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Review article

The Trend of Research in Abrasive Flow Machining

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A B S T R A C T

Review of this article about AFM. The objective is to find trends and gaps in research and development in the AFM production process. From researching related articles it consists of 5 steps: Step 1. They are researching research on AFM. Step 2. Screening redundant articles. and are not directly related. Step 3. Analysis of important issues such as primary variables, scope, workpieces, abrasives, and dependent variables. Step 4. Trends in each area of research and development. Step 5. Summarize the results from 73 articles from various journals. AFM finds applications in various industries, including aerospace, automotive, medical devices, molds and dies, and precision manufacturing. It is employed for achieving high-quality surface finishes, deburring internal passages, improving aerodynamic performance, enhancing fluid flow characteristics, and optimizing the functionality of critical components. The advantages of AFM include its ability to finish complex internal surfaces, remove burrs and imperfections, and achieve precise control over surface finish. AFM offers a non-contact and non-thermal machining method, which minimizes the risk of damage to delicate workpieces and preserves their dimensional accuracy. AFM has become a valuable tool in industries that demand precision and enhanced surface quality. Further research and development in AFM will continue to expand its applications and optimize its capabilities.

Can be grouped into 6 main groups: Group 1 is a research study that works on a one-way, two-way AFM machine, etc. Group 2 has the addition of workpiece rotation. Group 3 has done a simulation and compared it with the experiment. Group 4 adds a magnetic field to help. Group 5 studies abrasives mixed with polymers and carriers, and Group 6 uses ultrasonic to help.

Here are some potential research gaps or trends in AFM: 1) Optimization of Process Parameters Surface Integrity and Material Property Analysis 2) Further research is needed to understand the impact of AFM on the surface integrity and material properties of different materials. 3) Modeling and Simulation. 4) Advanced Media Formulations 5) Sustainability and Environmental Considerations 6) Hybrid Machining Approaches. 7) Real-time Monitoring and Control.

1. INTRODUCTION

1.1 Abrasive Flow Machining (AFM)

Previous studies have examined the effects of different AFM process parameters such as the number of cycles, the concentration of abrasive, abrasive mesh size, and media flow speed. Material removal and surface finish have been studied as important processes, including the concentration of abrasive followed by the mesh size of the abrasive number of abrasive cycles, and abrasive flow rate. High-precision abrasive flow machining consists of two subsystems: a high-viscosity media; the range of between 150-1,000,000 centipoise as a viscos-elastic plastic media (a semisolid polymer composition) and a low-viscosity media; 1-50 centipoise as a liquid abrasive slurry, including abrasive suspended or slurried in fluid media by cutting fluids of honing fluids, consisting of a thixotropic slurry plus a rheological additive and finely divided abrasive particles incorporate therein.

Abrasive flow machining (AFM) is a nontraditional machining process that removes material from a workpiece by flowing an abrasive media through the workpiece under pressure for finishing and deburring complex internal passages or cavities in various materials. A semi-solid abrasive media is forced through the workpiece under pressure to remove unwanted material and improve surface quality. The media, which consists of a viscoelastic polymer mixed with abrasive particles, is forced through the workpiece using hydraulic pressure. The media's abrasive particles help remove material and achieve the desired surface finish. AFM is commonly used for finishing internal passages and complex geometries that are difficult to access through conventional machining methods. It is widely applied in aerospace, automotive, medical devices, and mold-making industries. Some specific applications of AFM include deburring, edge radius, polishing, and improving surface finish.

The theory behind AFM involves the flow behavior of the abrasive media and its interaction with the workpiece. Here are a few key points:

1. Rheology: The abrasive media used in AFM consists of a viscoelastic compound, often a polymer-based carrier mixed with abrasive particles. The rheological properties of the media, such as viscosity and elasticity, play a crucial role in achieving effective material removal and surface finish.
2. Tooling Design: AFM utilizes specially designed tooling, typically consisting of a pair of cylinders or cones with channels or grooves. These channels facilitate the controlled flow of the abrasive media through the workpiece. The design of the tooling is critical in ensuring uniform distribution of the abrasive media and achieving desired results.
3. Pressure and Flow Rate: The pressure applied to the abrasive media and the flow rate through the workpiece are key parameters in AFM. The pressure helps in forcing the media into the internal passages, while the flow rate determines the speed at which material is removed. Optimal pressure and flow rate need to be carefully selected to avoid overloading or underloading the workpiece.
4. Material Removal Mechanism: The abrasive particles suspended in the media act as cutting tools, gradually wearing away the material as they flow through the workpiece. The combination of shear forces, abrasive wear, and the viscoelastic behavior of the media contributes to material removal.

5. Surface Finish Improvement: AFM is known for its ability to improve surface finish by removing surface irregularities, burrs, and other imperfections. The controlled flow of the abrasive media helps in uniformly smoothing the internal surfaces of complex geometries, resulting in enhanced part quality.

Certainly, here are some literature and references related to Abrasive Flow Machining (AFM):

1. "Abrasive Flow Machining: Principles and Applications" by Shivraj B. Bhosale and Vijay M. Kore - This book provides a comprehensive overview of AFM, including its principles, applications, and process parameters. It also discusses the latest advancements and future trends in the field.
2. "Abrasive Flow Machining: Fundamentals and Applications" by M. Kanthababu - This book covers the fundamental aspects of AFM, such as material removal mechanisms, process parameters, and tool design. It also includes case studies and practical examples of AFM applications in various industries.
3. "Abrasive Flow Machining: A Review" by Dr. R. Ramachandran and Dr. V. Jeyapaul - This research paper provides an in-depth review of AFM, including its history, working principles, process parameters, and applications. It also highlights the advantages and limitations of AFM compared to other machining processes.
4. "Abrasive Flow Machining of Complex Internal Surfaces: A Review" by Dr. K. Senthil Kumar and Dr. R. Ramanujam - This review paper focuses on the application of AFM for machining complex internal surfaces, such as internal cooling channels in turbine blades and molds. It discusses the challenges and strategies for achieving the desired surface finish and dimensional accuracy.
5. "Experimental Investigation and Optimization of Abrasive Flow Machining Parameters" by Dr. S. A. Chavan and Dr. V. S. Nadgir - This research paper presents an experimental investigation of AFM parameters, such as abrasive concentration, flow rate, and pressure, to optimize the material removal rate and surface finish. It also discusses the effects of different variables on the machining performance.

To lead to the development of ideas for further development of AFM machines. who want to use knowledge in engineering design, and development Conceptual Design in Abrasive Flow Machining involves the initial phase of planning and creating a framework for the machining process. Here are some key considerations for the conceptual design in Abrasive Flow Machining:

1. Define the objectives: Clearly define the goals and objectives of the machining process. This may include surface finishing, deburring, polishing, or improving dimensional accuracy. Understanding the desired outcome will help guide the design process.
2. Material selection: Identify the material to be machined. Different materials may require specific abrasive media and parameters. Consider factors such as hardness, viscosity, and flow characteristics to determine the appropriate abrasives for the process.
3. Component geometry: Analyze the shape and complexity of the component to be machined. Consider the internal passages, intricate features, and surface areas that need to be addressed. This information will help determine the appropriate tooling, fixture design, and abrasive flow pattern.
4. Flow medium selection: Choose the suitable flow medium, typically a viscoelastic compound, that will carry the abrasive particles during the machining process. The medium should have the desired viscosity and flow properties to effectively reach all areas of the component.
5. Tooling design: Design the tooling system that will hold the component and allow the abrasive flow to pass through. Consider factors such as tooling material, flow channels, and sealing mechanisms to ensure proper distribution of the abrasive medium.
6. Process parameters: Determine the appropriate process parameters such as pressure, flow rate, and cycle time. These parameters will affect the material removal rate, surface finish, and overall efficiency of the machining process.
7. Safety considerations: Ensure that proper safety measures are in place during the abrasive flow machining process. This may include protective equipment, containment systems, and proper ventilation to minimize hazards associated with the abrasive media.

When it comes to engineering design in AFM, there are a few important considerations to keep in mind:

1. Geometry and Accessibility: The design of the workpiece should allow for the flow of abrasive media through the desired internal features. Complex geometries with intricate internal passages may require careful planning to ensure proper flow and desired results.
2. Material Selection: The choice of material for the workpiece is crucial as it should be able to withstand the abrasive media flow without any significant damage. Compatibility between the workpiece material and the abrasive media should be taken into account to avoid any adverse reactions.
3. Flow Control: The design should incorporate features that help in controlling the flow of abrasive media through the workpiece. This can include the use of channels, restrictors, and valves to regulate the flow rate and pressure, ensuring uniform material removal and consistent surface finish.
4. Tooling and Fixturing: Proper tooling and fixturing are essential for holding the workpiece securely during AFM. The design should consider the accessibility of the internal features for the tooling, as well as the ability to apply the necessary pressure for effective material removal.
5. Surface Finish Requirements: The desired surface finish should be defined in the design specifications. This will help in determining the parameters for the AFM process, such as the type and size of abrasive media, flow rate, and pressure. The design should ensure that the AFM process can achieve the desired surface finish within the given tolerances.

2. APPROACH OF AFM STUDIES

The methods used in this study consisted of Step 1. Researching research on AFM. Step 2. Screening redundant articles. and are not directly related. Step 3. Analysis of important issues such as primary variables, scope, workpieces, abrasives, and dependent variables. Step 4. Trends in each area of research and development. Step 5. Summarize the results.

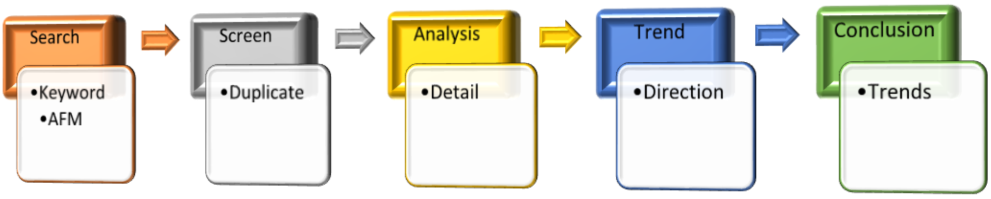


Fig. 1. Review methodology.

Some general guidance on finding journals that publish articles related to Abrasive Flow Machining (AFM). To identify journals that publish research on AFM, can consider the following steps:

1. Consult Databases and Directories:
   - Check relevant academic databases such as Scopus, Web of Science, or Google Scholar.
   - Utilize search filters to narrow down results to journals specific to manufacturing, machining, or precision engineering.
   - Explore directories such as the Directory of Open Access Journals (DOAJ) for open-access options.
2. Review Relevant Publications:
   - Look for recently published articles or reviews on AFM to see which journals are commonly publishing research in this field.
   - Note the journal names and consider their reputation and impact factor.
3. Seek Recommendations:
   - Seek recommendations from colleagues, mentors, or experts in the field of manufacturing, machining, or precision engineering.
   - Attend conferences or workshops related to these fields where researchers may share insights on publishing venues.
4. Analyze Journal Metrics:
   - Once you have identified potential journals, assess their impact factors, quartile rankings, or other relevant metrics.
   - These metrics can provide an indication of a journal's reputation and influence within the research community.

2.1 Research Paper

Journal articles on AFM from various databases 73 Articles Found. The articles are summarized in order of the year of study. And can be grouped into 6 main groups: Group 1 is a research study that works on a one-way, two-way AFM machine, etc. Group 2 has the addition of workpiece rotation. Group 3 has done a simulation and compared it with the experiment. Group 4 adds a magnetic field to help. Group 5 studies abrasives mixed with polymers and various carriers. And Group 6 uses ultrasonic to help. And summarize the number of articles from 1998 to 2023 in Table 7 and Figure 59.

3. REVIEW RESULTS

3.1 Development of AFM

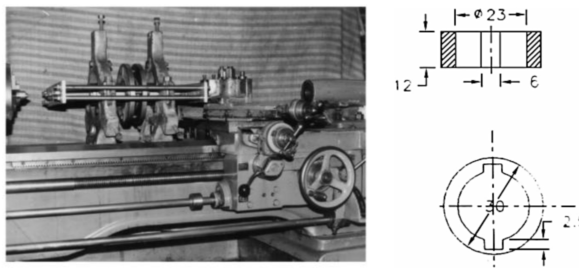
Group 1 is a research study that works on a one-way, two-way AFM machine, etc.

From a review of articles focused on AFM. The most basic is the development of a machine with a unidirectional grinding system. and bidirectional by studying variables such as pressure, abrasive powder size, resin materials, brass, aluminum, and workpieces with different shapes. Changes were found in AFM studies and SL with the resin workpiece [1-3]. To find variables based on surface smoothness. Metal content removal rate and take pictures with a camera Using the least amount of time. Experimenting with brass and aluminum materials Complex-shaped workpieces used in various industries by varying the number of polishing passes. Abrasive concentration Grain size of abrasive powder and flow rate to find the dependent variable the difference in surface smoothness values. Metal removal rate and mathematical models [4-7]. Experimental investigation into cutting forces and active grain density during AFM. The variables of interest are Cutting force and active grain density. controllable variable: extrusion pressure, abrasive concentration, and grain size) 23 full factorial experimental technique Disc dynamometer for measuring axial and radial force components during AFM extrusion pressure: 4 to 8 MPa, mesh number: 80, 220 concentration: 40, 60%. Dependent variables were material removal (MR), reduction in surface roughness (Ra value), cutting forces, and active grain density) and photographed with SEM [8-12]. Experiments were carried out with collet spring specimens. Chromium-molybdenum material to remove small edges of the workpiece to study the dependent variable is the deburring rate. Use silicon and alumina abrasive powder, size 80 mesh, abrasive mixed with polymer at a ratio of 1:1 by weight, with a low viscosity of 1900, and medium size of 2400 [13,14]. And there has been a study of workpieces that have been cut with EDM into small slots. Analyzed using Taguchi's method. Important variables were studied: size of abrasive powder, abrasive concentration, pressure, and polishing time. with stainless steel workpieces to find the answer for the dependent variable is Surface roughness value regardless of temperature There is a three-dimensional image display [15-19]. In 2008, an experiment was conducted on polishing aluminum and EN8 components. To find improvements in surface roughness and creep. Study the flow properties variables and evaluate the performance results. Number of polishing cycles Use silicon carbide (SiC) abrasive powder size 80, 220, 400, 800, and 1200 mesh mixed with the naphthenic oil polishing compound [20-26]. In the same year, an investigation was made by comparing the experimental results between AFM and FEM. To find the response of pressure and number of polishing cycles of brass workpieces (62% Cu, 2% Pb, and balace Zn) to determine the rate of workpiece removal and surface finish 330 μm silicon carbide abrasive, 56% by weight, pressure of 20 to 60 bar and number of polishing passes 5 to 25. [27,28]. In 2009, the SKD11 complex drill hole; the chain hole of the punched mold, was studied and CFD programming method was used. Silicone gel polishing compound Medium viscosity, abrasive number 100, abrasive concentration 50%, working temperature 27 degrees C, pressure 400 psi. To study the dependent variables, namely surface roughness, speed ratio, and strain of the abrasive [27-31].

In 2012, a study was conducted to determine surface roughness. and residual stress. The variables of interest are Viscosity of the abrasive, abrasive powder size of 80 mesh, abrasive concentration of 57% at a pressure of 3.5, 6 MPa, abrasive time of 1800 seconds, tested with workpieces AISI D2, 59 HRC, SR: Ra: 1.67 μm that had passed through an EDM machine [32-34].

One-way interrupted flow was studied. To find the surface roughness value that has been improved surface quality. and the reduction of residual stress in the AISI 4140 workpiece, considering the axial force at 15 polishing cycles, higher piston pressure will lead much faster to the desired surface finish and tolerance is a critical design parameter [35,36]. AFM, FEM, CFD, and Taguchi Method Study the compression pressure (15 bar), size of abrasive powder (100, 150, and 200 mesh), polishing time (5, 7, and 9 min.), and flow rate of abrasive substance (567, 796, and 995 cm^3/min). and initial surface roughness before polishing (SR: 1.4 to 1.8 μm) Experiment with EN8 gear workpiece to determine the improved surface roughness value. and the rate of metal removal [37-39]. The wear of SLM specimens was studied. To find the surface roughness value Metal removal rate. The workpiece material has a hardness of 209 HV and a surface roughness starting at 8 μm with Rheological and granulometric characterization methods [40-45]. In 2018, there was an AFM study. The initial variable was 250 cycles in AFM with LV50%-150. 55 bar (MV35%, 50%, and 65%) 36 and 56 HRC, 200 cycles Material: Selective laser melting (SLM); mold industry Ra: about 10 μm Abrasive: High-concentration Media (MV65%-150) The dependent variable is Ra [46,47]. In 2018, an AFM study was conducted. with AM aluminum alloy parts (AISI10Mig) to find surface roughness Residual stress Metal removal rate and take photos with SEM Silicon carbide abrasive powder, 20-80 mesh, 45% polymer mixture, applied pressure 2 Mpa, initial SR: 13-14 μm [48-50]. And in the same year, there is an experiment with the workpiece. To find the dependent variables, namely surface roughness, residual stress, and edge rounding value, with flow rates between 7000 and 16000 mm/s, microhardness boreholes, diameters 4 and 9 mm, length 4 times 50 mm and 1 time 200 mm [51-54]. In the year 2019, study AFM, the primary variable is surface integrity. rubbing, plowing, and cutting. Pressure: 55 bar (5.5 MPa) and a media flow volume of 50 inches per stroke for 150 cycles. The depth 0 to 140 μm workpiece is a 15-5PH stainless steel internal channel surface. Boring Big abrasive grains (54 grit size) MV65%-150 medium grit size and the highest concentration of the dependent variables are Topography and Srru, SR, residual stress (MPa) [55].

