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Various developments in Abrasive Flow Machining Process: A Review

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Abstract :Abrasive flow machining is a nonconventional process used for polishing of metallic components, internal inaccessible cavities or recesses using a semi liquid paste. It was developed to deburr, polish the surfaces having complex geometries and edges by flowing abrasive particles with a visco-elastic nonconductive media over them. Abrasive particle sharp cutting edges remove the material by abrasion mechanism from the workpiece surface. In the recent year, work has been carryout towards the development of abrasive flow machining for achieving the higher material removal and improved surface finish. This method has a unique property of simultaneous improvement in material removal and surface finish. In this paper authors discussed about various recent developments in abrasive flow machining with major objective of improving the productivity of the process.

Keywords:Abrasive flow machining, semi liquid paste, surface finish.

1. INTRODUCTION

In recent past industry used conventional techniques for obtaining better finished product, but a lot of competition in the market related to better performance and life cycle of the product leads to the development of new techniques that can improve the constraints. Abrasive Flow Machining (AFM) is a nontraditional technique which can provide high level of finishing in the complex geometries [1]. This process removes the material by the abrasion mechanism, provided by the sharp cutting edges of the abrasive particles. These sharp cutting edges particles are mixed with a semi solid paste called as Abrasive laden media [2]. This abrasive laden media is forced to flow with a high pressure through the restrictive path to abrade the workpiece surface. The media made by the combination of abrasive particles and polymer consist low viscosity and has a good capability for abrasion. It removes the layer thickness of material in range of 1 to 10 µm. It can achieve best surface finish in the range of 50 nm [3].

Due to Industrial revolution, manual work has been replaced by machines in many of the industrial processes.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

AFM minimizes the surface roughness up to 75 to 90 percent on machined surfaces and the surfaces being cast. AFM has its need to increase surface quality, enhance high cycle fatigue strength, increase air flow, extend component life, increase engine performances, improve fuel economy and reduces emissions, reduce product cost, and increase throughout production. AFM process has a wide range of applications in field of aerospace, automotive, medical components etc. It is also capable of removing the recast layer from the surface developed after EDM process. AFM process can finish surfaces in the range of 0.05 micrometer [4], removes burr of holes of minimum size of 0.2 mm, radiusing edges from 0.02 to 1.5 mm [4]. It saves 90% time in finishing operation as compared to hand finishing operation [5].

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

2. TYPES OF AFM

AFM process is classified in three cateogries, one way AFM, two way AFM and Orbital AFM but normally two way AFM is used for commercial application.

ONE WAY AFM

One way AFM process as shown in figure.1 consists a hydraulically actuated piston and media collecting chamber having capability of receiving and pressurizing the media to flow in a single direction towards the inner surface of workpiece. Fixture makes the media to flow through the extrusion medium chamber to the internal passage of workpiece surface. The material extruded out from the internal passages is collected by medium collector.

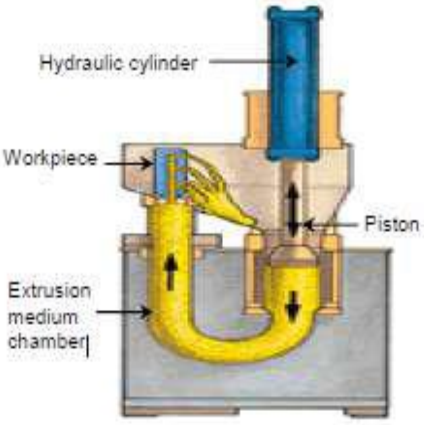

Figure1.Shown operation of One way AFM [6]

It has advantages such as faster cycle processing, easy clean up, media temperature control generally not required, able to process larger parts, simpler tooling and part change-over. The disadvantage associated with One way AFM is poor process control and radius generation.

TWO WAY AFM PROCESS

In two way AFM, there are two hydraulic cylinders and two media cylinders as shown in figure 2. The abrasive media is extruded in the forward and backward direction through the restrictive path generated by the workpiece and tooling arrangement with the help of difference of pressures employed between two opposite cylinders. When the media passes from restrictive path of the hollow workpiece, material from work piece is removed by abrasion action.

