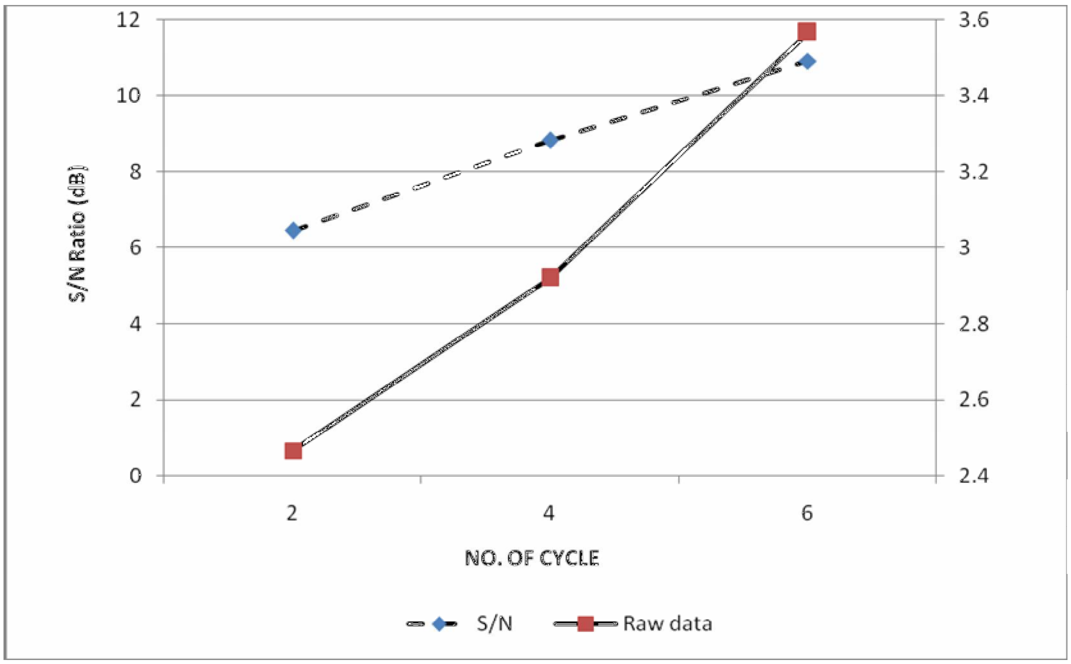

Figure 6.1(c) Effect of No of Cycle on S/N Ratio(db) and MR

It is clearly shown in fig that as the no of cycle increase from 2 to 6 the material removal increase. More no of cycle means more abrasion action and more material removal. The material removal rate initialy is low but as the no of cycle increases material removal rate increases. The reason is as the no of cycle increases some of the abrasive particles become dull so along with cutting action rubbing action takes place which result in more material removal rate. However rubbing action deteriorate the surface finish. The effect of No of Cycle is significant in ANOVA table based on Raw Data and S/N ratio (Table 6.3).

6.1.2 Selection of optimum levels

In order to study the significance of process parameters towards the MR, analysis of variance (ANOVA) was performed. The pooled version of ANOVA of raw data and S/N data for MR are given in tables 6.2& 6.3. From the data it is clear that parameters N (Number of cycle), P (Extrusion Pressure), H (Drill bit type) significantly affect both mean and variation. The percentage contribution of Drill bit type is 33.57%, percentage contribution of Number of cycle is 19.53% and the percentage contribution of Extrusion pressure is 23.46%. As we know that material removal is "higher the better" type quality characteristic. Therefore, higher value of MR is considered to be optimal. It is clear from the figure 6.1(a,b,c) that material removal is higher at third level in all the three cases.