In 2020, there was an AFM study. And shows the mathematical equation for the difference in surface roughness and PISF (percent improvement in the surface finish), which determines the primary parameters: the number of polishing passes (20, 40, and 60), the force used (800 kgf), the temperature (32 °C), and the volume of the abrasive flowing through the workpiece (200 cm^3). Experiment with ring-shaped cylindrical aluminum alloy pieces and the max. % improvement SR: [56-61]. AFM studies were performed on SLM specimens (internal channels by selective laser melting). To find the surface roughness value, XRD was performed and SEM photographs were taken of the workpiece that had been sintered into Wrought bars [62,63]. In 2023, three studies were conducted with different workpieces: first, AFF, a copper workpiece made from ADAM (additively manufactured nano-finish) using abrasive visco-elastic hydrogel (Siloxane, natural or synthesis elastomers, thermoplastics polymers, a cost-effective, eco-friendly, and biodegradable. The dependent variable is the Surface roughness value and the rate of metal removal [64-69]. AFF experiments with helical gear micropre diameter: 4, 6, 8, and 12 mm. Size: length: 40 mm, width: 40 mm, height: 10 mm. to determine the Improved gear surface quality and higher microhardness resulting from the AFF process also improves the gear tooth surface's wear properties [70]. And finally, an AFM experiment with AISI 304 micropre diameter: 4, 6, 8, and 12 mm. Size: length: 40 mm, width: 40 mm, height: 10 mm. Cassava starch medium, Fine finishing A fine finish on the internal surface. Shear thickening polishing slurry (STP-s). Numerical simulation. The polishing agent used is the polyborosilixane mixed with SiC to find the dependent variable: Finished surface roughness value Metal removal rate photographed with AFM: atomic force microscope [71-73]. Details are shown in Table 1. AFM review: One-way, Two-way, and others.

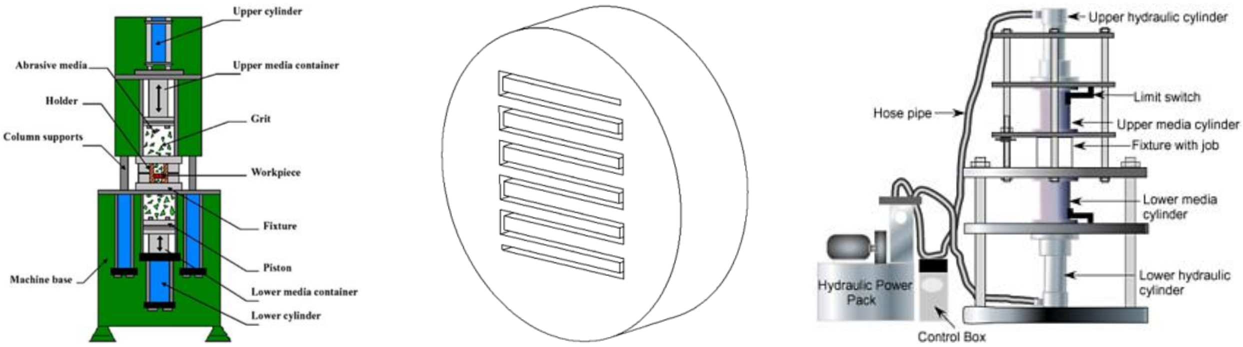


(a) (b)

Fig. 2. (a) The setup is mounted on an LB-17 HMT lathe and (b) workpiece [7].

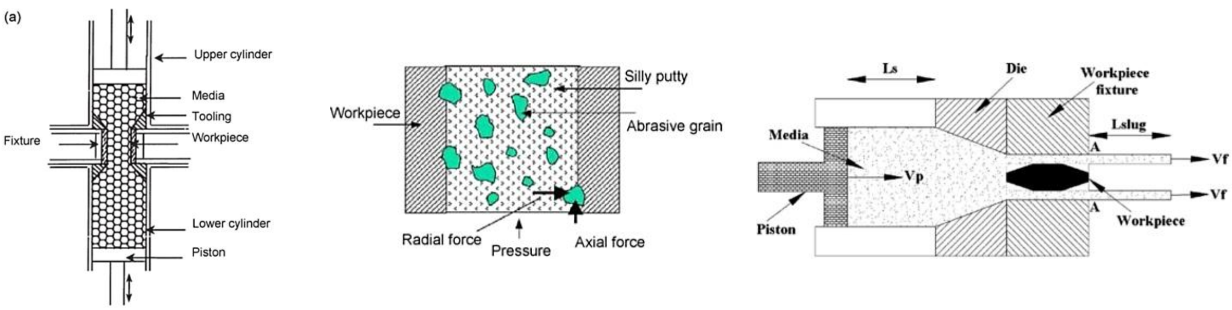
(a) (b)

Fig. 3. (a) Deburring process of spring collet and (b) AFM system [14].



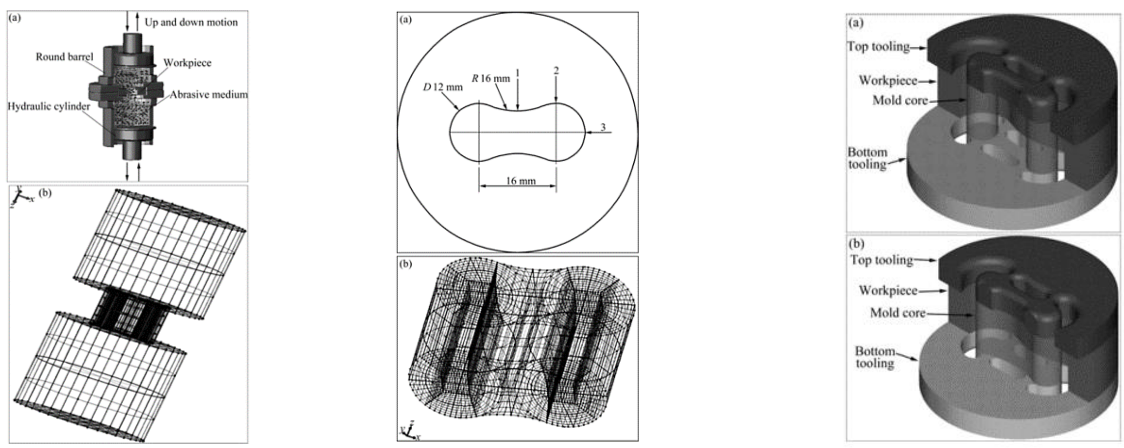
(a) (b) (c)

Fig. 4. (a) Schematic diagram of experimental apparatus and microchannel (b) Workpiece [19], (c) Diagram of laboratory fabricated AFM set-up [26].



(a) (b) (c)

Fig. 5. (a) Schematic diagram (b) types of forces acting, and (c) Slug length [28].



(a) (b) (c)

Fig. 6. (a) AFM (b) Workpiece, and (c) Workpiece Assembly [31].

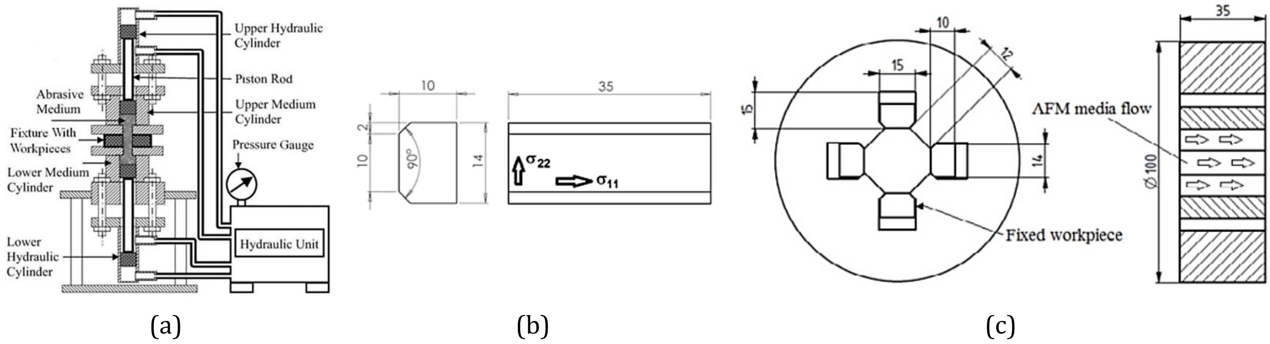


Fig. 7. (a) Two-way AFM (b) Workpiece (c) Fixture with workpiece [34].

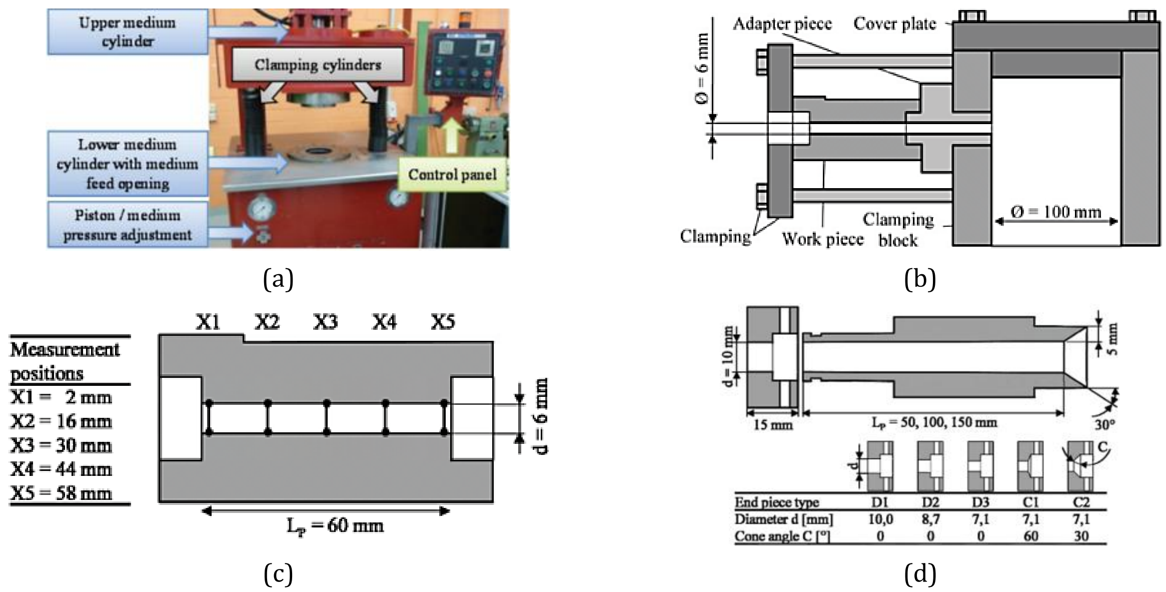


Fig. 8. (a) ExtrudeHone AFM (b) Flexible clamping block (c) Workpiece [36].

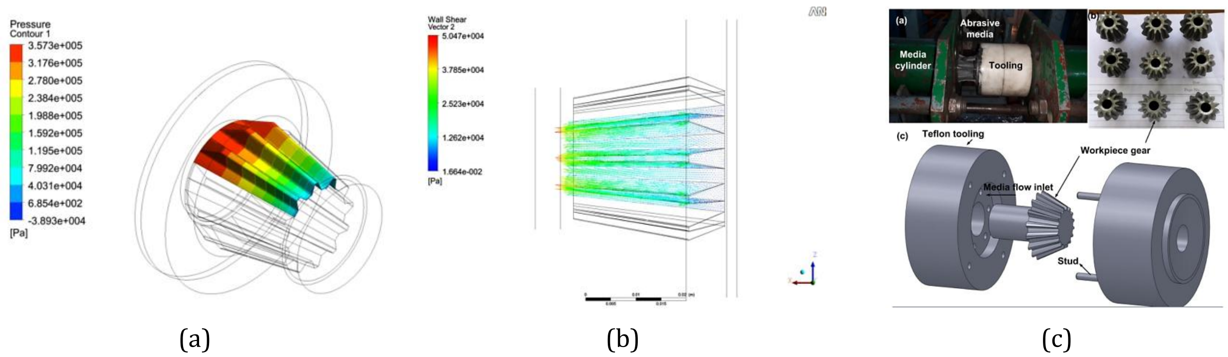


Fig. 9. (a) Dynamic pressure distribution (b) Wall shear distribution (c) Workpiece [39].

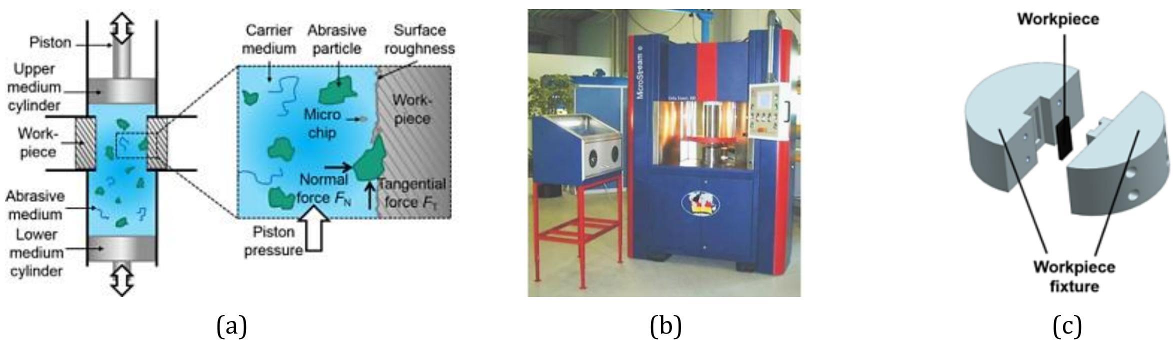


Fig. 10. (a) Two-way AFM, (b) ExtrudeHone machine, (c) Workpiece [45].

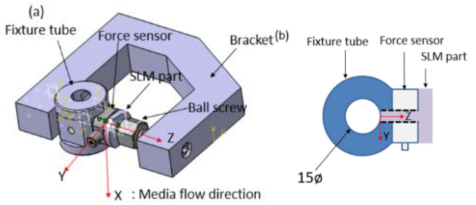
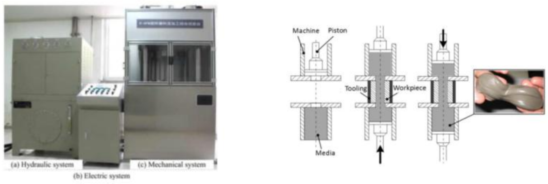
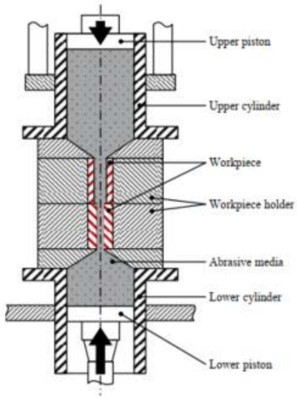


Fig. 11. (a) Assembled parts in AFM, (b) SLM parts, (c) Fixture tools [47].

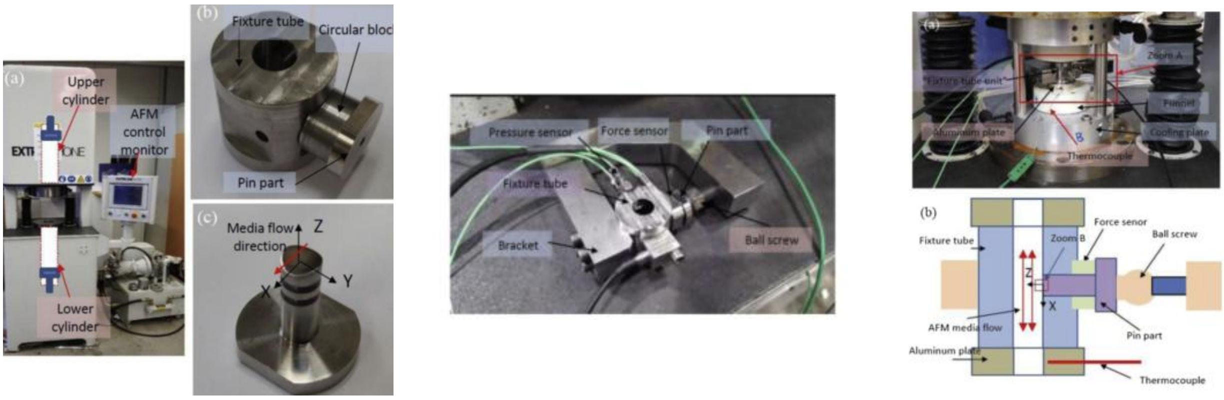


(a) (b)



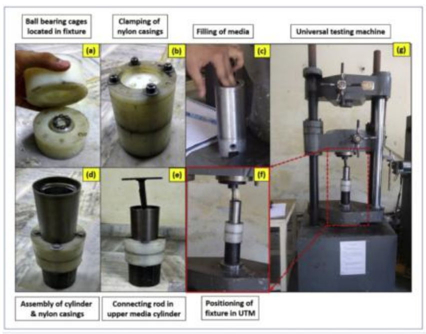
(c) (d)

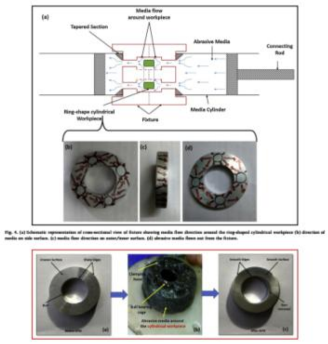
Fig. 12. (a) AFM (b) Principle of AFM [50] (c) Machining Technology (d) Workpiece [51].



