Innovations in Different Abrasive Flow Machining Processes: A Review

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Abstract: With advent of need for fast productivity in terms of material removal and surface roughness of the workpiece, abrasive flow machining (AFM) process is gaining rapid importance in the industries. In this process, the fine finishing of the internal surfaces is done that are difficult to reach spaces using abrasive laden polymer media. The media is extruded past the surface under high pressure with the help of two sets of extrusion piston cylinder arrangements. In this paper, various innovations done in the field of abrasive flow machining have been studied in detail in a tabulated form. It included the applications of the process and the different variant forms of AFM process. Due to addition of external forces in variant of AFM process, high speed machining is obtained with smoother surface integrity. Hence it can be concluded that this form of non-conventional machining process is efficient both in terms of surface roughness and material removal.

Keywords: AFM, modelling, media, polymer

1. Introduction
In abrasive flow machining process, nano level finishing of the surfaces is obtained which results due to abrading action of the grains embedded in media. The media is flown two and fro past the work surface. The process is basically of three types namely one way, two way and orbital process. Various variants of the process comprise helical AFM, rotational, electrolytic AFM, etc. The type of drill bit and the extrusion pressure of the machine decides the force by which abrasive particles strike the surface in helical AFM while in rotational AFM process, centrifugal force results in more removal of material. The AFM process is mainly divided into three parts, i.e.

(a) Machine
(b) Tooling
(c) Process input parameters of AFM

Its applications can be diversified into pharmaceutical, chemical, production, automobile and aeronautics industry, etc. Nanotubes find applications as additives to various structural materials so an attempt is made to use of nano particle (CNTs) as abrasive with the carrier and Al2O3 to machine the cast iron workpiece. Nano particles have extraordinary properties over available abrasives, so to enhance MR and surface finish nano particles can be used.
2. Elements of Abrasive Flow Machining (AFM) Process:

There are various elements included in the AFM process. The abrasive media determines the type of abrasion occurring, the fixture determines its exact location and machine decides the extent of abrasion as the abrasive particles are responsible for direct material removal action on the surface and fixture is responsible for holding the work piece against the flow of abrasive particles. The type of drill bit and the extrusion pressure of the machine decides the force by which abrasive particles strike the surface.

2.1 Fixture

The uniform results are obtained in processing of parallel restriction on the process. By using fixture the flow passage part is included in tooling thereby external and internal edges of workpiece can be easily machined by AFM process.

2.2 Abrasive media

The non-Newtonian polymer base media is used, 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. The different mesh size abrasive particles, having limited life and generally the ratio of 2 to 12 is taken for abrasive particles and base material. Machined parts should be properly cleaned before use, by acetone. In order to obtain the media rheological and flowability characteristics, the different additives are added. The lubrication purpose in polymer media is fulfilled by the hydrocarbon gel. All additives are carefully blended in predetermined quantities to obtain consistent formulation.

2.3 Machine setup

In AFM machine setup, hydraulic system to provide extrusion force, clamping fixtures and two sets of cylinder piston arrangements are used. The media flow rate, abrasion limit and extrusion pressure are determined by the AFM machine. Standard units operate within 10 bar to 200 bar pressure range with flow rates up to 400 liters/minute. The clamping and unclamping of fixture and tool, media volume flow rate and hydraulic pressure controls are provided, in addition, for controlling temperature of media, viscosity, programmed microprocessors are installed on the machine setup. The vertical double acting AFM machine setup has been depicted in fig.1. Several accessories such as part cleaning stations, automatic flow timers, automatic media lubricant replenishment, and media heat exchangers units may also be integrated to the conventional AFM systems.

![Figure 1. Vertical double acting AFM machine setup.](image-url)

Finishing operation is not only time consuming but also very costly process. In some cases, finishing operation is done manually. The manual finishing is replaced by AFM machine and standardization is
done and increasing the abrasive particles concentration in the media results in more effectiveness of the process. The different innovations made in the field of AFM process are tabulated as shown in Table 1.