Table 6.2 Pooled ANOVA (Raw Data MR)

SOURCE	SS	DOF	V	F-RATIO	P%
DRILL BIT TYPE	7.867	2	3.9	14.33*	33.57
NUMBER OF CYCLE	4.579	2	2.3	8.34*	19.53
EXTRUSION PRESSURE	5.499	2	2.7	10.01*	23.46
ERROR	5.49	20	2.7		23.42
TOTAL(T)	2.343	26			100
All parameter are significant at 95% confidence level, $F_{critical}$= 3.49 SS-Some of square, DOF-Degree of freedom-variance					

The S/N ratio analysis suggests (P_3) levels of parameters as the best levels for max MR of cast iron in AFM process. The other parameters are also significant and should be set at comfortable or economical setting within the selected experimental ranges.

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

SOURCE	SS	DOF	V	F-RATIO	P%
DRILL BIT TYPE	28.664	2	14.33	34.99*	36.12
NUMBER OF CYCLE	19.995	2	9.997	24.41*	25.20
EXTRUSION PRESSURE	29.858	2	14.92	36.45*	37.63
ERROR	0.8190	2	0.409		1.032
TOTAL(T)	79.337	8			100
All parameter are significant at 95% confidence level, $F_{criticle}$= 19 SS=Some of square, DOF-Degree of Freedom, V-Variance					

6.1.3 Effect on %age improvement in surface roughness

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

Process parameter	Level	Shape of Drill Bit(H)		Extrusion pressure		Number Of Cycle(N)	
Type of data		Raw Data(mg)	S/N Ratio	Raw Data(mg)	S/N Ratio	Raw Data(mg)	S/N Ratio
Average value	L1	12.20	17.10	11.368	19.202	10.581	18.85
	L2	13.08	18.54	18.453	21.828	22.623	25.64
	L3	16.44	23.12	11.913	17.748	8.5311	14.27
Main Effect	L2-L1	0.878	1.438	7.0844	2.6259	12.042	6.794
	L3-L2	3.364	4.582	-6.54	-4.079	-14.09	-11.36
DIFFERENCE $((L_3\text{-}L_2)\text{-}(L_2\text{-}L_1))$		2.485	3.143	-13.62	-6.705	-26.132	-18.16
L1, L2 and L3 represent levels 1, 2 and 3 respectively of parameters. L2-L1 is the average main effect when the corresponding parameter changes from level 1 to level 2. L3-L2 is the main effect when the corresponding parameter changes from level 2 to level 3.							

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

The main effects of various parameters at the selected levels on the %age improvement in surface roughness are plotted in the Fig 6.2(a, b, c).