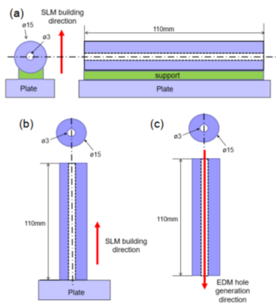
(a) (b) (c)

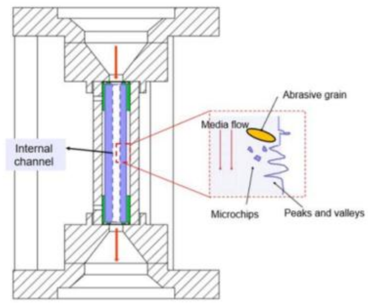
Fig. 13. (a) AFM and 15-5P11 Stainless steel, (b) Fixture and Sensor, (c) Adapter [55].





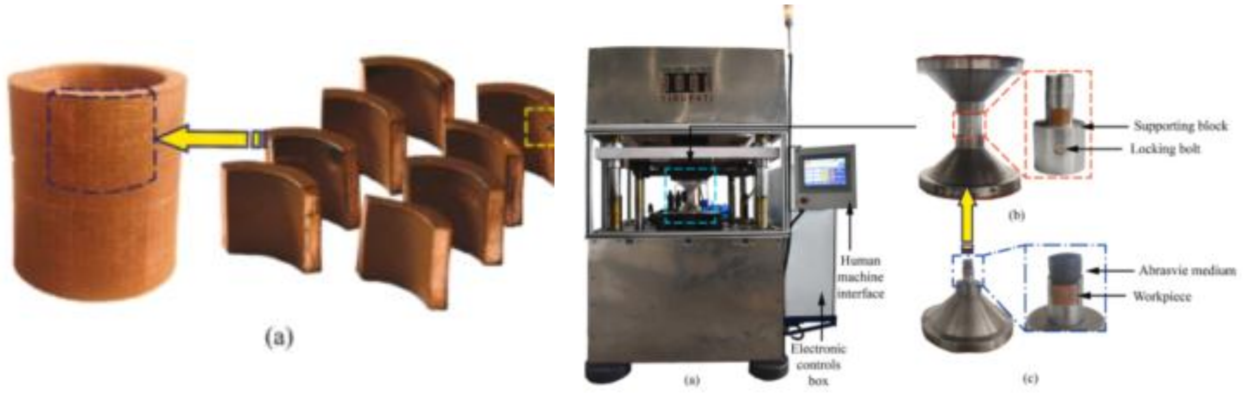
(a) (b)





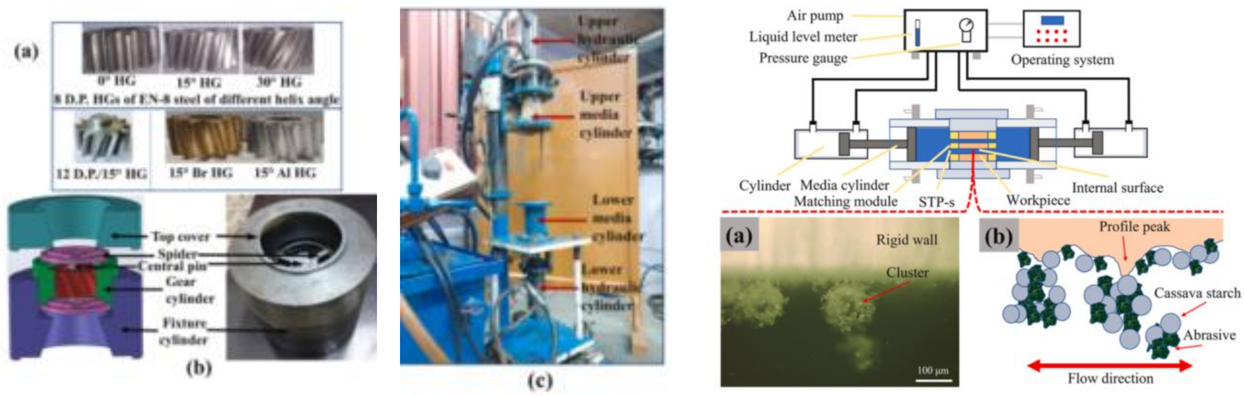
(c) (d)

Fig. 14. (a) AFM, (b) Workpiece [61], (c) SLM, EDM, (d) AFM channel [63].



(a) (b)

Fig. 15. (a) Workpiece (b) AFF setup, fixture, and abrasive medium [69].



(a) (b) (c)

Fig. 16. (a) Workpiece (b) Fixture (c) AFM [70] (d) Two-way AFM [72].

Table 1. AFM review: One-way, Two-way, and others; an example of 22 articles.

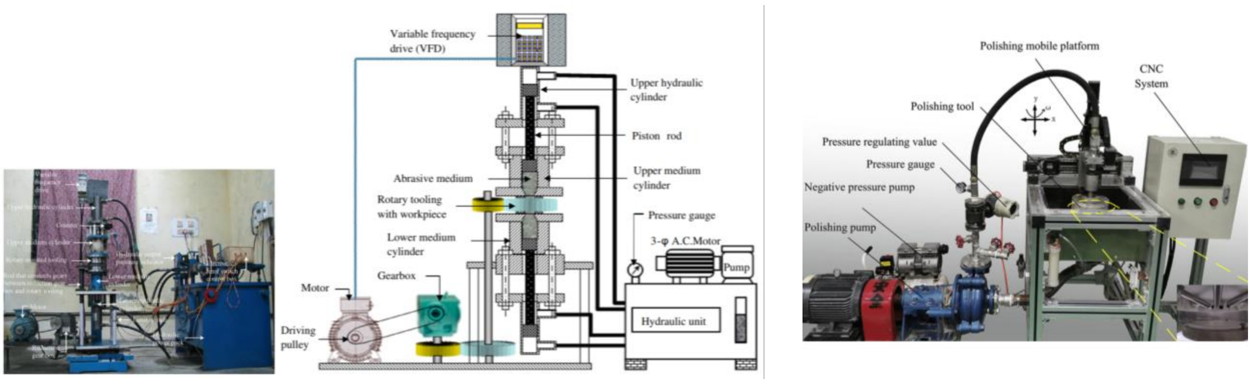
Reference	Changing	Parameters	specimens	Abrasive media	Responses	Inference
AFM						
Robert E. Williams, Vicki L. Melton, 1998 [3]	AFM and Stereolithography (SL)	Pressure, Grit size, build style, build orientation, and resin type	Resin		Surface roughness profiles. Material removal rate, SEM images	To minimize the time to develop a finished prototype. Pressure, Grit size, and build orientation were significant.
V.K. Jain, S.G. Adsul, 2000 [7]	Experimental investigations into AFM	Number of cycles, concentration of abrasive, mesh size, and media flow speed	Brass and aluminum complex passages aerospace, dies and molds, automotive parts, medical components, etc.	A semisolid visco-elastic/visco-plastic abrasive-laden medium	MR (material removal), ΔRa (surface finish improvement) Mathematical modeling	The dominant process parameters: are concentration of abrasive, mesh size, number of cycles, and media flow speed consequently.

V.K. Gorana, V.K. Jain, G.K. Lal, 2004 [12]	Experimental investigation into cutting forces and active grain density during AFM	Cutting force and active grain density controllable variable: extrusion pressure, abrasive concentration, and grain size) 2^3 full factorial experimental technique	Disc dynamometer for measuring axial and radial force components during AFM extrusion pressure: 4 to 8 MPa, mesh number: 80, 220 concentration: 40, 60%	Silly putty (Dow Corning 3179 dilatant compound; generally used for moulding clay toys: (the viscoelastic behavior of 80% rebound, plasticity of 0.82, specific gravity of 1.14 (at 25 °C) and kinematic viscosity about 20,000,000 cSt (20,000,000 cSt=20m^2/s (in SI units)	on the responses: material removal (MR), reduction in surface roughness (Ra value), cutting forces, and active grain density) SEM	Extrusion pressure, abrasive concentration, and grain size affect the cutting forces, active grain density, and reduction in SR (Ra value)

3.2 Development of AFM: Rotational Workpiece

Group 2 has the addition of workpiece rotation.

The AFM review shown in Table 2 has grouped this group according to the characteristics of the workpiece that is rotated while the polishing machine polishes the workpiece. For example, in 2008, an experiment was conducted with R-AFF (Rotating workpiece Abrasive flow finishing) using powder. Sanded to a size of 6 microns with an initial surface roughness value of 0.4+- 0.1 microns. The semisolid abrasive medium mixture, workpiece hardness 40+- 2 HRA, and metal matrix composite (MMCs) workpiece to determine the surface roughness value. and compare AFM with R-AFF [27]. In 2009, R-AFF experiments were performed with speeds of 2 to 10 rpm and the medium reciprocates (hydraulic actuators). helix angle decreased from 22 to 9 and the helix path length increased from 67 to 160 mm. Complex internal and external geometries Al alloy, Al alloy/SiC, and metal matrix composites (MMCs) Viscoelastic abrasive medium to determine the dependent variables delta Ra and MRR (material removal rate) [32]. And in 2020, it was an experiment: A soft abrasive rotary flow (SARF) polishing process. The experimental workpiece was A large-size K9 optical glass surface. ANOVA, Taguchi method Low damage and ultra smoothness A 6-outlet rotary polishing tool, orthogonal arrays, and the signal. -to-noise ratio (S/A), time: 1.5 h, rotation speed: 10 rpm, use CeO2 Pressure: 0.35 MPa, concentration is 5 wt%, average particle size: 0.7 um to find the dependent variable: Surface roughness value (SR) [60]. Details are shown in Table 2. AFM review: Rotational Workpiece.



(a) (b)

Fig. 17. (a) R-AFF experimental set-up and Schematic diagram of R-AFF set-up (b) Schematic of SARF polishing system [27] [32] [60].

Table 2. AFM review: Rotational Workpiece.

Rotational Workpiece						
Mamilla Ravi Sankar, et al., 2008 [27]	Experimental investigations into the rotating workpiece R-AFF AFF (Abrasive flow finishing)	Average particle size of (6.0 ± 0.5) µm initial average SR of 0.4 ± 0.1 µm	Al alloy/SiC (10%) Al alloy/SiC (15%) metal matrix composites (MMCs) average hardness 40± 2 HRA, 55±3 HRA, 6.0±5 HRA	Semisolid abrasive medium	SR near nano levels ΔRa Compared AFF and R-AFF in term	Can produce 44% better ΔRa and 81.8% more MR compared to the AFF process. Hydrocarbon processing oil from 7.5 to 12.5 wt% and better ΔRa at 10wt%. R-AFF; MR and ΔRa achieved are higher.
M. Ravi Sankar, et al., 2009 [32]	Rotational AFF (R-AFF)	Rotated (speed: 2 to 10 rpm) and the medium reciprocates (hydraulic actuators). helix angle decreases from 22 to 9 and the helix path length increases 67 to 160 mm.	Complex internal and external geometries Al alloy, Al alloy/SiC, and metal matrix composites (MMCs)	Viscoelastic abrasive medium	Low finish (finishing rate) and MR rates (MRR) ΔRa, MR	R-AFF can reduce 44% better ΔRa and 81.8% more MR compared to the AFF process
Jun Zhao, et al., 2020 [60]	A soft abrasive rotary flow (SARF) polishing process Polishing	ANOVA, Taguchi method Low damage and ultra smoothness A 6-outlet rotary polishing tool, orthogonal arrays, and the signal-to-noise ratio (S/A), time: 1.5 h, rotation speed: 10 rpm	A large-size K9 optical glass surface.	CeO2 Pressure: 0.35 MPa, concentration is 5 wt%, average particle size: 0.7 um,	SR	The original value of Ra: 37.28 nm to Ra= 4.51 nm, and SR improves by 87.9%

3.3 Development of AFM: Simulation and Mathematic model

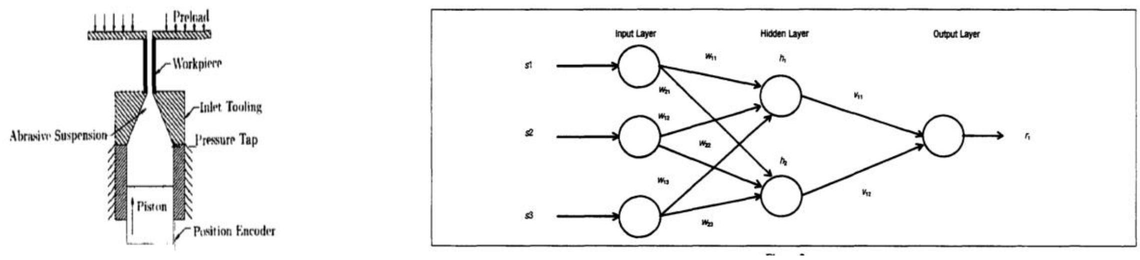
Group 3 has done a simulation and compared it with the experiment.

AFM review: modeling in this subtopic Shown in detail in Table 3 is the part related to with the calculation results using the mathematical model. This makes it possible to predict results reliably. Modeling has been developed for a long time, such as an experiment in 1998 that predicted abrasive wear and studied stress. and shear stress to find the variable is wear performance [1]. In the same year, a neural network process model was studied. The variables studied using the Heuristic search method were process parameters; workpiece, media characteristics, machining, etc., to find the dependent variables. An effective technique for modeling the AFM process. A program that is used is the BrainMaker ProfessionalTM software package, VB, and Pascal

[2]. In the following year, Simulation and experiments (response surface analysis: RSA) were studied. Mild steel (0.25%C) hardness: 2177.80 N/mm2 the primary variables are the Number of cycles, percentage concentration, mesh size, reduction ratio, and extrusion pressure. The abrasive is SiC: silicon carbide. mesh: 50-60, density of SiC: 3220 kg/m3 P: 20-80 bar, %Concentration: 56-76%, N= 5-25 cycles to know the results, the dependent variable is Surface roughness value (SR) and workpiece removal rate (MR) Simulation and RSA are in good agreement [4]. And experimental results A Simple Neural Network for AFM process the effects of machining parameters on MR rate and SR, back-propagation algorithm, theoretical, experimental results, and MVRA (multivariable regression analysis) Training the network with noise-injected inputs Mesh size: 90 to 240% Concen.: 32 to 44 Media flow speed: 40to80 (cm/min) to Find the dependent variables: Surface Roughness (SR), Material removal (MR) [6]. In 2000, Optimum selection; Neural network (NN) approach GA (Genetic algorithm) Simulation NN for modeling and optimal selection; four inputs, two outputs, and one hidden layer were introduced. ALM (the augmented Lagrange multiplier) algorithm NN model prediction for the the AFM process has been confirmed. The optimal input conditions maximize the MRR [8]. A model Heat transfer Theoretical and experimental results the primary variables are Specific energy and tangential forces. Grain size, applied pressure, hardness of workpiece material, number of cycles, and number of active grains DDS (data-dependent system) is a stochastic modeling and analysis technique. The workpiece used is Mild Steel (0.25%C). The variable of interest. is Specific energy (J/mm3) Fraction of heat entering into the workpiece (%) Rise in temperature (°C) [9]. In 2004, a Stochastic simulation model of active grain density Theoretical and experimental studies were conducted. The main variables were SiC, Boron carbide, Aluminum oxide, and diamond. Carrier: polyborosilixane. Initial SR of workpiece: 2.25 µm Hardness WP: 2177.80 N/mm2 A semisolid abrasive-laden compound "media" The dependent variable is the active grain density on the media surface SEM; analysis of the topography of media [13]. In a theoretical model of forces acting on a single grain, the primary variables were the axial force, radial force, and active grain density during the AFM process. Scratching experiment vs AFM Compared with the experimental data of force and active grains during obtained AFM. extrusion pressure: 40, 50, 60, 70, 80 bar Mild steel, SiC, 80# Dependent variables are Force on a single grain Chip formation on a single grain Chip thickness Radial force on a single grain and photographed with SEM [16]. In 2006, another 3 articles were studied in the following order: Parametric optimization, real coded genetic algorithms (GA) AFM, and MAF. Volumetric concentration: 5-50%, mesh size: 4.6-0.008 mm, Number of strokes: 1-100, extrusion pressure: 0.7-25.0 MPa for a nano-level surface finish [17]. followed by an article that studies the Prediction of SR. In the kinematic analysis model; grain vs workpiece the primary variables are Grain size, grain concentration, and extrusion pressure and the dependent variables are the Prediction of: active grain density, radial forces, SR, and Effective grain spacing [20]. Optimization models Genetic algorithms AMPs (advanced machining processes) The variables of interest are Global-optimum or near global-optimum, concept of statistical DOEs, SBX parameter, and polynomial mutation parameter [21]. Simulation for the prediction, Abrasive flow finishing (AFF) Magnetic Abrasive Finishing (MAF) Magnetic Abrasive Flow Finishing (MAFF) The primary variable is Magnetic abrasive flexible brush (MAFB) to find the answer. Magnetic field Machining pressure magnetic flux density of the magnetic brush and workpiece [22]. In 2008, studies were conducted on Neural networks and regression analysis methods Artificial neural networks (ANNs) ANOVA and F-test. The primary variable is Abrasive waterjet machining (AWJ). 13 input neurons, 22 hidden neurons, and 1 output neuron. Taguchi's orthogonal array. The workpiece is AA 7075 aluminum alloy. To find the dependent variables: Surface roughness striation and waviness an initial damage region (IDR), a smooth cutting region (SCR), and a rough cutting region (RCR) and a rough cutting region (RCR), photographed with SEM [24]. In the same year, there was a study of AFM, and CFD (computational fluid dynamics) to predict; a 2D model. The primary variables were Influence factors; temperature, media viscosity, abrasive hardness, particle sharpness, and density, workpiece hardness, pressure, and piston moving speed, etc. The workpieces are AISI 1080, 1045, and A36 steels to find the dependent variables: MR, and SR [30]. In 2009, AFM;