The piston is used to pressurize the media presented in the cylinder to flow in the forward or backward direction on the basis of pressure differences in the hydraulic cylinders. Workpiece is abraded by the abrasive laden medium align co-axially with media cylinder with the help of fixture.

The movement of media from top hydraulic cylinder to the bottom and vice- versa makes a cycle [7]

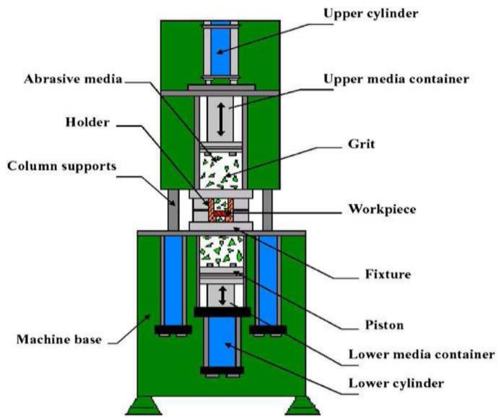

Figure 2. Shown Two way AFM [8]

This type of AFM has advantages of excellent process control and faster change-over of media.

ORBITAL AFM

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

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

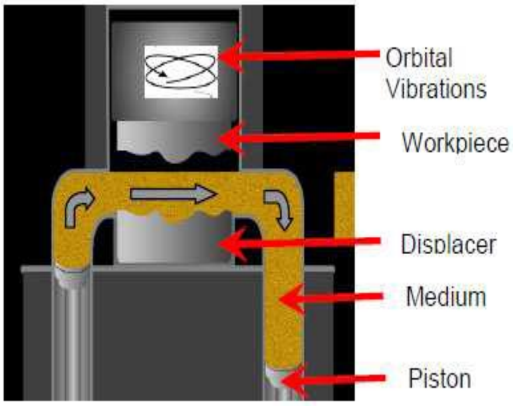

Figure.3. Operational set up of Orbital AFM before start of finishing [3]

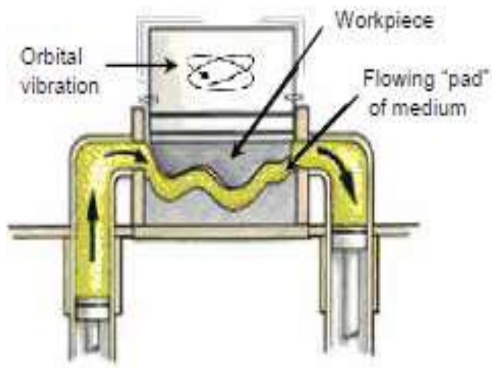

Figure.4 Set up of Orbital AFM while finishing [3]

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

This process has a limitation of low material removal which made researchers to hybridize the process by clubbing the process with other nontraditional techniques such as magnetic AFM, Ultrasonic assisted AFM, Rotational AFM, Electro-chemical assisted AFM etc.

Rotational AFM increased the radial force acting on the surface and improved the material removal by increasing the impact force developed by the abrasive particles [9-11].

Magnetic assisted AFM improved the contact area between the abrasive particle and wok surface. This process used magnetic abrasive particles with a electromagnet coil. Whenever the dc supply is given to the electromagnet it develops a magnetic field which attracts the magnetic abrasive particles towards the workpiece surface [12-14]. Williams and Rajurkar found the media viscosity as the significant parameter towards surface roughness [15]. Gorona et. al [16] found from the experiment that better surface finish is achieved at larger grain size of abrasives and abrasive concentration. Kenda et. al [17] finished EDM generated surface by AFM process and observed tensile residual stress on the surface and compressive stress below the surface. Walia et. al [18] used a CFG rod in the media flow path which generated a centrifugal force in the media flow path and increased the dynamic abrasive particles. Sankar et. al [19] used a drill bit in the media flow path which directed the media to flow through the flutes of the drill and increased the active abrasive particles.