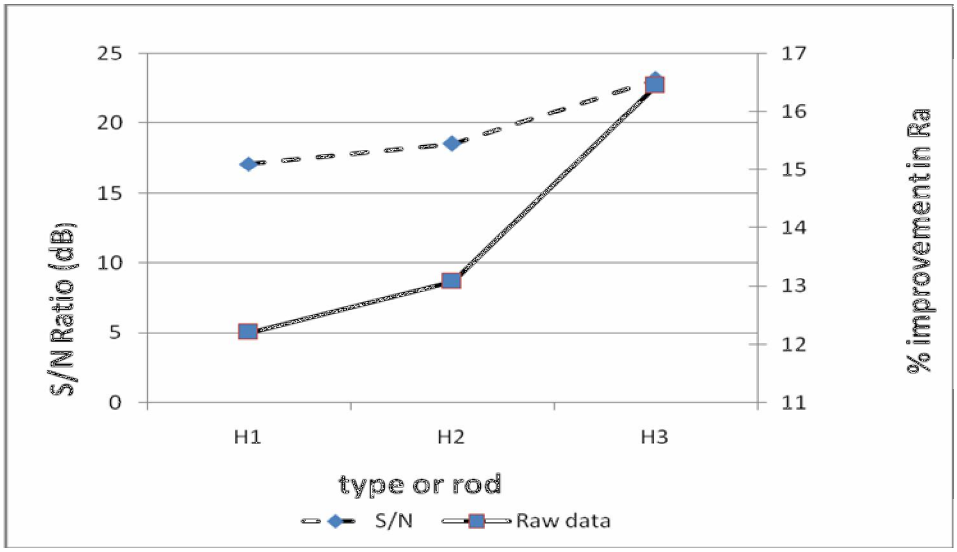

Fig 6.2(a) Effect Of Type Of Drill Bit on %age improvement in R_a

Fig 6.2(a) shows that max ΔR_a and S/N Ratio is at the third level (H_3) of helical profile i.e. three start profile. It is due to the large surface contact of abrasive particles in case of 3-start helical profilew with the inner surface surface of the workpiece, leading to more finish. The lowest ΔRa and S/N ratio has been observed at first level (H_1) of drill-bit i.e. spline. The effect of 2-start (H2) is also better than the spline. Overall the effect of type of Drill bit on the %age improvement in ΔRa is singnificant based on S/N Ratio data (ANOVA Table no. 6.5), but is insignificant based on raw data (Table no 6.6).

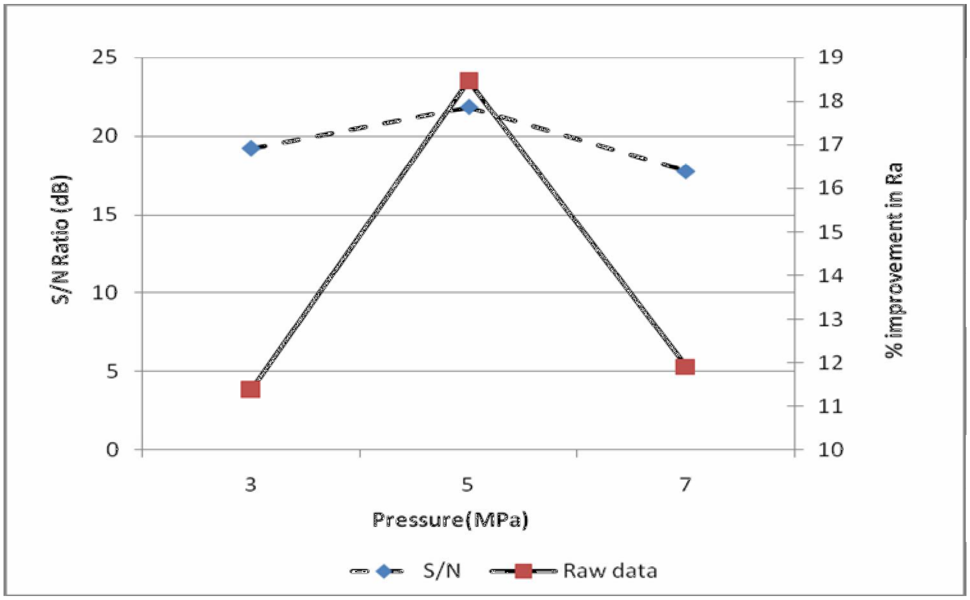

Figure 6.2 (b) Effect of Pressure on(ΔRa and S/N Ratio)

Fig 6.2(b) shows that %age improvement in Ra and S/N ratio increases as the pressure increases up to 5MP than it decreases with further increase in pressure up to 7 MP. the increase up to 5 MP can be attributed to the fact that as the pressure increases the force involved in cutting action increases and resulting in more no of peaks are sheared off which result in smother surface. At this pressure we got very smooth surface further increase in pressure enable the abrasive particles to strike the Surface with greater force and resulting in deeper scratches, and poor surface finish. Although the effect of extrusion pressure is significant in the ANOVA Table based on Raw Data (Table 6.5), and insignificant based on S/N ratio.