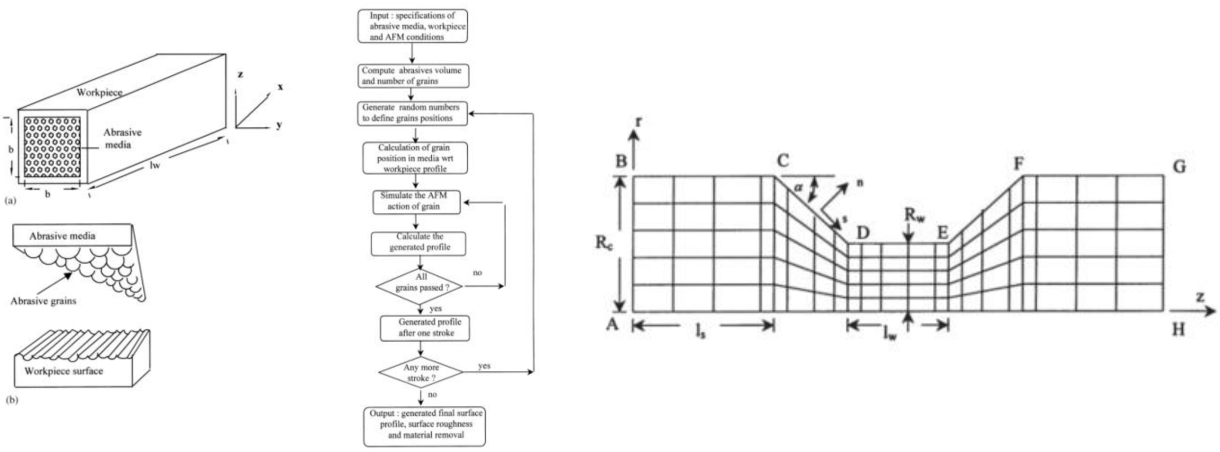
Statistical calculation; and ellipsoidal particles were studied. Particle movement patterns in the AFM process; sliding-rubbing and rolling; elastic/plastic deformation; and grooving (micro-cutting) to know the results Relationship between e/h and μk with varying rotation angle grama in different normal loads [29].

In 2013, there was a study of Simulation, Rheological model. the standard Maxwell model of elastomers and extending it to the Generalized Maxwell model. Modulus G, Frequency, Viscosity The visco-elastic properties of a polymeric carrier, combined with abrasive grains. The dependent variables are MR, and SR [38]. In 2014 studied Model Axial forces of one-way AFM. The main parameters were the piston pressure: which is 28 to 105 bar Grain size: 300-600 μm workpiece: 50, 100, and 150 mm., and a cone of 30 degrees. AISI 4140 (high strength steel) adapter dia. 6 mm. A silicate-based medium; a ready-made high viscous EM24640 medium (polymeric carrier with additives and abrasive grains. Density: 1.9 g/cm3 dependent variables are removal rate, and surface quality [40]. And in the same year, there was a study on Modeling and Energy Efficiency AFM. novelty-movable/Rotating mandrels (AFMmm) Kennametal Extrude Hone Profile 80 polishing m/c tool polishing time 400 to 1500 s Power (W) Tooling Industry WEDM (wire-EDM) AISI H11, 52 HRC initial roughness RA: 0.68 μm convex gear tooth Boron-carbide polishing fluid concentration 57% Viscosity: 2650 Pas Mesh size: 80 Dependent variables are SR micro geometry, Residual stress [41]. The following year, a study of CFD Simulation AFM ANSYS CFX v15 was compared to experimental results. Deburring, edge rounding, and surface quality. non-Newtonian, shear-thinning characteristics of a Maxwell fluid into the inelastic Narvier-Stokes equations the workpiece is an Additively manufactured SLM workpiece. For turbine blades the viscoelastic abrasive medium. The variable of interest is SR [43]. The year 2016 studied Pragmatic modeling in AFM consisting of the following variables: Deburring, Regression analysis borehole length l: 50 mm borehole dia: 4, 6, 9 mm Combinations of stacked cylinders: 4-6-9, 4-9-4 The workpiece is Complex. -shaped automotive components 50CrMo4 (1.7228; 100Cr6 (1.305) The viscosity of the abrasive medium the dependent variable is Edge rounding, mean roughness Ra [46]. In 2019, there was a study of A new predictive method in AFM. near-uniform material removal Pressure and velocity can be determined by CFD simulation; non-Netonian fluids the workpiece is an aero-engine blade; complex components Semi-solid abrasive media (a mixture of styrene butadiene rubber and silicone oil), loose abrasive, and other additives. The dependent variable is the whole surface profile finished [53]. In the same year, A new predictive model in AFM was studied. experimental and predictive (numerical simulation) Profile height variation ΔH and variation trend of mass variation ΔM Pressure: 1.25 MPa and 1.75 Mpa. The Maxwell viscoelastic model (35) Volumetric flow rate: Q1/t1 (L/s): 0.678, 0.464, 0.818, 0.353 The workpiece is H65 copper inserted the grooves. SiC abrasives, butadiene-styrene rubber, and the modifiers. The dependent variables are Profile height variation ΔH and variation trend of mass variation ΔM [54]. Year 2019 Numerical Modeling and Experimental AFM Mass loss, part geometry, and dimensions. CFD (computational fluid dynamics) Max. force of 54kN, 10 rpm (1.06 mm/s), Koll morgen WorkBench s/w (v.1.14) Workpiece is Laser powder bed-fused Ti. -6Al-4v (LBPF-built Ti-6Al-4v parts) LMV-24BCE supplied by Extrude Hone LLC, Boron carbide (~60%), a polyborosilixane polymer (~37%), lubricating greases (≤2.5%), and oleic acid (1%) The dependent variables were Final geometry and surface roughness, MR [56]. In the same year, the Experimentation and modeling of CNT additive abrasive media AFM two-way AFM Micro Finishing was studied. ANSYS and Fluen s/w CNT (carbon nano tube) Taguchai L9 OA compared with Reye-Archard-Khrushchove wear law. P: 11, 22, 33 MPa C: without CNT, 5, 10g, N: 3, 6, 9. Items are Aluminum CNT (carbon nano tube) and Alumina (Al2O3). A non-Newtonian liquid polymer containing nanotubes CNT + Al2O3. Dependent variables are SR, and MR [58]. The year 2020 Prediction and compensation of MR for AFM modeling, CFD simulations A nozzle guide vane (NGV) The two-piece assembly is a laser-sintered part with five blades. (M 290, EOS) and the material is Maraging Steel MS1 (EOS), pressure: 20 MPa, speed: 500 mm/s, time: 15 min. Additively manufactured. (AM) metal components of the 5-blade industrial AFM equipment (EX4250, Extrude Hone Corp.) Piezoelectric cavity pressure sensors (Type 6178A, Kistler) Media: MV36 (Extrude Hone Corp.); grit size: #36 (about 700 μm medium) The dependent variable is MR [59]. In the same year, AFM, Microsphere flow burnishing (MFB) was studied. The primary variables are Mathematical model Quadratic polynomials, Normal force, penetration depth (nm), Grain size, concentration, pressure, and number of machining cycles. The workpiece is a Diameter of less than 1 mm. 2017A aluminum alloy elements Glass microspheres for flow machining the abrasive is A semi-fluid polymer medium. The dependent variable is Surface texture [62]. In 2020, Rheological behavior, and CFD simulation AFM were studied. The primary variables were the Carreau-Yasuda model Navier slipping model. The intense peak value in the creep curve (3.55 Pa-1), shear stress, and normal stress difference. Flow rate: 1.5 m/ s, pressure: 200 psi., machining time: 100s Workpiece is Micro holes dia. 0.3 mm Ni-base wrought super-alloy (GH2132) The turbine blads micro film-cooling holes after EDM/drilling. The abrasives are Soft matrix and dard abrasive grits. the volumetric flow rate is about 7x10-8 m3/s. and the dependent variables are SR, MR, Modulus/Pa, and Relaxation Modulus (Pa). Normal stress and photographed with SEM [68]. And the year 2023 study Theoretical and numerical analysis CFD simulation the volumetric rate of finished nozzles was around 0.824 L/min. The workpiece is a Micro-porous structure, micro spray hole/nozzle. Unique viscoelastic characterization and the dependent variable is Surface topography [71].



(a) (b)

Fig. 18. (a) AFM [1], (b) Typical Neural Network structure [2].

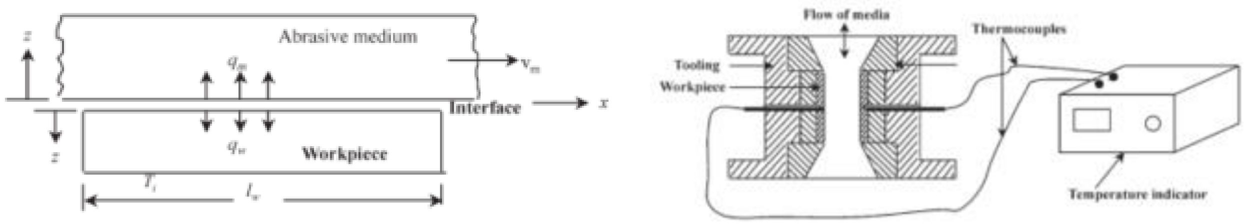


(a) (b) (c)

Fig. 19. (a) Schematic, (b) Flow chart [4], (c) Domain and FEM [5].

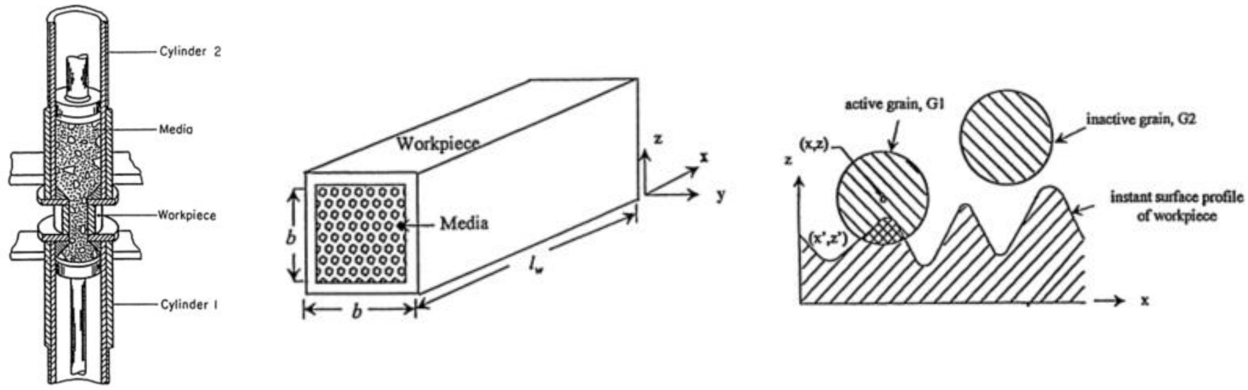
(a) (b)

Fig. 20. (a), (b) Three-layer neural network [6], [8].



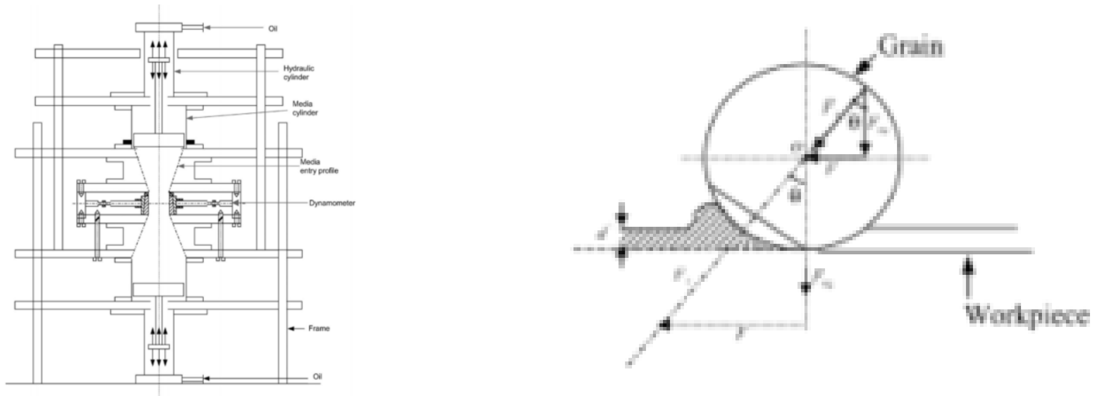
(a) (b)

Fig. 21. (a) Model of AFM zone, (b) Experimental arrangement [9].

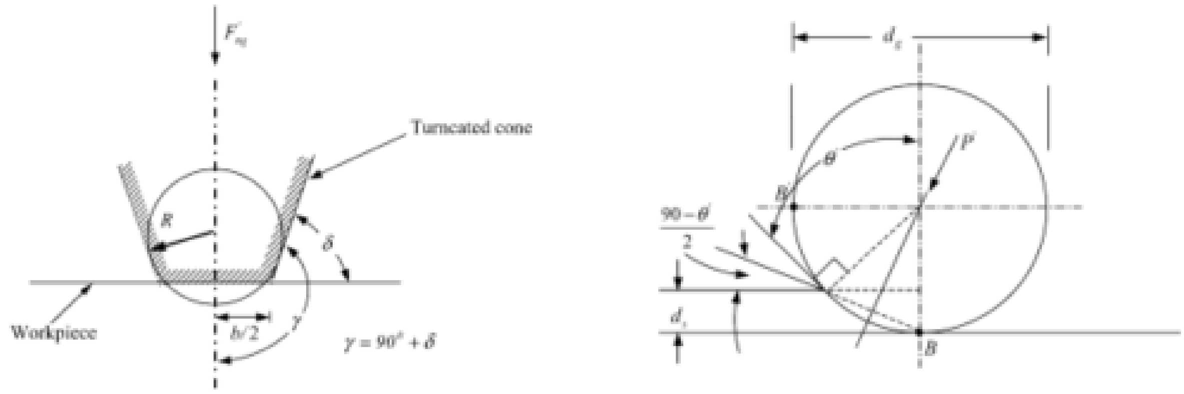


(a) (b) (c)

Fig. 22. (a) Two-way AFM, (b) Media passing, (c) Interaction of an abrasive grain [13].



(a) (b)



(c) (d)

Fig. 23. (a) Schematic diagram of set-up, (b) Depth, (c) Normal load, (d) Grain [16].