| S.No. | Topic                                           | Work done                                                                                                                                 |
|------|------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| 1    | Magnetorheological abrasive flow finishing (MRAFF) process [1] | The principle of MRAFF process and the pressure, number of cycles effect on Ra is studied.                                               |
| 2    | Ellipsoidal particles’ pattern movements in AFM [2]   | The ellipsoidal particles movement on the basis of equivalent circle is analyzed. It includes sphere particle modelling, prediction of 2-D ellipsoidal particle in relation to rotation angle. Further oblate sphere approach along with movement of ellipsoidal particle in 3-body abrasion is analyzed. |
| 3    | Bevel gears finishing [3]                           | For finishing bevel gears, AFM simulation is done and experimental procedure based on Taguchi analysis is done. Then effect of parameters on roughness is analyzed followed by optimality check and surface morphology. |
| 4    | Magnetic pole arrangement study in Magnetic Abrasive Machining [4] | Effect of surface finish w.r.t. abrasive mixing ratio, dry and wet processing conditions, spindle speed and magnetic pole arrangements is studied in detail. |
| 5    | MR fluid rheological characterization [5]            | Magnetorheological polishing fluid rheological behavior, characterization and experimentation along with capillary magnetorheometer design is done. The results of rheological properties’ variation with SiC mesh sizes and magnetic flux density are analyzed in detail. |
| 6    | Surface roughness modelling and simulation in MRAFF process [6] | In this the chain structure and unit cell modelling is done, forces are analysed and surface roughness simulation is done. |
| 7    | Fine finishing of Al/15% SiC-MMC [7]                | Here, response characteristics-based parameters optimization, ANOVA for material removal, Ra and improvement in Ra, development of mathematical models and SEM examination is done. |
| 8    | Micro channel surfaces finishing by AFM using self modulating abrasive medium [8] | In this paper, effect of media concentration, size, machining time on media viscosity is studied. In addition, abrasive mesh size, machining parameters, abrasive concentration, extrusion pressure, machining time effect on surface roughness is analysed. The wearing of abrasive on grain before and after AFM is done and shape precision is increased. |
| 9    | Temperature and specific energy determination in AFM [9] | The material removal mechanism, forces and specific energy, transfer of thermal energy in AFM process and media thermal properties evaluation is done. |
10 Steel pipe cleaning technology in AFM [10] Here cleaning of steel pipes was done using abrasive flow machining process.

11 Polymer abrasive gels development [11] In this the effect of abrasive polymer gel properties, its effect during up and down cycles, abrasive concentration, mesh size is studied. Further, surface situation after AFM is studied and abrasive medium durable properties are analyzed.

12 Micro-hole design and simulation in AFM [12] Here system designing is done, parts options, system power design is done. The process equipments key structure design including abrasive cylinder, common rail pipe fixture, AFM equipment overall structure design was done. Then finite element analysis of the components, common rail part modelling and simulation is achieved. Further entrance and exit condition exchange simulation, separate branch machining and four branch synchronous machining simulation is also done.

13 Twin flapper nozzle valve injector hole prediction system in AFM [13] Here processing parameters and quality interactional relationship including grinding index, pressure, abrasive mesh size is analysed. The prediction model for injector nozzle, RBF network design, its training algorithm, sample data obtaining and pre-processing s done followed by network learning and system realization and experimental validation.

14 Laminated tooling conformal channels sealing and finishing using AFM [14] In this PEL tooling, conformal cooling, its design specimen and then leak testing is done. Then material removal statistical analysis and 3-D surface profiling is done.

15 MMCs nano finishing using AFF process [15] The pressure, processing oil and cycles effect on surface roughness and MR is analyzed.

16 Polishing and equipment study of AFM process [16] In this abrasive flow technology, polishing fluid, application and characteristics of abrasive flow, polishing equipment, micro hole flow polishing device is studied. In addition, polishing fluid preparation and micro hole surface roughness testing is done.

17 Mould softness structural surface machining using AFM [17] The softness abrasive flow math model includes volume fraction equipment, additional scalar equation, turbulent kinetic transport equation, dissipation rate transport equation and boundary equation re studied. In addition, model calculation, initial conditions and grid division is studied.

18 Butyl rubber based media rheological characterization and performance evaluation for AFM process [18] In this the experimental work included materials like abrasive, visco-elastic carrier, processing oil, metals used and the measurements include AFM setup, two-roll mill, pneumatic cutter, hydraulic press, AR 1000 rheometer and Ra tester.
Then Ra was used to evaluate media, characterization of media and creep testing was done.

19 Rheology study of abrasive gel and its finishing behaviour in AFM [19]

In this paper, the finishing geometry is studied and coefficient of power law and simulation results of velocity, pressure, shear rate and shear forces is analyzed in detail.

20 Complex holes uniform surface polishing [20]

In AFM process of complex holes, power law usage with and without mould core of chain hole, chain hole with two cylinders and chain hole with chain shape core is studied and analyzed in detail.