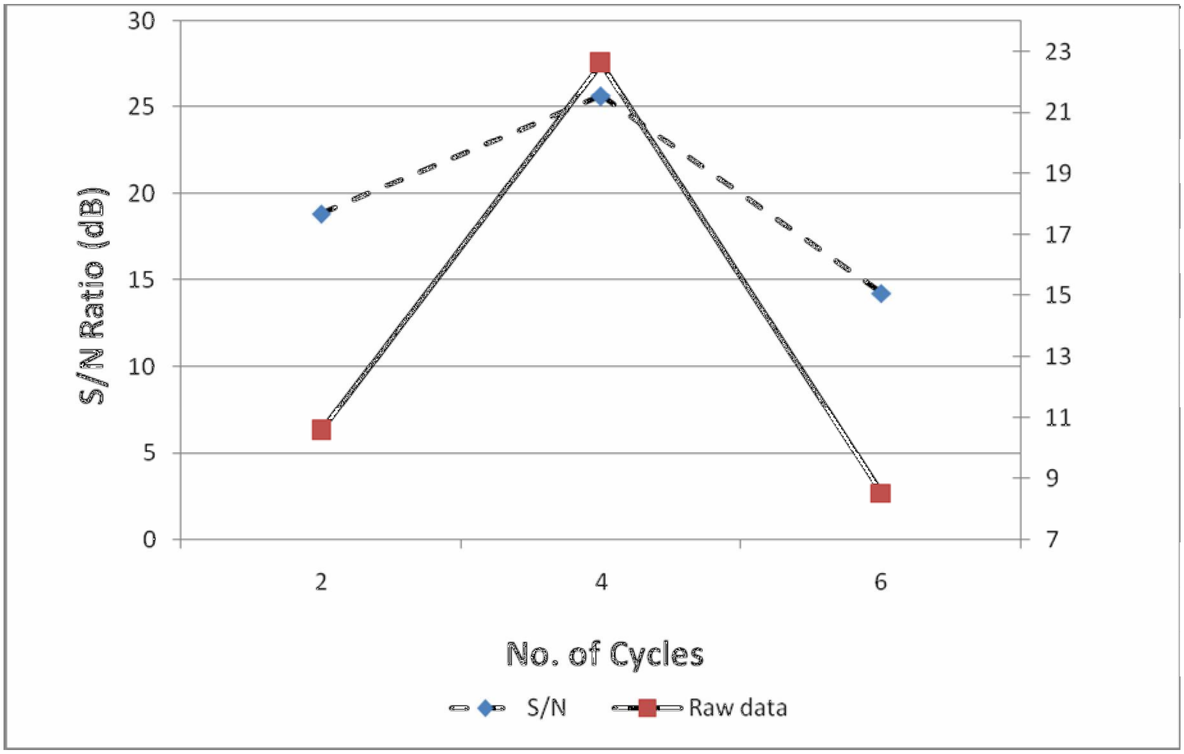

Fig 6.2(c) Effect of Number of Cycle on (ΔRa and S/N Ratio)

Fig 6.2(c) shows that initialy as the number of cycle increases %improvement in Ra and S/N ratio increases and is max at 4 no of cycle with further increase in no of cycle increases %improvement in Ra and S/N ratio decreases. As no of cycle increses we get better and better surface finish and a very good surface finish at 4 no of cycle. Further movement of abrasive particles on the surface beyond 4 no of cycle erode the surface and we get detirerated surface finish. Overall the effect of no of cycle on %improvement in Ra is significant in both S/N ratio and raw data table.

6.1.4. Selection of optimal levels

analysis of variance (ANOVA) wae performed to study the significance of of process parameter towards the percentage improvement in R_a. The pooled version of ANOVA of raw data and the S/N data for ΔR_a are given in Table 6.5& 6.6. From the table it is clear that type of rod is signifiacant for variation but insignificant for mean, extrusion pressure significant for mean but insignificant for variation, whereas number of cycle is significant for both mean and variation. The percentage contribution of number of cycle is maximum i.e. 47.22% followed by extrusion pressur which contribute 12.67% and the contibution of helical profile is 4.08%. The percentage improvement in R_a.is “higher the better” type of quality characteristics. There for heigher value of ΔR_a are considered to be optimal. It is clear from the figure 6.2(a,b,c) that percentage improvement in R_a for raw data is higher at third level for type of rod, at the second level for pressure and second level for number of cycle.