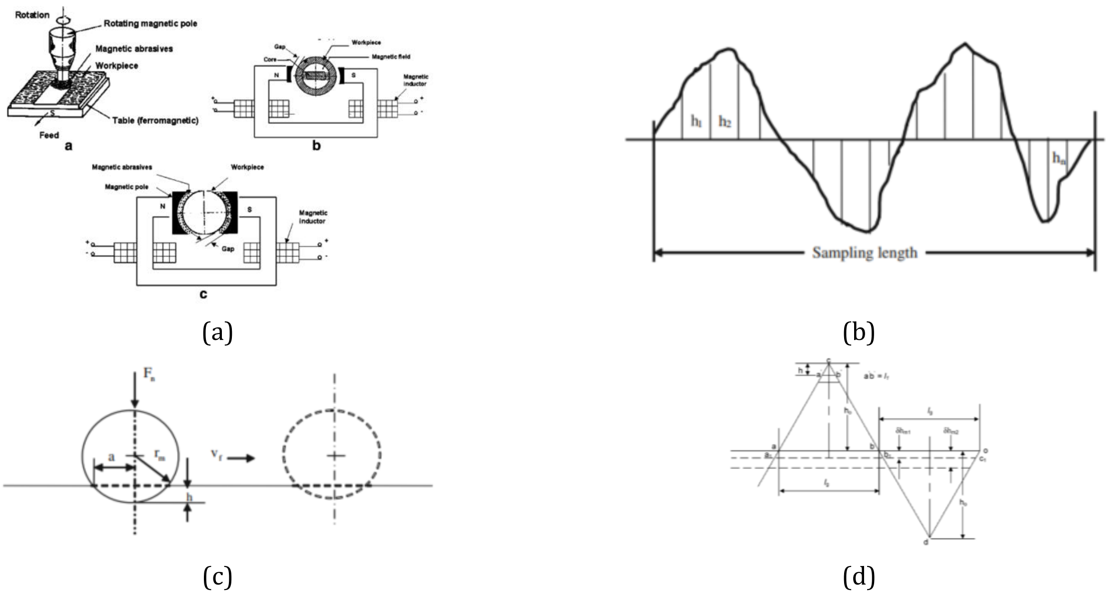


Fig. 24. (a) Scheme of MAF, (b) Internal finishing, (c) External finishing, (d) Concept of measurement of SR, (e) Geometry of indentation, (f) Geometrical of AFM [17].

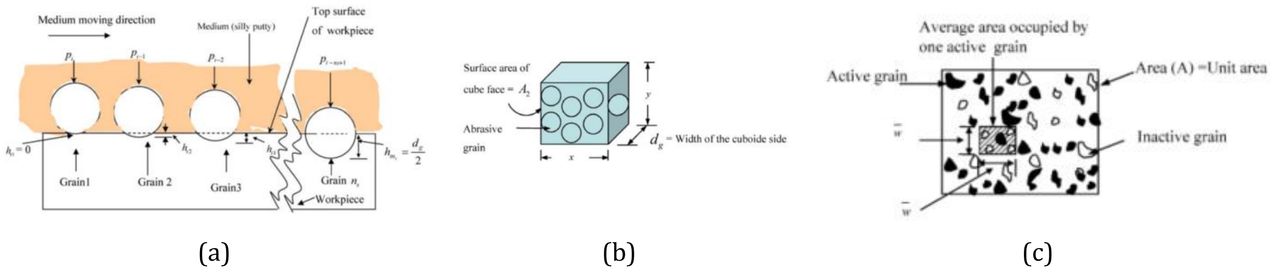


Fig. 25. (a) Model of a part with spherical tips, (b) Element of the medium, (c) Active and inactive grains, (d) Sphere, (e) Effective grain spacing, (f) Equilateral triangle [20].

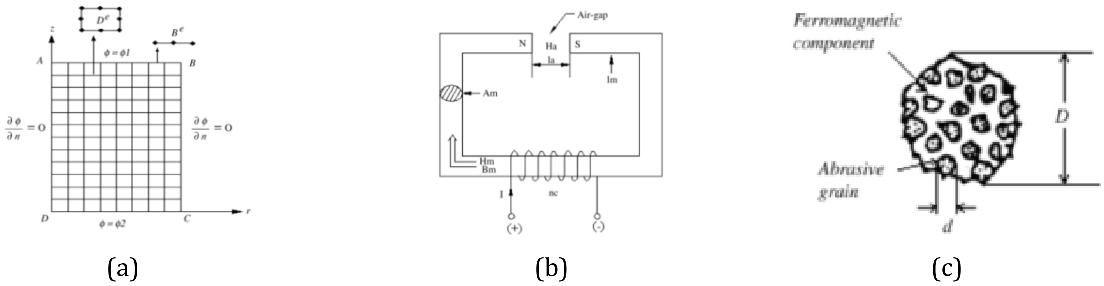


Fig. 26. (a) The axis-symmetric domain, (b) Magnetic circuit, (c) Magnetic abrasive particle [22].

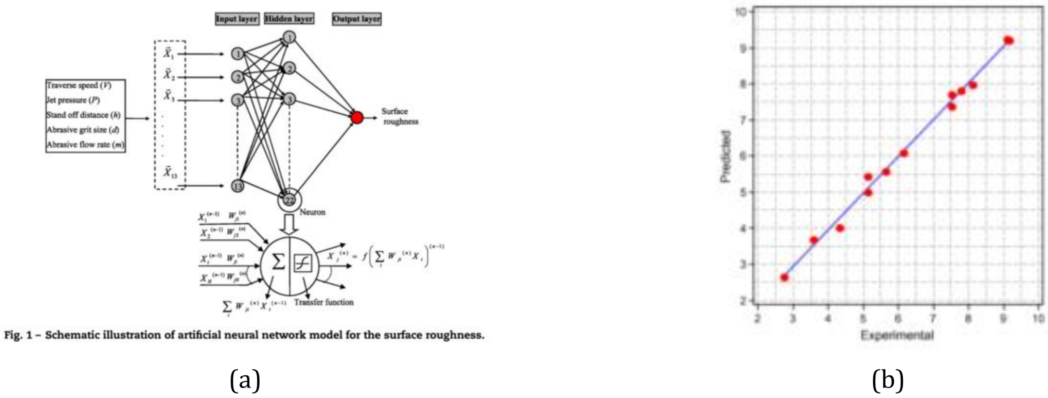
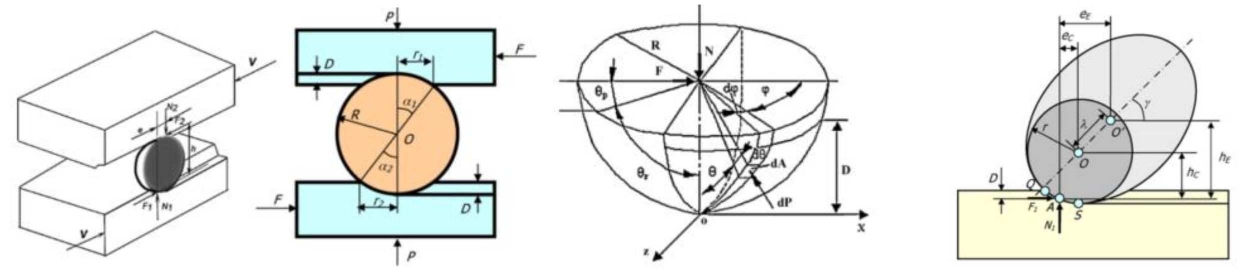
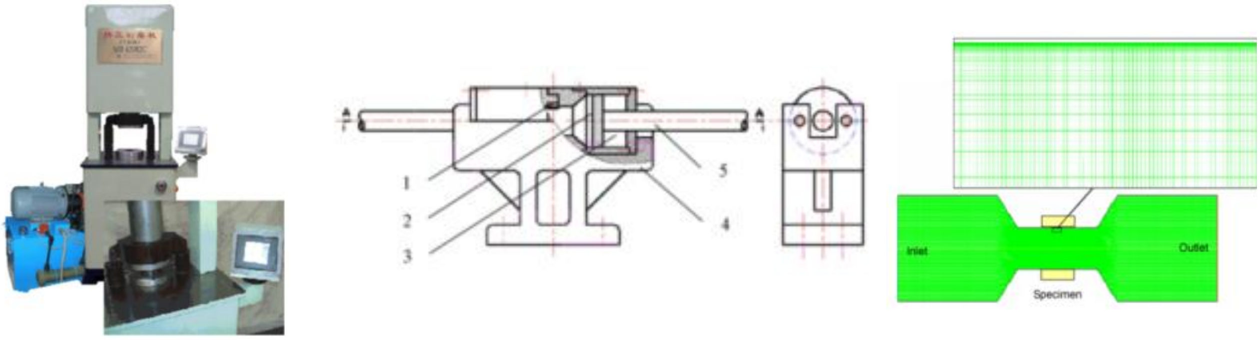


Fig. 27. (a) schematic of the ANN model, (b) Regression model vs Experimental [24].



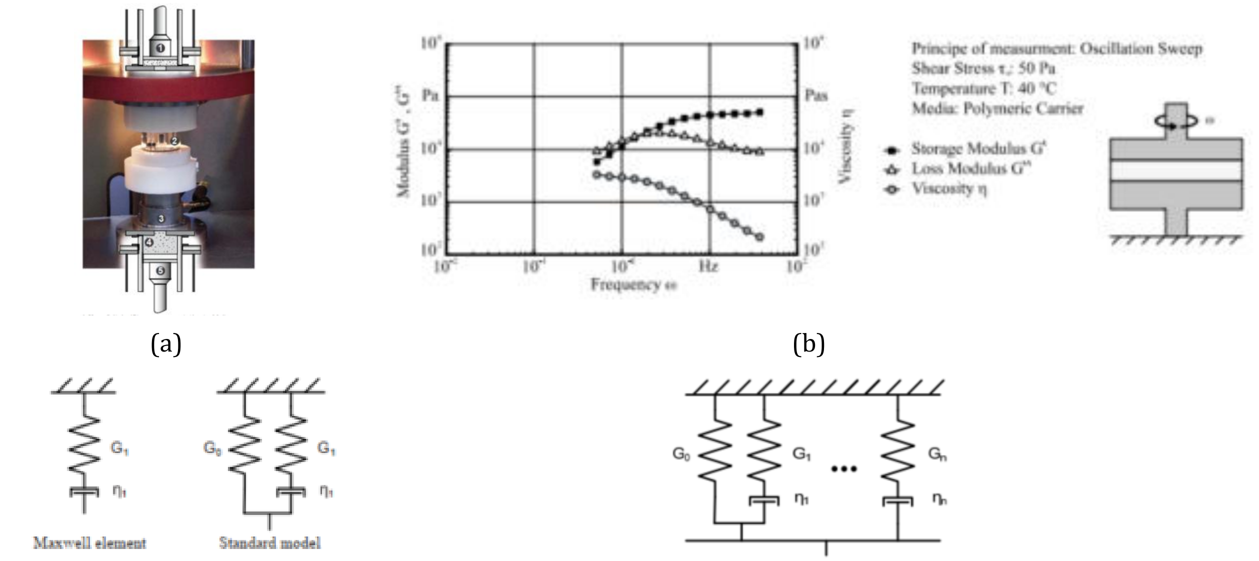
(a) (b) (c)

Fig. 28. (a) Schematic of force analysis, (b) Geometric of a half sphere, (c) Elipsodal particle [29].



(a) (b) (c)

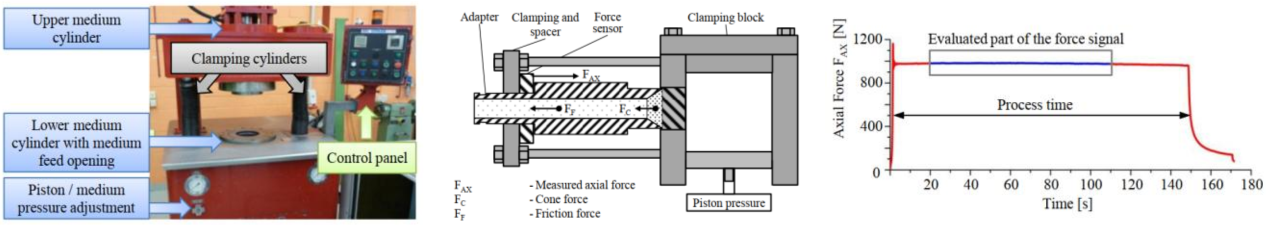
Fig. 29. (a) Commercial AFM, (b) Assembled AFM test rig, (c) FEM and meshes for CFD [30].



(a) (b)

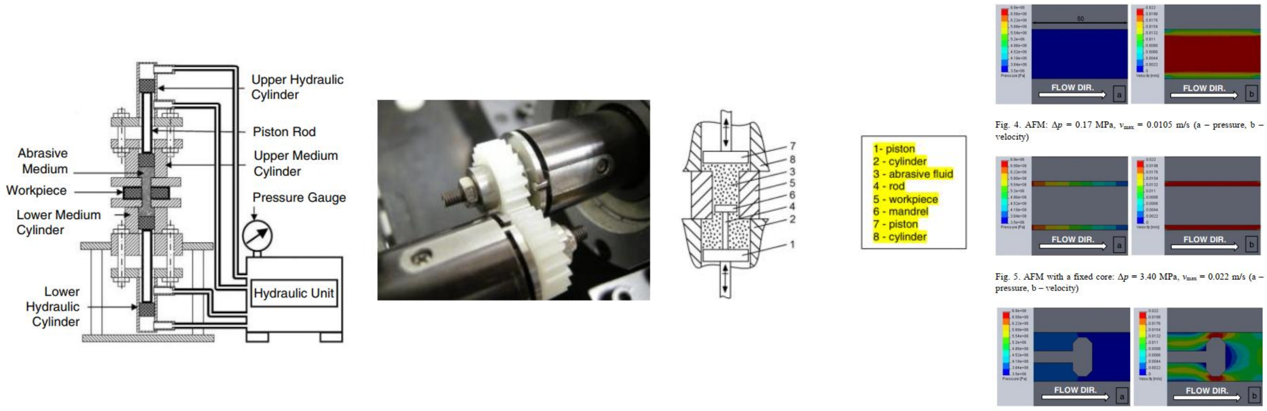
(c) (d)

Fig. 30. (a) AFM set-up, (b) rheological measurement, (c) Modeling element, (d) Maxwell model [38].



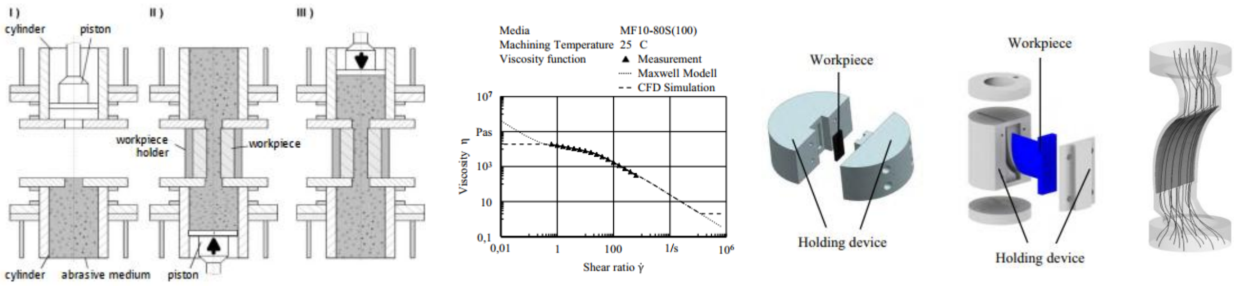
(a) (b) (c)

Fig. 31. (a) ExtrudeHone, (b) Experimental set-up, (c) Force signal for adapter 100mm 40bar [40].



(a) (b) (c) (d)

Fig. 32. (a) Schematic AFM, (b) Platic gear, (c) AFMmm, (d) FEM [41].

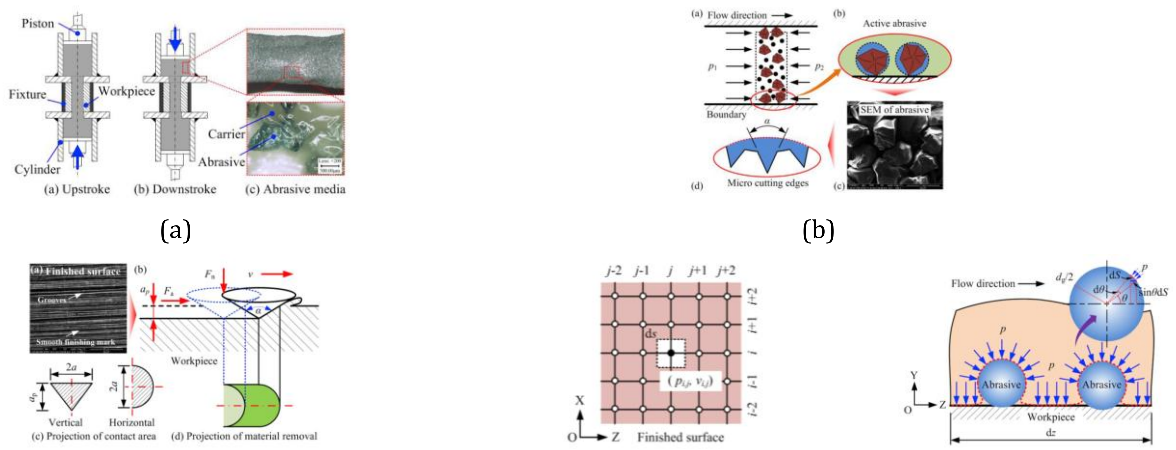


(a) (b) (c) (d)

Fig. 33. (a) AFM step, (b) Shear ratio and Viscosity, (c) Workpiece, (d) Simulation Streamline [43].