21 AFM of micro slit fabricated by wire-EDM [21]

The machining time and media viscosity relation is analyzed using signal to noise ratio, ANOVA and shape of surface and form of micro slit after wire EDM process is analyzed. In addition, the effects of temperature, abrasive particle concentration and extrusion pressure on roughness of workpiece is studied.

22 Ultrasonic assisted AFM (UAAFM) process [22]

Here material removal mechanism is understood in detail, along with machine setup, media and workpiece preparation, measurement and characterization. Then process parameters are selected for regression analysis and the finishing through AFM and UAAFM processes are compared. Afterwards X-ray diffraction analysis and SEM of machined surfaces is done.

23 AFM application in gas turbines [23]

In this paper, it was found that abrading was highest where media velocity was greatest. The turbine applications included airfoil polishing, edge radiusing and removal of thermal recast surfaces.

24 Polygon holes helical passageways AFM study [24]

Here, material property, internal helical motion, and simulation results including helical grooves different numbers, helical passageways on square, hexagonal, octagonal hole effects were studied and compared with the corresponding experimental results.

25 CFD simulation and process modelling in AFM [25]

In this, modelling methodology approach of media flow governing equation, abrasive media rheology model, material removal model, wall slip model are built and then extraction of model constants and the equations solutions are obtained. Then extracted models, experimental and simulated setup results are compared.

26 Surface roughness and material removal modelling [26]

Media flow modelling constituting basic continuity i.e., mass conservation equations, non dimensionalization, formulation of finite elements and boundary equations were generated. Then modelling of both MR and roughness was done.
27 Surface roughness prediction simulation in magnetic AFF process [27] Here mathematical modelling including governing equation, modelling of machining pressure, material removal and surface roughness is done followed by experimental validation.

28 AFM process modelling on ceramic materials [28] In this the technological investigation of the process in simple structures, complex structures surface formation and process model was developed.

29 AFM modelling and energy efficiency [29] The AFM of gear manufacturing, novel AFM upgrade to AFM mm was done followed by energy efficiency of both processes and geometrical and fatigue results.

30 AFF of stereolithography prototypes [30] Here rapid prototyping of stereolithography is done and flatness and other results were recorded along with scanning electron microscopy and data dependent system analysis.

31 New nozzle AFM machine tool [31] Here the nozzle AFM tool mechanism of working and its control algorithm comprising flow coefficients, intelligent control algorithm, control system development platform and control system software is generated.

32 Small hole abrasive flow ultra precision polishing technology [32] In this study the AFM equipment and clamp was designed and media was prepared and the process parameters i.e. extruding pressure and extruding range and time were measured.

33 Micro hole AFM based on Delphi language [33] The motion control method of AFM was based on system design, software design and experimental test results.

34 Plastic gear matrix polishing using AFM [34] It included CFD analysis of process, and surface roughness experimental results included gear tooth face profile, prediction models, plastic gears lifespan tests and analysis.

35 Work efficiency monitoring using temperature in AFM [35] Here data comparison between AFM machine and test rig was done and effect of extrusion cycles, media viscosity on MR and Ra was studied.

3. Outcome Discussion
In conventional machining process there is direct tool and workpiece contact and the condition of cutting of material from work surface is that tool hardness must be more than that of workpiece hardness. But AFM process falls under the category of non-traditional machining process where abrasive laden media under high pressure results in abrading of work surface. Since the usage of different types of newly developed media is done, hence new tremendous results were obtained in terms of removal of material. Further the innovations in the field of hybrid AFM process utilizing magnetic, electrolytic and centrifugal forces obtained high accuracy of finish and rapid production rate. Lesser extrusion cycles and low voltage input parameters in rotational AFM process resulted in same output results as compared to conventional process. In addition, mathematical models developed by various scientists helped in improving the prediction of forces involved and the output MR and Ra results.
4. Conclusion
It can be concluded from the above review of AFM process that it is a non conventional method of material removal that results in faster removal and helps in better surface finish on the products. The highly precision work requirements are fulfilled by this process. The efficiency of AFM process can be improved by making it hybrid i.e., combining the traditional process with other processes like electrochemical, helical, rotational forces etc. Even the addition of magnetic force in case of AFM process resulted in higher material removal but in this case either the magnetorheological fluid has to be prepared or iron particles have to be added in the polymer media. Further modelling and simulation of the process has been done successfully by various scientists. Different process parameters have been selected and used to obtain optimized results in terms of output response, viz. Material removal and roughness.

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