Table 6.5 Pooled ANOVA(Raw Data,%age imp inΔRa)

SOURCE	SS	DOF	V	F-RATIO	P%
TYPE OF DRILL BIT	90.293	2	45.167	1.136	4.089
EXTRUSION PRESSURE	279.77	2	139.88	3.520*	12.67
NUMBER OF CYCLE	1043.45	2	521.71	13.13*	47.22
ERROR	794.59	20	39.72		35.98
TOTAL	2208.08	26			100
*significant at 95% confidence level, $F_{criticle}$=3.49 SS-Sum of Square, DOF-Degree of Freedom, V-Variance					

The S/N ratio analysis (table 6.6 and figure 6.2(a,b,c)) suggests that parameter number of cycle is significantly affecting and giving better surface finish at (P_2) levels. Type of drill bit is also significant giving better surface finish at (H_1) level. The other parameter can be set at any comfortable or economical level.

Table 6.5 Pooled ANOVA (S/N Ratio Data, %age imp in ΔR_a)

SOURCE	SS	DOF	V	F-RATIO	P%
TYPE OF DRILL BIT	59.310	2	29.65	19.78*	20.86
EXTRUSION PRESSURE	25.647	2	12.82	8.555	9.021
NUMBER OF CYCLE	196.34	2	98.17	65.49*	69.06
ERROR	2.99	2	1.499		1.054
TOTAL	284.30	8			100
*Significant at 95% confidence level, $F_{critical}$= 19 , SS-Sum of squares, DOF-Degree of freedom, V-variance					

6.2. Estimation of optimum response characteristics

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

As observed the optimum values for the maximum MR are $H_3P_3N_3$ for raw data and $H_3P_3N_3$ for S/N data. For the confirmation experiments on the basis of raw data the optimal settings have been take as $H_3N_3P_3$.

For maximum percentage improvement in R_a are N_2P_2 with any level of H for raw and H_3N_2 with P set at any level for the S/N data. Based on raw data the optimum settings for the maximum percentage improvement in the surface roughness are N_2P_2.

Based on the optimal selection of the process the optimum response parameters of the material removal and Percentage improvement in surface roughness have been estimated with the confidence intervals as further.

6.2.1. Material Removal (MR)

The mean at the optimal MR (optimum values of the response characteristics) is estimated [52] as

$$MR = \overline{N_3} + \overline{P_3} + \overline{H_3} - 2\,T$$

T = overall mean of the response = 2.98 mg (Table 5.4)

Average value of MR at the third level of type of rod

= 3.64 mg (6.1)

Average value of MR at the third level of extrusion pressure

= 3.42 mg

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

= 3.56 mg

Substituting these values, MR = 4.66 mg

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

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

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

Where $F_{\alpha}(1, f_e)$ = The F- ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom f_e = 4.35 (Tabulated F value)

f_e = error DOF = 18 (Table 6.2)

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

R = Sample size for confirmation experiments = 3

V_e = Error variance =2.7 (Table 6.2)

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

= 3.85

So, $CL_{CE} = \pm 2.63$

and $CL_{POP} = \pm 1.74$

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

Mean $MR - CI_{CE} < MR > MR + CI_{CE}$

$2.03 < MR > 7.29$

The 95% confirmation interval of the predicted mean is :

Mean $MR - CI_{pop} < MR > MR + CI_{pop}$

$2.92 < MR > 6.4$

6.2.2 Percentage improvement in R_a

The mean of the percentage improvement in R_a optimum values of the response characteristics is estimated [G3] as :

$$\Delta R_a = \bar{N}_2 + \bar{P}_2 - \bar{T}$$

T = overall mean of the response = 13.91 % (Table 5.4)

Average value of % age improvement in R_a at the second level of extrusion pressure = 18.45 %

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

= 22.62 %

Substituting these values, % improvement in R_a = 27.16 %

The confidence interval of confirmation experiments (CL_{CE}) and of population (CL_{POP}) calculated by using the following equation [41]:

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

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

Where F_{α} (1, f_e) = The F- ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom fe = 4.35 (Tabulated F value)

fe =error DOF = 18 (Table 6.5)

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

R = Sample size for confirmation experiments = 3

Ve = Error variance =39.72 (Table 6.5)