(a) (b)

Fig. 34. (a) AFM process principle, (b) Characteristic diagram the process model [46].



(c) (d) (e)

Fig. 35. (a) Schematic diagram, (b) Simplification of abrasive, (c) MR of single cutting edge, (d) Quadrilateral surface direction of the finished surface, (e) Static pressure on the finished surface [53].

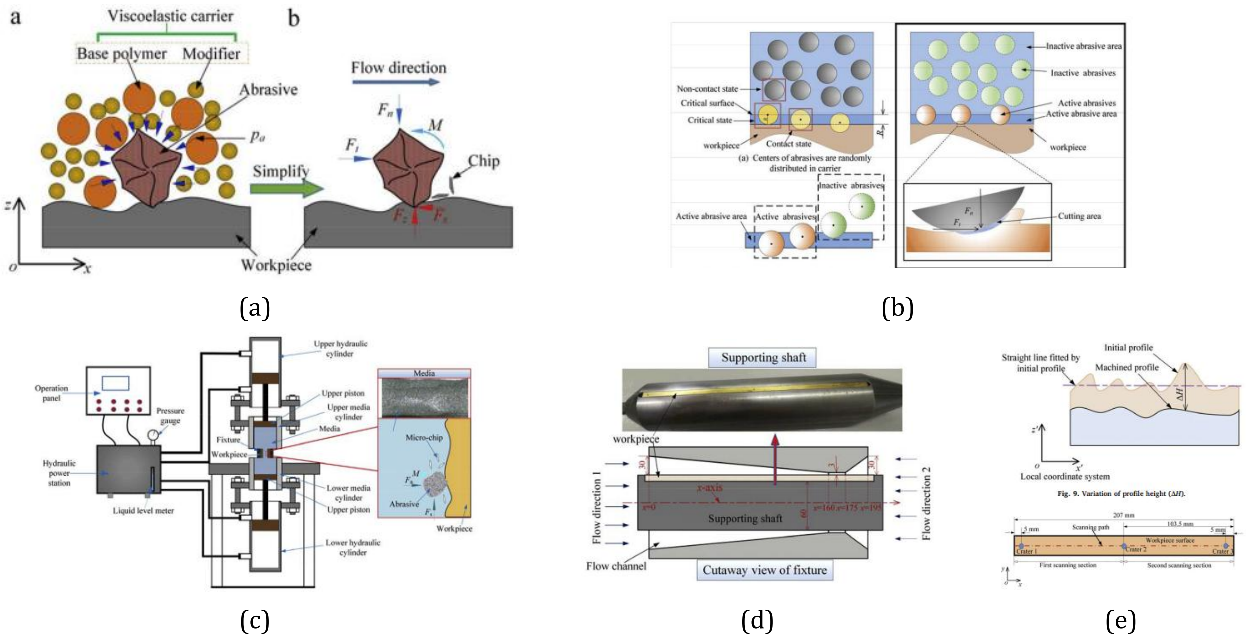


Fig. 36. (a) Force analysis and simplified model, (b) Active abrasive, (c) AFM, (d) Fixture and flow channel, (e) Craters and scanning section, (f) Profile height variation [54].

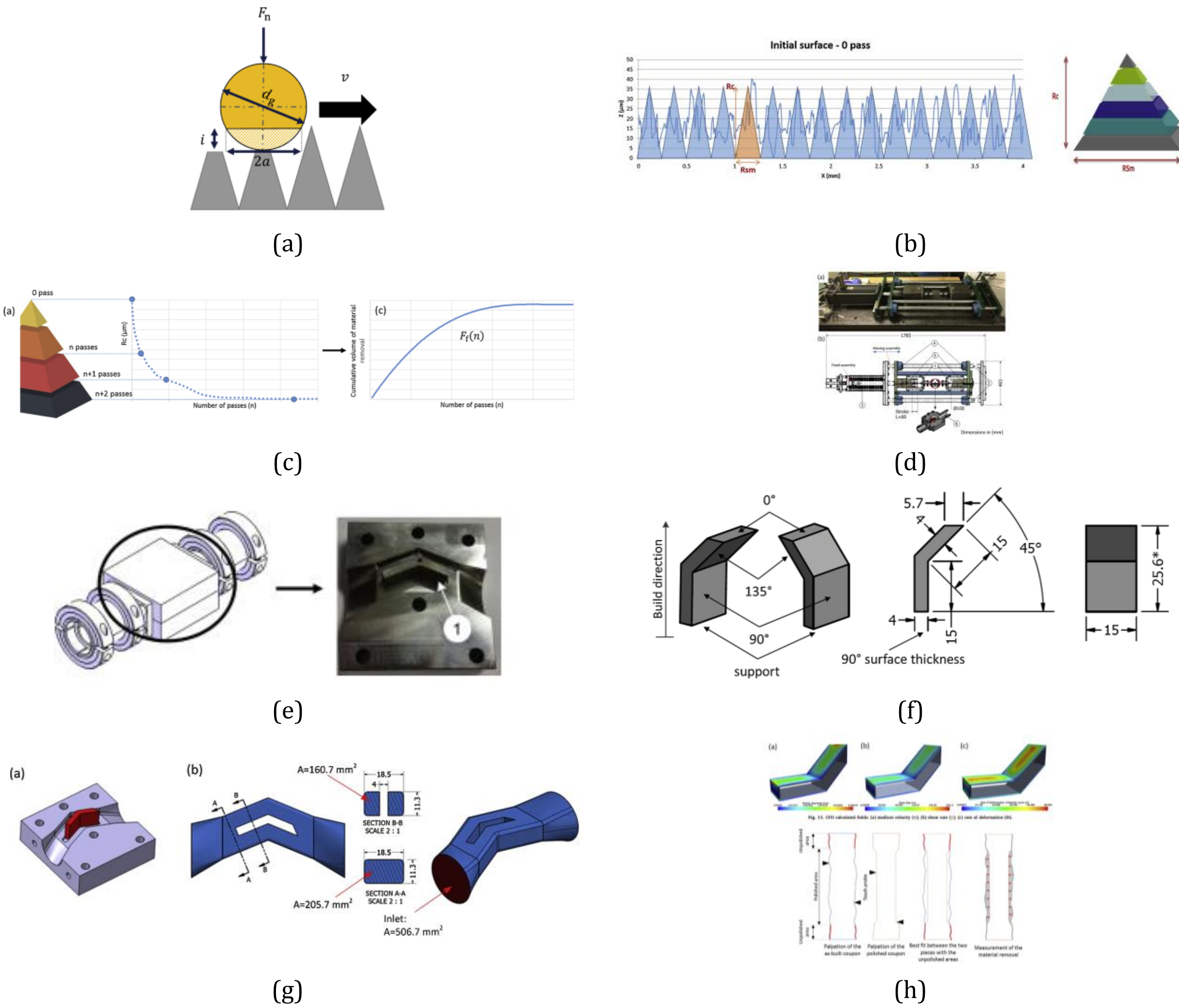
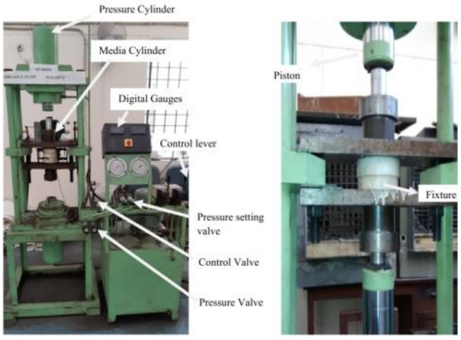
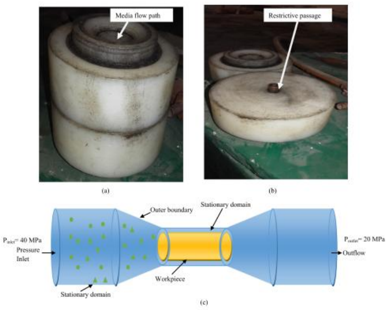


Fig. 37. (a) Sphere grain, (b) a surface profile, (c) Pyramid, (d) Holder, (e) V-shaped test, (f) V-shaped test coupon, (g) V-shape and Fixture, (h) MR measurement [56].



(a)

(b)



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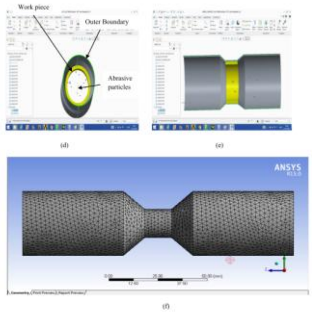
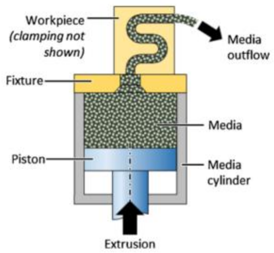
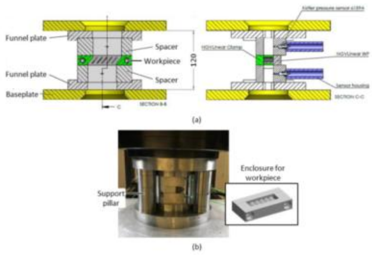


(d)

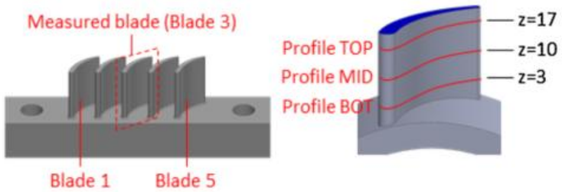
Fig. 38. (a) Two-way AFM, (b) Fixture set-up, (c) Media flow path, (d) ANSYS [58].



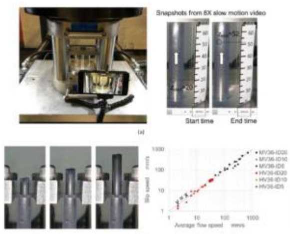
(a)



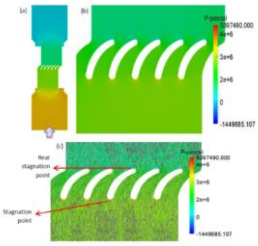
(b)



(c)

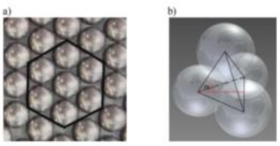


(d)

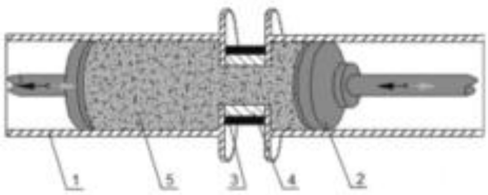


(e)

Fig. 39. (a) One-way AFM, (b) AFM set-up, (c) 5 Blade, (d) Flow speed, (e) Computational domain and Modeling [59].



(a)



(b)

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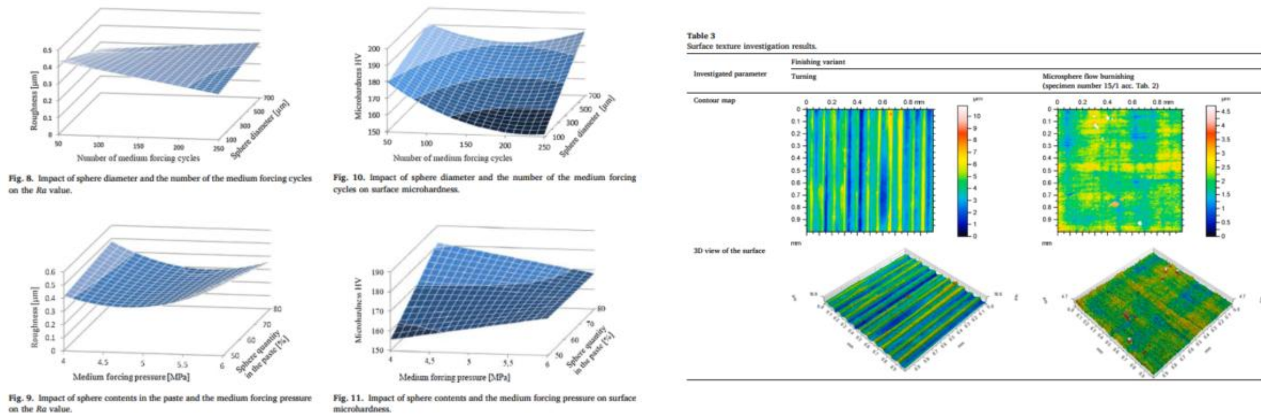
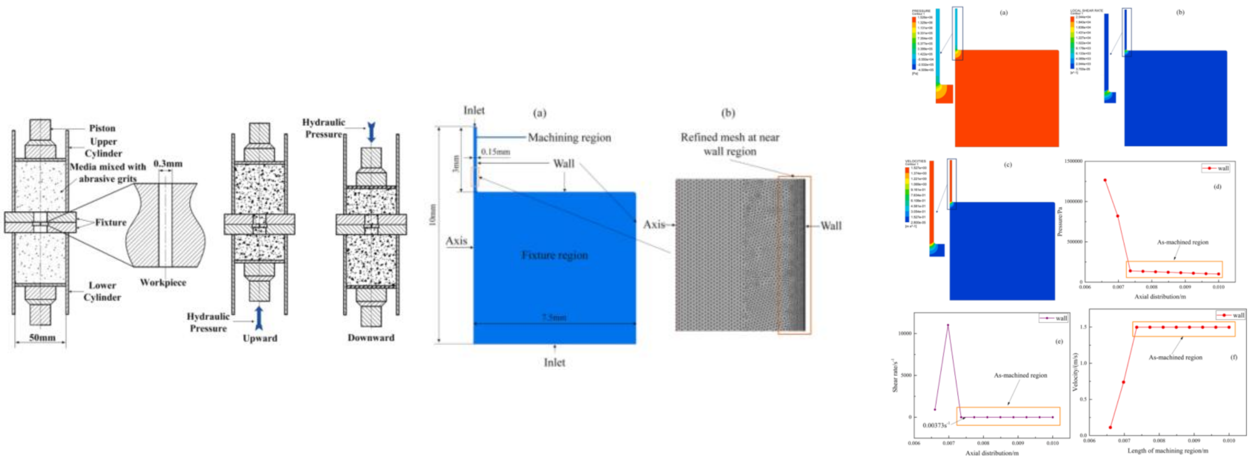


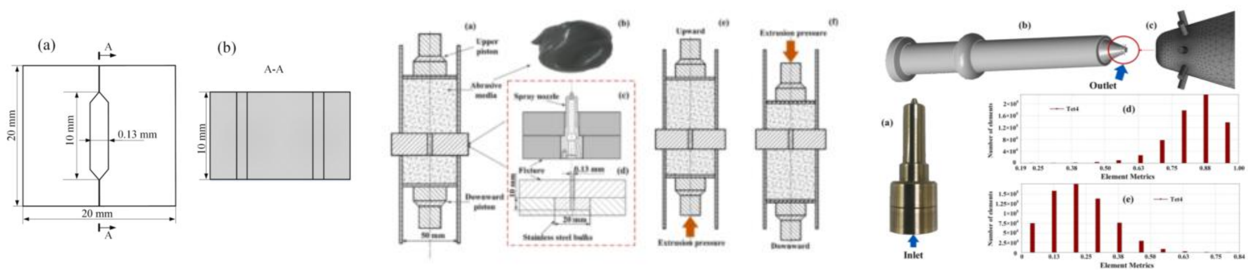
(d) (e)

Fig. 40. (a) Concentration of media, (b) Surface model, (c) Arrangement sphere, (d) Two-way AFM, (e) Impact of sphere, (f) Modeling [62].

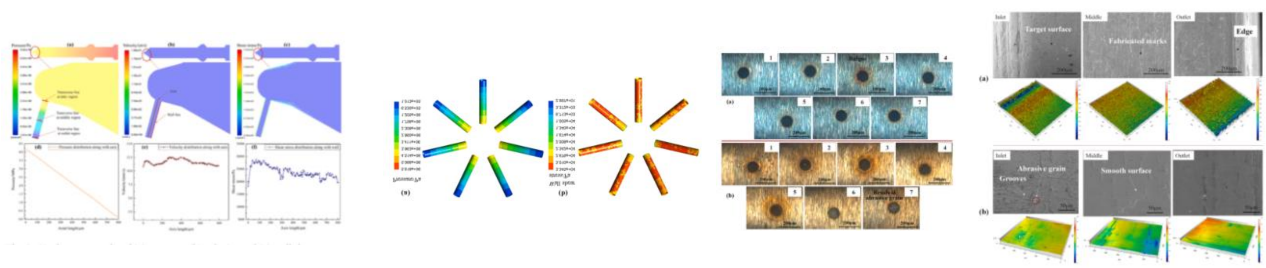


(a) (b) (c)

Fig. 41. (a) Schematic AFM, (b) a Micro hole and mesh, (c) Modeling [68].