Brar et. al. [20] developed Electro chemical assisted AFM and remove the surface material by the chemical action. The researcher used this process for cylindrical workpiece. Singh and Walia [21] developed Centrifugal and Magnetic assisted AFM and remove the material by magnetic and centrifugal effect both. Venkatesh et.al [22] finished bevel gear using Ultrasonic assisted AFM process and observed increase in active abrasive grain particles. Mohammadian et. al [23] used Chemical abrasive flow polishing for Inconel 625 and found this feasible for finishing. Chaneac et. al [24] used laser melting mechanism for the finishing of non heat treated maraginig steel 300 and observed that media viscosity and abrasive concentration affected the areal roughness. Bremerstein et. al [25] calculated the wear of abrasive particles in the media and found that using continuously the same media decreased the surface quality up to 20 percent. Walia et. al [26] analyzed the stress generated on the workpiece surface using the Finite Element Method. Dabrowski et. al [27] used Electrochemical assisted AFM for flat surfaces and found significant improvement in surface roughness.

Vaishya et. al [28] developed Electrochemical and centrifugal assisted AFM and observed that it saved 20-30 % machining time. Jain et. al [29] calculated the stress generated on the workpiece surface using Finite Element Method and found that stress generated on the impact and media properties did not change with respect to time. Stief and Haan [30] proposed a model and found that stress is induced on the contact of abrasive particle with the finishing surface. Petri et. al [31] proposed a neural network model for polishing using circular and non circular path of media. Ravi et. al [32] observed that voltage has a contribution of 45.35 % towards material removal in case of Electrochemical assisted AFM. Tzheng et. al [33] stated that micro channel formed in EDM consisted recast layer with blow holes which effected the surface integrity. Sushil et. al [34] experimentally found that extrusion pressure and material of workpiece has a significant role in material removal.

Tzheng et. al [35] performed experiment on stainless steel containing micro slits and found optimum conditions at 150 µm abrasive particle size, 50% concentration, 6.7 MPa extrusion pressure and 30 minutes machining time. Wan et. al [36] concluded that if the variation in slip line velocity and wall shear stress is low in cross section then zero order methodology should be used. Mali et. al [37] found abrasive particle mesh size as the significant parameter towards material removal. Marzban et. al [38] concluded using spin motion along the rotary motion of workpiece gave better MRR.

TRENDS IN ABRASIVE FLOW MACHINING (AFM) RESEARCH

Hybridization is a process in which a nontraditional process is used with other machining process to improve the productivity of the nontraditional process. The hybridization of AFM is important to get desired results among the various modern machining processes. In hybridization researchers try to club the advantages and to avoid the adverse effect produced in recent processes. AFM has needed to hybridize to overcome its limitations and to improve surface integrity. The hybridization is also required to improve the system efficiency in less cost and time. So many researchers have successfully hybridized AFM with other machining process.

MAGNETIC ASSISTED AFM

Singh & Shan developed Magnetic assisted AFM in 2002. The abrasive flow machining was hybridized with the magnetic effect to enhance MR and R_a value as shown in figure 5. Singh and Shan [12] developed magnetic field using electromagnet along the complete length of the hollow workpiece and observed significant improvement in the MR and R_a value. On applying the magnetic field around the workpiece surface, it requires reduced amount of cycles for removing more material. This process gave better MR and R_a value for brass workpiece material at higher value of magnetic flux density and low media flow rate. In this hybrid machining the magnetic abrasive particle are used for abrasion. The ferromagnetic particles are sintered with less grain size abrasive particles.

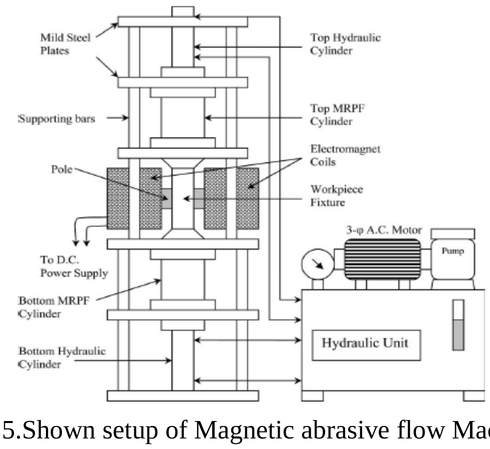

Figure.5.Shown setup of Magnetic abrasive flow Machining [12]

The magnetic field holds the abrasive particles in the restrictive path and acted as a binder. The normal component of magnetic force causes penetration on the finishing surface. Material is removed in the form of small chips. The result shows increase in material removal with the magnetic field.The best results of material removal was obtained at 0.4 tesla magnetic flux density [39].