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

= 5.4

So, CL_{CE} = ± 9.46

and CL_{POP} = ± 5.65

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

17.7< %age improvement in $\Delta\mathbf{R_a}$ >36.62

The 95%age confirmation interval of predicted mean is

21.6<%age improvement in $\Delta\mathbf{R_a}$ >32.81

Confirmation Experiments

In order to validate the results obtained, three confirmation experiments have been conducted for response characteristics of MR and %age improvement surface roughness .For the maximum MR, the optimal levels of the process parameter are $H_3N_3P_{3.}$Whereas for the maximum %age improvement surface roughness the optimal parameters settings are $H_3N_2P_{2.}$

H3 –3-start helical profile has been employed.

N_2 – Second level of number of cycles (4 cycles)

N_3 - Third level of number of cycle(6 cycle)

P_2 – Extrusion Pressure at the second level (5 MPa)

P3 – Extrusion Pressure at the third level (7 MPa)

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

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

Response Characteristic	Optimal Process Parameters	Predicted Optimal Value	Confidence Intervals 95%	Actual Value(Avg of Confirmation Exp)
MR	$H_3N_3P_3$.	4.66 mg	CI_{CE} 2.03<MR>7.29 CI_{POP}:2.92<MR>6.4	4.87 mg
%Improvement In	$H_3N_2P_2$.	22.62%	CI_{CE}: 17.7<%Δ$\mathbf{R_a}$>36.62 CI_{POP} :21.6<%Δ$\mathbf{R_a}$>32.81	24.40%
CI_{CE} – Confidence interval for the mean of the confirmation experiments CI_{POP} – Confidence interval for the mean of the population				

CHAPTER 7

CONCLUSION AND SCOPE FOR FUTURE WORK

7.1 CONCLUSION

- In the experimental investigation on drill bit assisted AFM setup, its process parameters – a profile of drill bit, number of cycle and extrusion pressure have been studied successfully by TaguchiL_9 OA method to quantify the response parameters-material removal rate and percentage improvement in the surface finish of workpiece (Cast Iron).

- For material removal rate of Cast Iron, the three process parameters of DBA-AFM viz drill bit type, number of cycle, extrusion pressure all have significant effect.

- For metal removal rate of Cast Iron, the result shows that response parameter of the type of drill bit have 33.4%, extrusion pressure have 23.46% and number of cycle have 19.53 % contribution for response parameter of material removal rate.

- For percentage improvement in surface finish of Cast Iron, the process parameters of DBA-AFM, extrusion pressure and number of cycle are significant for whereas the process parameter type of drill bit is insignificant.

- For percentage improvement in surface finish of Cast Iron, it has been found that extrusion pressure has 12.67% contribution and number of cycle has 47.22% contribution for response parameter %age improvement in R_a.

- Extrusion pressure has a contribution of 19.53% and 12.67% towards the MR and %age improvement in $R_{a,}$ respectively. Within the selected range of 3MP to 7MP as the pressure increases MR increases. But we get better surface finish at the middle value i.e. at 5 MP. So between the selected range if pressure is increased the surface roughness decreases to minimum at 5MP while with increase of pressure the surface roughness increases

- Number of cycle has contribution of 23.46% and 47.25% towards the MR and %age improvement in R_a respectively within the selected range of 2 to 6 no. of cycle. As the number of cycle increases MR increases. But we get better surface finish at the middle value i.e. at 4 number of cycles. So between the selected ranges if number of cycle is increased the surface roughness decreases to minimum at 4 no. of cycle and then with increase of pressure the surface roughness increases.

- At selected parameters a maximum improvement of 28.12% has been observed in the surface finish. With the initial roughness 6.2 microns, an improvement to 4.45 micron has been observed on the inner cylindrical surface of the cast iron work piece.

7.1 SCOPE OF FUTURE WORK

- Different types and size of Helical profiles in place of Drill Bit can be explored for better result

- Results can be analyzed for different pressure and different flow rate.

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