(a) (b) (c)



(d) (e) (f) (g)

Fig. 42. (a) Workpiece, (b) AFM apparatus, (c) Equation, (d) Nozzle, (e) Modeling, (f) Spray hole, (g) SiC, (h) Modeling [71].

Table 3. AFM review: Modeling; an example of 29 articles.

Reference	Changing	Parameters	specimens	Abrasive media	Responses	Inference
MODELLING						
J.J.Hann, P.S. Steif, 1998 [1]	Model for predicting the extent of abrasive wear	stress in terms of extensional and shear strain rates			Wear efficiency	Wear efficiencies were in the range of 10^{-5} to 10^{-3}, three-body wear
Kimberly L. Petri, et. al. 1998 [2]	A Neural Network Process Model	Heuristic search process parameters; workpiece, media characteristics, machining, technical spec., process objectives	BrainMaker ProfessionalTM software package, VB, and Pascal		An effective technique for modeling the AFM process.	Reduce the time for new applications in the production process.
Rajendra Kumber Jain, Vijay Kumar Jain, 1999 [4]	Simulation and experiments (response surface analysis: RSA)	Number of cycles, percentage concentration, mesh size, reduction ratio, and extrusion pressure	Mild steel (0.25%C) hardness: 2177.80 N/m[m^2	SiC: silicon carbide mesh: 50-60, density of SiC: 3220 kg/m^3 P: 20-80 bar, %Concentration: 56-76%, N= 5-25 cycles	Surface profile Finished surface and material removal (MR) change in surface roughness (delta Ra)	Simulation and RSA are in good agreement.

3.4 Development of AFM: Magnetic-Assisted

Group 4 adds a magnetic field to help.

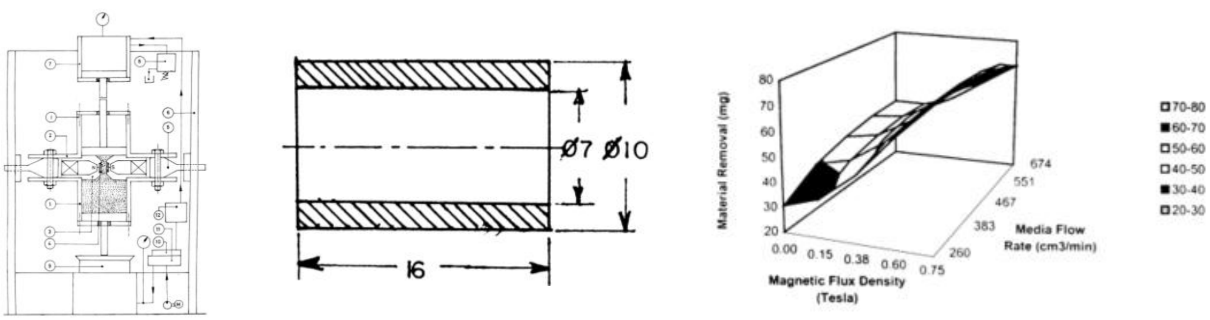
Magnetic-Assisted AFM Review In 2002, an experiment was conducted using a magnetic field to improve the polishing efficiency of AFM. An experimental study (mixed factorial design) Wear behavior Magnetically assisted AFM. The primary variable was MAAFM vs AFM pressure: 15 bar media volume flow rate: 450 cm4/min reduction ratio: 0.9 concentration: 1.5:1 (by weight), the average grain size of abrasive particles: 355 µm, media viscosity: Low (fixed polymer to gel ratio) The workpiece is Brass, aluminum, and Mild. Steel (MS), the abrasive is Al2O3, and the dependent variables are MR, ΔRa, and the wear behavior, photographed with SEM (scanning electron microscopy) [10]. In the same year, there was a study of MAFM (Magneto abrasive flow machining). The primary variable was Pole and Yoke material: M.S. (Mild steel) 0.25%C Each pole size: dia. 35 mm Coil: copper wire, dia. 1.21 mm, 1500 turns Power supply: 0-50 V, 0-5A, Max. flux density: 0.9 T at 3.5A Dependent variables are MR (material removal), and ΔRa (surface finish improvement) [11]. In 2004, the study MRAFF: the magnetorheological abrasive flow finishing process Experiments were conducted on stainless steel workpieces at a different magnetic field strength Non-magnetic; stainless steel Abrasive laden magnetorheological finishing medium; carbonyl iron powder and silicon carbide abrasives dispersed in the viscoplastic base of grease and mineral oil. The dependent variable is the final surface finish. and photographed with SEM micrograph; surface characteristics [15].

The year 2012, studied Magnetic abrasive finishing six neodymium permanent magnets, residual flux density (1.26-1.29 T) The primary parameter is the high-speed multiple pole-tip finishing equipment, rotating the spindle up to 30000 min-1 Processing time: 10 and 20 min the workpiece is 304 Stainless steel tube (dia. 1.27 x dia. 1.06 x 100 mm, wp Revolution; 500, 5000, 10000, 20000, and 30000 min-1. The abrasive is a PTFE (Polytetrafluoroethylene) Soluble-type barrel finishing compound (pH: 9.5, Viscosity: 755 mPa·s at 30 °C and the dependent variable is Rz, MR mg [35]. In the same year, Magneto AFM (MAFM) was studied. Hybrid machining processes (HMP) Electromagnet; two poles RSM (Response surface methodology) Initial surface roughness Brass, cylindrical workpieces A semi-solid medium (a polymer-based carrier and abrasives Silicon-based polymer, hydrocarbon gel, and abrasive grains. Brown Super Emery (trade name), 40% ferromagnetic constituents, 45% Al2O3 and 15% Si2O3. Dependent variables are MRR, and SF (surface finish) [37]. In 2015, the Rotational-Magnetorheological AFM (R-MRAFF) process was studied to improve external surfaces of relatively simple geometry. controlling two motions (axial and rotational) Workpiece: Stainless steel (knee joint implant) Nanofinishing of freeform surfaces Dependent variable: Improved finishing rate (nanometer/min) SR [44].

In 2021, there was a study Modeling a novel rotational magnetorheological AFF process R-MRAFF process. The main parameters are MRP (magneto-rheological polishing fluid) the rotation of the rams, the magnetic field; A current (A): 1, 2, 3, 4, 5, B: number of cycles: 2, 4, 6, 8, 10, C: rotational: (rpm): 2, 4, 6, 8, 10 Mathematical modeling multiple regression Abrasives are Carbonyl iron, abrasive grits, and viscoelastic medium, the iron particles and the dependent variables are MRR, and SR [64].

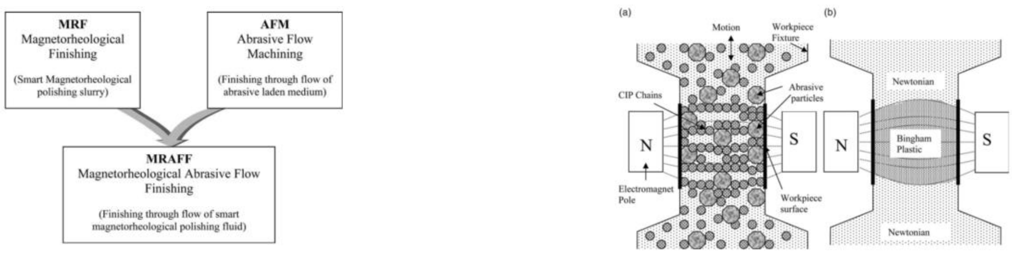
(a) (b)

Fig. 43. (a) Schematic of MAFM, (b) Magnetic shielding effect [10].

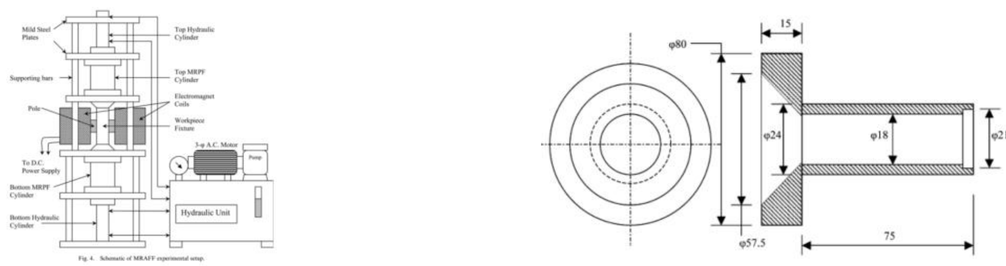


(a) (b) (c)

Fig. 44. (a) Schematic of M AFM, (b) Workpiece, (c) Magnetic flux density and MR [11].

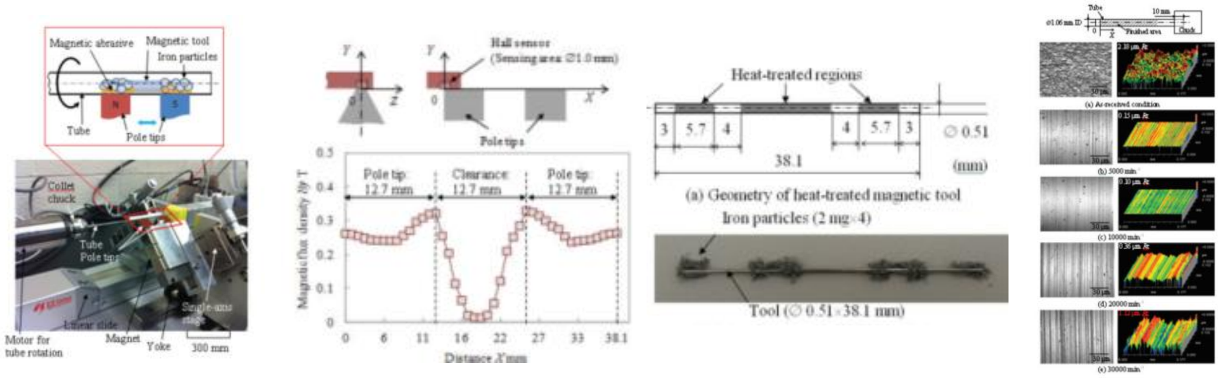


(a) (b)



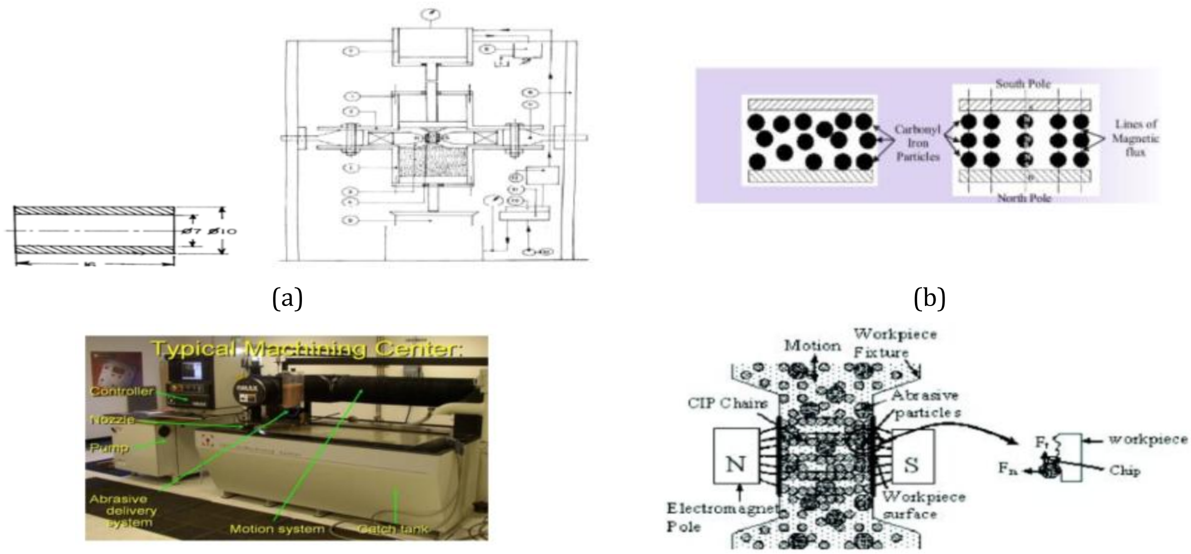
(c) (d)

Fig. 45. (a) MAFM, (b) Process, (c) MAFM system, (d) Workpiece, (e) SR and Profile [15].



(a) (b) (c) (d)

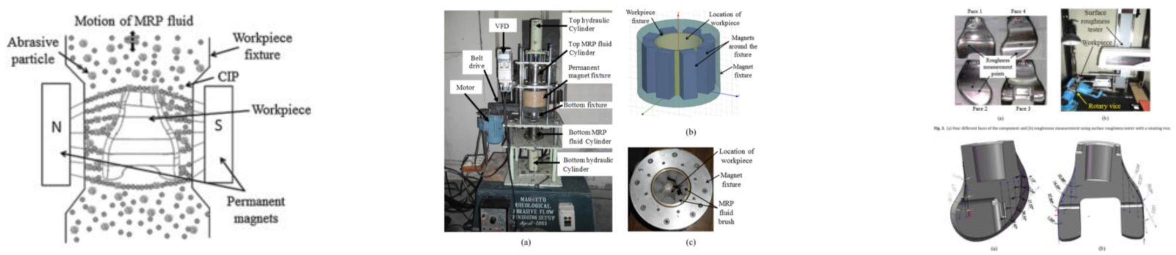
Fig. 46. (a) Schematic, (b) Change in Magnetic flux, (c) Geometry and Tools 3D [35].



(a) (b)

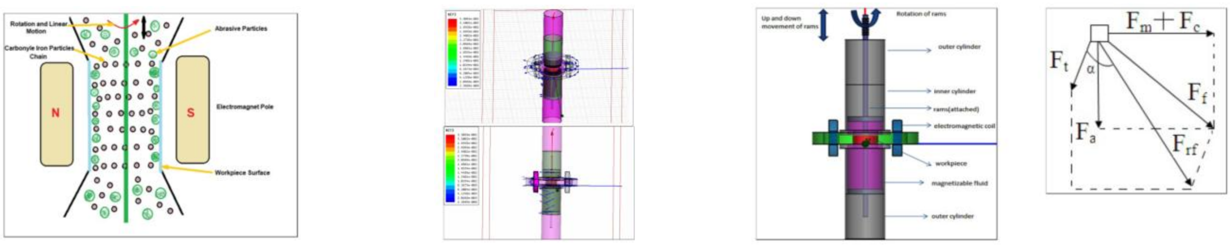
(c) (d)

Fig. 47. (a) Workpiece & MAFM, (b)Principle, (c)Machining, (d)Mechanism [37].



(a) (b) (c)

Fig. 48. (a) Mechanism, (b) Set-up, (c) Workpiece and measurement point [44].



(a) (b) (c)

Fig. 49. (a) R-MRAFF process, (b) Modeling, (c) model set-up and forces [64]

Table 4. AFM review: Magnetic-Assisted; an example of 7 articles.

MAGNETIC-ASSISTED						
Sehijpal Singh, et al., 2002 [10]	An experimental study (mixed factorial design) Wear behavior Magnetically assisted AFM	MAAFM vs AFM pressure: 15 bar media volume flow rate: 450 cm4/min reduction ratio: 0.9 concentration: 1.5:1 (by weight), the average grain size of abrasive particles: 355 µm, media viscosity: Low (fixed polymer to gel ratio)	Brass, aluminum, and Mild Steel (MS)	Al^2O^3	MR ΔRa the wear behavior SEM (scanning electron microscopy)	Enhances the MR rate. The magnetic field does not appreciably improve the SR of the Al workpiece (2.41% concentration) Significant for Al but the same for brass.
Sehijpal Singh, H.S. Han, 2002 [11]	MAFM (Magneto abrasive flow machining)	Finished-machined by MAFM	Pole and Yoke material: M.S. (Mild steel) 0.25%C Each pole size: dia. 35 mm Coil: copper wire, dia. 1.21 mm, 1500 turns Power supply: 0-50 V, 0-5A, Max. flux density: 0.9 T at 3.5A	MR rate and % improvement in SR significantly improved the performance of MAFM over AFM	MR (material removal), ΔRa (surface finish improvement)	It affects both MR and ΔRa N required for removing the same amount of MR Magnetic field and medium flow rate interact with each other. Low flow rates and high mag. flux yields more MR and smaller ΔRa

3.5 Development of AFM: Abrasive Media

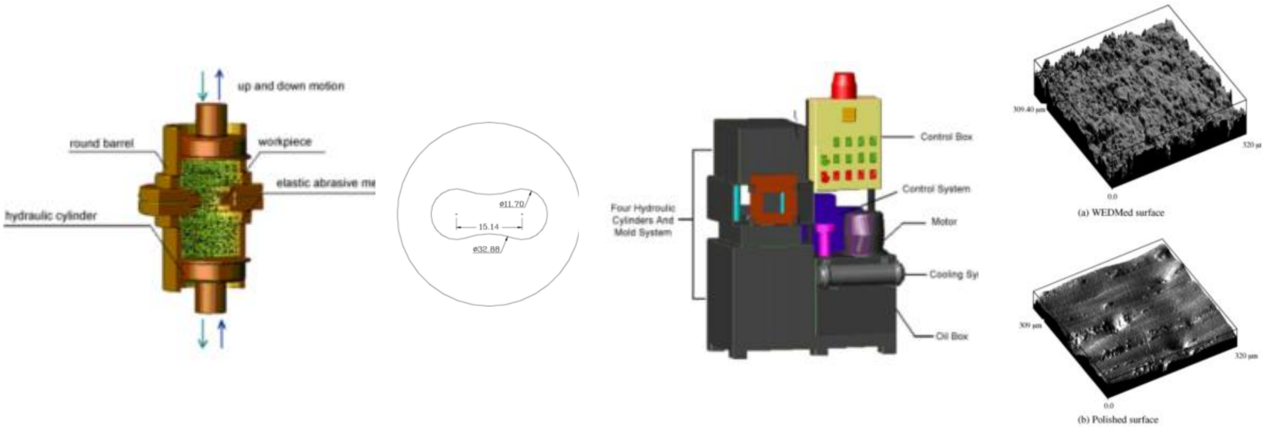
Group 5 studies abrasives mixed with polymers and various carriers.