CENTRIFUGAL FORCE ASSISTED AFM

Walia. et. al [40], developed CFAAFM process to enhance the material removal and surface finish and used a media having low viscosity. The researchers rotated different shapes of tiny rod at the centre of media flow path to develop centrifugal force. The researchers also used CFG rod for rotating the media which causes intermixing of grains and more number of active abrasive particles interacted with the surface. The developed centrifugal force acted in normal direction to the axis of the work piece [40]. Material removal occurs due to erosion mechanism due to more interaction of the abrasives particles with the finishing surface.

The increase in the material removal occurs due to increase in active particles in the media [18], Figure 6 shows the figure of an centrifugal force assisted AFM. It consisted two media cylinders which were mounted opposite to each other in vertical direction having pistons. Media cylinder stores the abrasive-laden media and hydraulic cylinders pressurized them to flow due to pressure difference. [18]. The work piece fixture consists three parts with the rotating attachment. The researchers observed 62 % improvement in active abrasive particles by using low viscosity media in CFAAFM process. Using a high viscosity media, no considerable change was observed in active grains density. On increasing the low viscosity media average increase in surface roughness was observed as 64.45 %, and in material removal was 69.40% respectively as compared to AFM [40, 41].

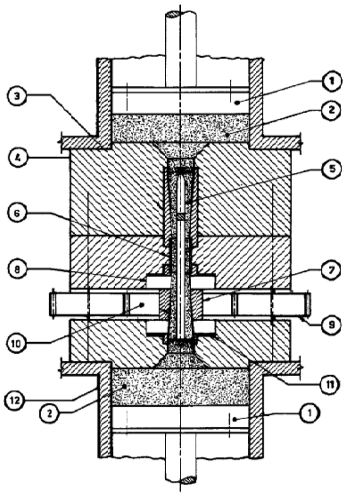

Figure 6 -Shown a CFAAFM setup:[42]

ULTRASONIC AFM

Ultrasonic assisted abrasive flow machining is a hybrid technique in which ultrasonic range vibrations are provided to the surface in normal direction [43]. It used a high frequency vibration of 5- 20 kHz and low amplitude vibration of 10-50 μm. This frequency and amplitude of vibration was supplied to the surface by a piezo-actuator and designed fixture. This vibration improves the relative velocity of abrasive particles by which they impact on the work piece [44]. The velocity of the work piece is higher in comparison of the velocity of the abrasive particles, which makes considerable increase in active abrasive grain density. This also adds an additional radial force during the process.

DRILL BIT GUIDED AFM

Ravi Sankar et.al. [19] developed Drill bit guided AFM by using a drill bit in the media flow path. This improved the material removal and surface integrity as shown in figure 7.When the media flows along the helical path, this makes abrasive particles to move in a random manner in the media. This causes more number of active grains interacting with the workpiece surface. The researchers observed that the abrasive traverse path was longer in comparison to the AFM abrasive traverse path in every cycle. This increases the finishing rate in DBG-AFF. It was observed that on decreasing the drill bit diameter, material removal decreases. It was found from the experiments that using drill bit guided AFM for AISI 1040 and AISI 4340, gave better results in comparison of conventional AFM [19].

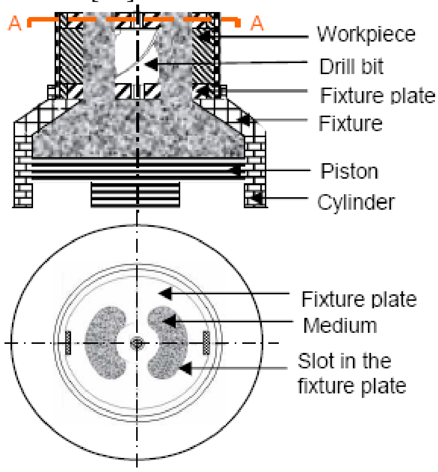

Figure.7. Sectional front view of tooling and top view of medium [19]

ROTATIONAL AFM

Rotational abrasive flow finishing has the similar principle as CFAAFM process. The difference between the both is the use of CFG rod in the media flow path in CFAAFM to generate the centrifugal force. In Rotational AFM, the work piece was rotated using a suitable setup as shown in figure 8. The workpiece is rotated along with the extrusion pressure on the media. This causes increase in abrasive action and hence increases the material removal. It consists four main components, named as machine frame, rotational arrangement, tooling, hydraulic cylinders and media [9]. Rotational AFM can give 44% better surface roughness and 81.8% better material removal in comparison to conventional AFM process. It can also be used for producing micro cross hatch pattern on the finished surface which improved the holding capability of lubricant [45].

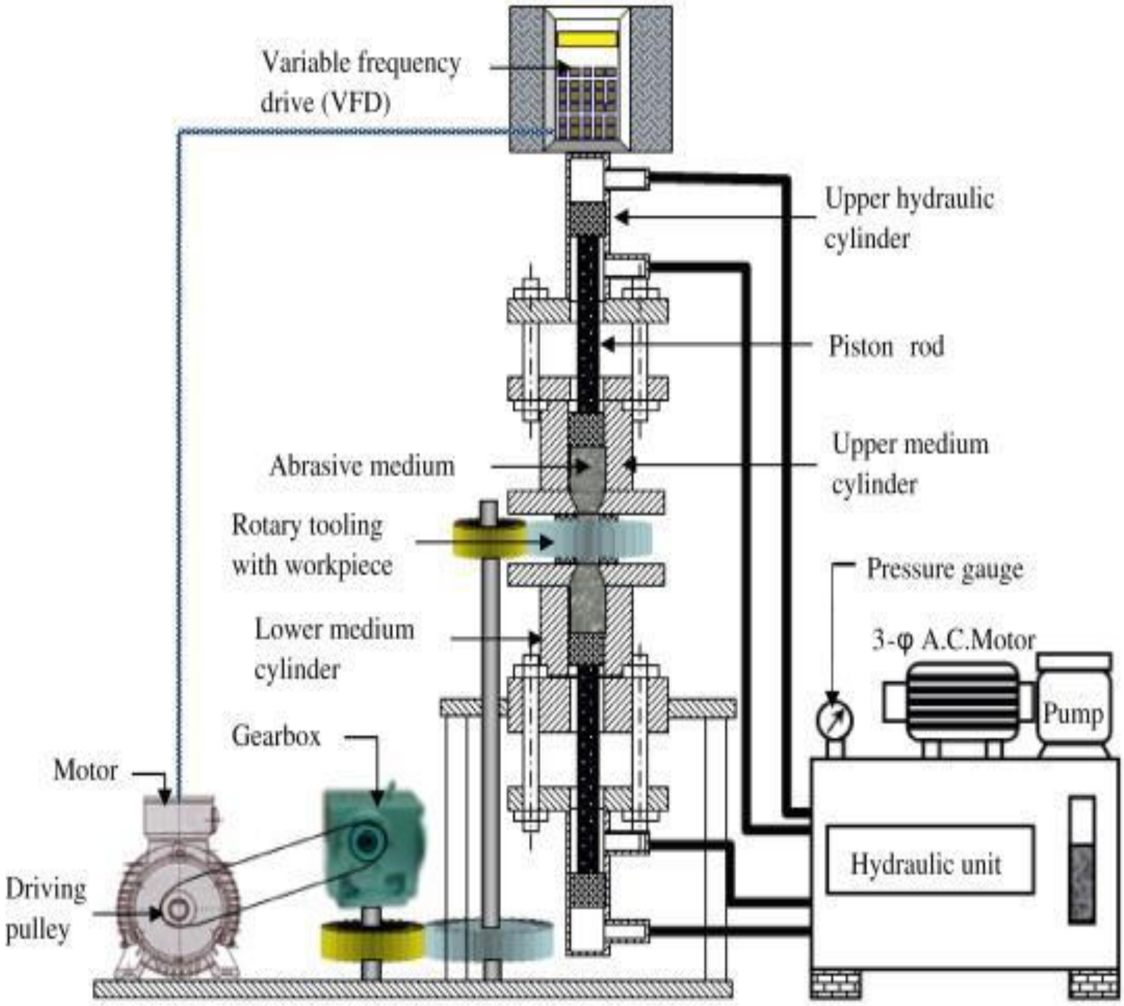

Figure.8- Shown a Rotational AFM setup [45]

ELECTRO CHEMICAL ASSISTED AFM

Electro-Chemical aid AFM was developed by Dabrowski et al. [46 & 27] in 2011. The researchers used this process for the finishing of flat surfaces while Brar et.al. used this for cylindrical surfaces. This process is a combination of AFM and Electro- Chemical Machining process and is termed as Electrochemical Assisted Abrasive Flow Machining (ECAAFM) as shown in figure 9. This process improved the material removal at very low pressures. The process uses an axially held electrode considering as cathode and work piece as the anode. As the media having salts and abrasives, flows between the both poles, work piece is machined due to the abrasive action and electrochemical action which resulted increase in material removal. Voltage is the significant parameter in electro chemical aided AFM. Voltage affects material removal and R_a value both. On increasing the voltage, more material removal and better surface finish was achieved. At larger voltage, surface becomes rough because of more material electrolytic dissolution which resulted in the deeper scratches on surface at 10V. This process produces 87.43% improvement in surface roughness on brass material [47].

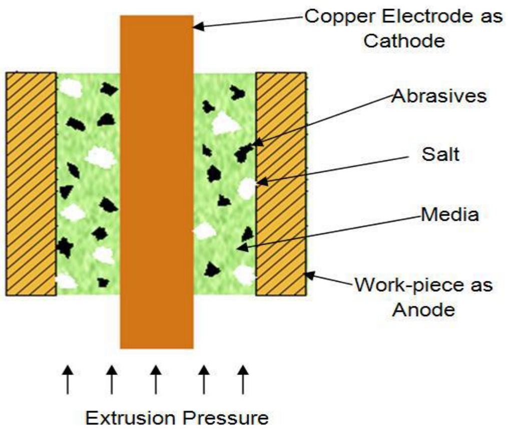

Figure.9-Shown the basic principle of (ECAAFM) process.[46]

HELICAL AFM

Helical AFM process as shown in fig 10 is a simple process and did not use any additional power drive. It uses a drill bit co-axially with workpiece which forces the media to flow in a helical path.

In Helical AFM, the drill bit is made stationary and media is pressurized to flow through the restrictive passage [48], so that it increases the active grains interacting with the finishing surface corresponded better surface finish and material removal. Status of the Helical drill bit, media pressure, media flow rate and number of cycle affects the material removal. The helix shape contributed 78.89% and number of cycle contributed 6.70% towards the material removal. Walia et.al [49,50] observed that same conditions on rotating the different shape rods and drill bit in the media flow path. This resulted 10 and 2.35 times increase in material removal while helical AFM process gave 2.66 times material removal in comparison to the conventional AFM process. Helical AFM process improved the surface roughness in the range of 2 microns [48].

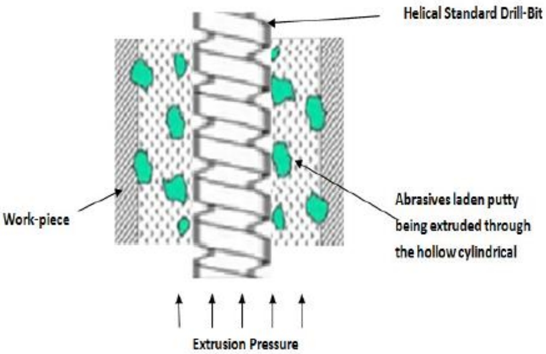

Figure.10-Shown a Helical AFM setup [48]

3. CONCLUSION

AFM is an important technique having wide applications in different areas. This process replaces the conventional finishing techniques. AFM process has a constraint of low material removal which requires hybridization to increase the process productivity by clubbing it with other processes to take advantage of other machining process. AFM has a wide range of applications in finishing of intricate shapes and complex edges. Much hybridization are done in AFM but still there is need for some more hybrid process to enhance the system efficiency. The most important part of this technique is the media, one of the areas in which there are lot of scope for future work which lies is in finding new and cost effective media.

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