The development of AFM abrasives in 2007 was the development of the polymer abrasive gels for polishing workpieces that have been made Wire-EDM (WEDM) and workpieces with Complex hole High abrasive concentration 60% (wt.%) 20 workpieces in 10 working cycles, especially the abrasive media that is Commercial abrasive media (very expensive) Vinyl-silicone polymer (or silicone rubber); (will not stick on the workpiece) to see the results, the dependent variable is RIR (the roughness improvement rate) that A-silicone with 60% [23]. In the same year, MRAFF (Magnetorheological AFM) was studied, especially the abrasive media: Bingham plastic, ferromagnetic and abrasive particles MR, SR (Ra). The workpiece was Nano-finishing of parts with complicated geometry. The dependent variable was SR (Ra), MR [25].

In 2011, the Rheological characterization of styrene-butadiene-based medium R-AFF was studied. The variable was nanoscale. Shear rate (Pa), % viscous component in medium, creep compliance with time (τ=100 Pa), plasticizer content in medium on shear. viscosity, storage modulus (Pa): 200000 to 600000 The workpiece is Complex shaped components, especially the abrasive is an Abrasive mixed polymer (medium). Co-polymer soft styrene butadiene-based polymer, plasticizer, and abrasives, static and dynamic rheological properties. The dependent variable is the change in surface roughness; ΔRa, MRR (mg) [33]. 2018 study AFM, abrasive gel has 2 types: Viscosity (Pa*s): 120, 500 P-silicone gel and A-silicone gel, where

P-silicone gel without abrasive A-silicone gel, the workpiece is A helical passageway; complex holes and curved surface. WEDM SKD-11 dependent variable is SR (surface roughness) [48]. In 2018, there was an AFF (Abrasive flow finishing) ANA study. SiC; abrasive particles (#220) workpiece is Al alloy/SiC (10%) metal matrix composite (MMC), especially the abrasives: Soft styrene polymer and silicone polymers are blended along with additives and silicon carbide. The dependent variable is SR; change in Ra, ΔRa [49]. In 2019, there was a study of AFM Guar gum hydrogel Modeling Shear-thining media prediction with Complex shaped components. AISI316 stainless steel; 10 x10 x 3 mm especially the abrasive is Styrene-butadiene rubber-based media New media increases from 69 mg/h to 351 mg/h, SiC: d=7.5 μm The dependent variables are SR in Ra and MRR in mg/h [52].

In 2020, A Novel Water-based Viscoelastic Polishing Fluid for AFM in Biological Micro Electro Mechanical Systems (Bio-MEMS) was studied. the monocrystalline silicon has an initial roughness of 11.13 nm, time: 2h, especially the abrasive is Adding NaOH to keep it alkaline. Hydrogel mass fraction of 10% CeO2 and 20% Al2O3: 1, 3, and 5 μm the dependent variables were SR, storage modulus G, and MRR [57]. In 2021, Xanthan gum-based abrasive media using AFM was studied. XG-based compared with polymer-based Seep tests, Thermo-Gravimetric Analysis (TGA), Differential Thermal Analysis (DTA), and Fourier Transform Infrared Spectroscopy (FTIR) Rheology media Viscotify (Pa*s) The workpiece is Copper workpiece with geometrical specifications. Specifically, the abrasives Xanthan Gum (XG) hydrogel, Locust Bean Gum (LGB), and Fumed Silica (FS) were added as crosslinking and thickening agents. The dependent variables were SR, %ΔRa, MR, Storage Modulus, G', and Loss. Modulus G' imaged with SEM and AFM (atomic force microscopy) [65]. In the same year, Rheological newly developed fly ash mixed polymeric media through AFM Self-deforming characteristics Through static and dynamic rheological tests. pressure: 2 to 8 MPa N for mild steel: 0 to 1000 and 0 to 600 for Al workpiece is Mild. steel and Al, especially the abrasives are Viscoelastic polymer SiC/diamond abrasives, low-cost AFM media with waste coal fly ash. (68% fly-ash) is ~56% for the aluminum and ~49% for mild steel workpieces. The dependent variables are Average surface and roughness (ΔRa) [66]. In 2022 Abrasive media for micro-porous structures will be studied. AFM, CFD simulation of the 80.85 loss ratio of plasticizer oil to polymer components. The primary variables are Matching uniformity and rheology. The Brid-Carreau model, the Mixture model, and the Discrete Phase model. Thermogravimetric analysis (TGA), temp: 25, 50, 75, and 100 °C. The workpiece is Microporous structures, the abrasive is Polymer matrix media, and the dependent variable is SR. and MR [67]. And in 2023 there is a study of Experimental Investigation, AFM polymer rheological abrasive medium. The primary variable is Polishing, AFF (abrasive flow finishing) Pressure: 7.5 MPa, 15 cycles, the workpiece is Selective laser melted 18Ni300 steel, the abrasive is Polysaccharide-based abrasive media with monomodal and bimodal abrasive particles. and the dependent variables are SR (ΔRa), and MR [73].



(a) (b) (c) (d)

Fig. 50. (a) AFM diagram, (b) Workpiece, (c) AFM system, (d) SR [23].

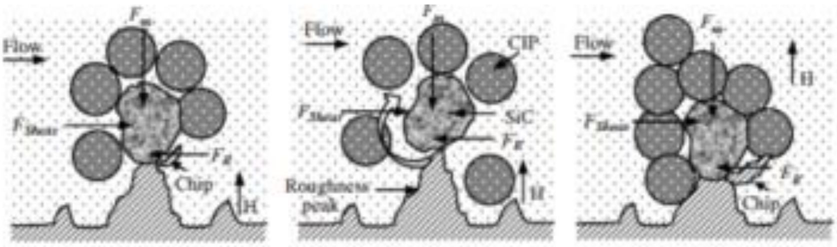
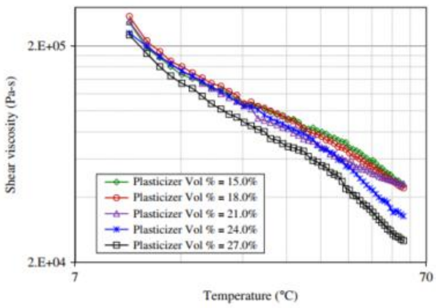
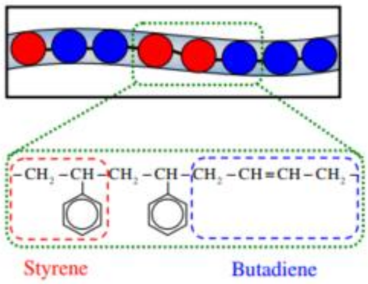


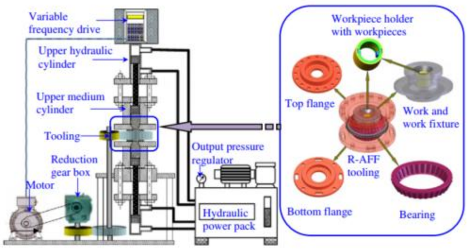
Fig. 51. A single peak by SiC in the MRAFF process [25].



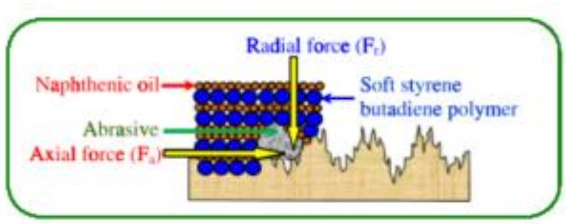
(a)



(b)

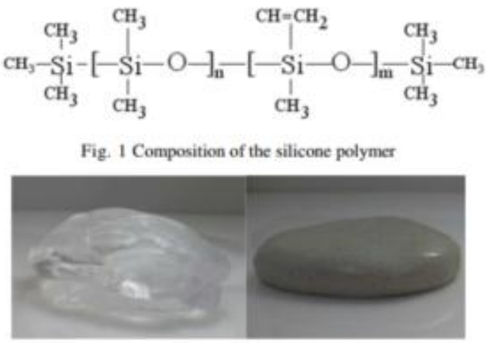


(c)



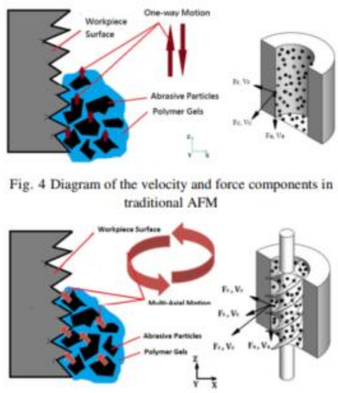
(d)

Fig. 52. (a) Effect of temp., (b) Polymer chain, (c) Intermolecular force, (d) Schematic of R-AFF, (e) the medium ingredients, (f) Force development [33].



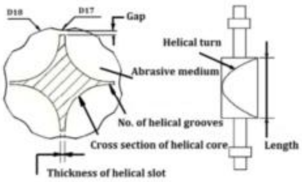
(a)

(b)



(c)

(d)



(e)

Fig. 53. (a) P-silicone gel, (b) A-silicone gel with and without abrasive, (c) Velocity and force, (d) SKD-11, (e) a Helical core [48].

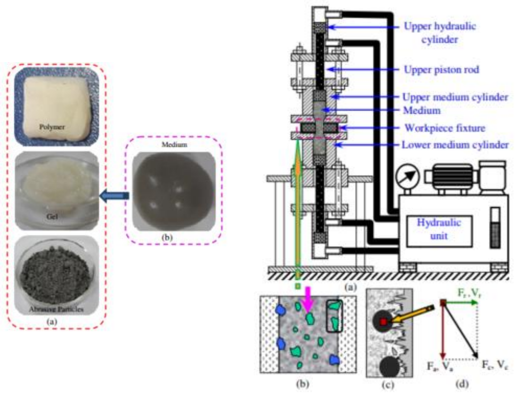
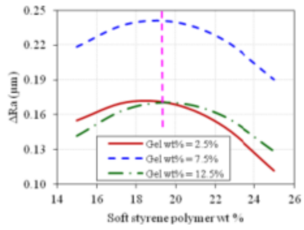


Table 2: ANOVA table for effect of polymers blended medium ingredients on ΔR_a of Al alloy/SiC (10%)

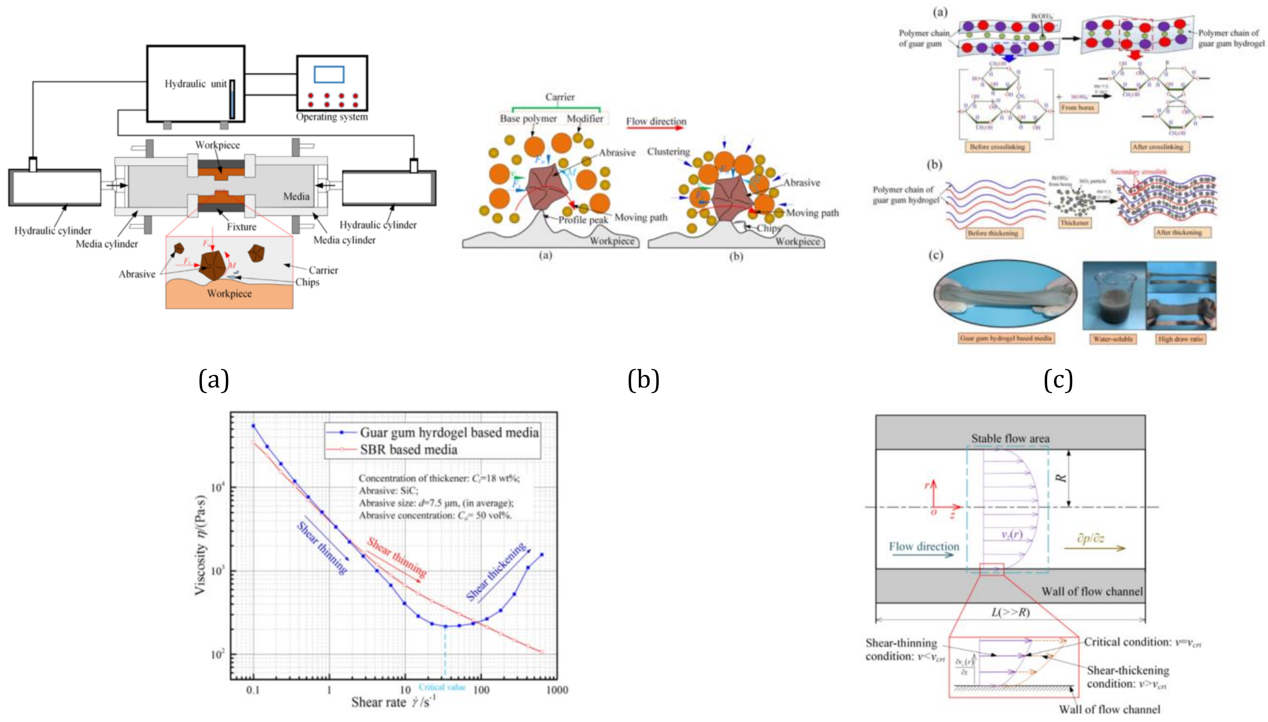
Source	F Value	p-value Prob > F	% Contribution
Model	10.6275	0.0005	
A- silicone polymer	17.2775	0.0020ᵃ	16.20
B-Abrasive particles	2.3970	0.1526	2.25
C-Plasticizer	9.2777	0.0123ᵃ	8.70
AB	0.0585	0.8138	0.05
AC	0.0585	0.8138	0.05
BC	4.7383	0.0545ᵃ	4.44
A^2	10.6378	0.0086ᵃ	10.00
B^2	36.1929	0.0001ᵃ	33.95
C^2	25.9885	0.0005ᵃ	24.35

a = Significant term



(a) (b) (c) (d)

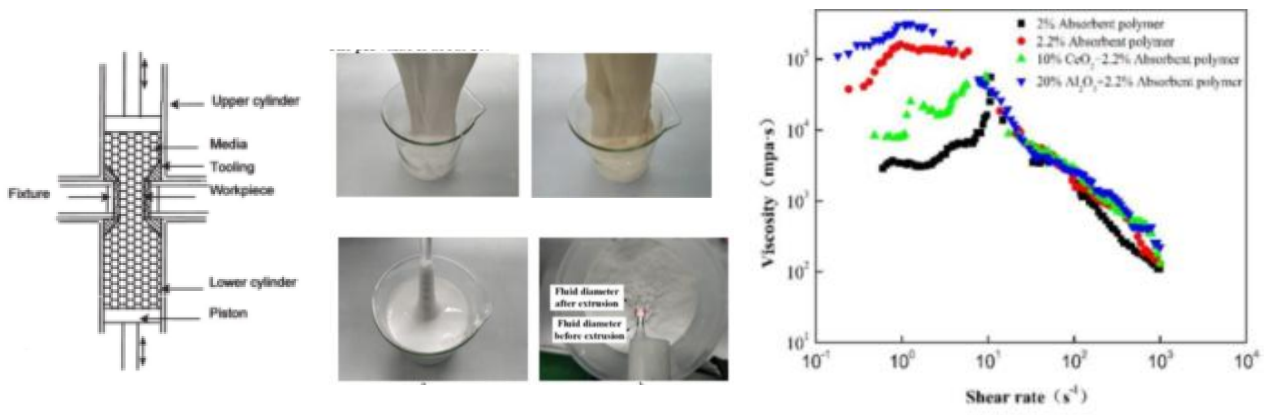
Fig. 54. (a) Medium preparation, (b) AFM, (c) ANOVA, (d) Effectf on delta Ra [49]



(a) (b) (c)

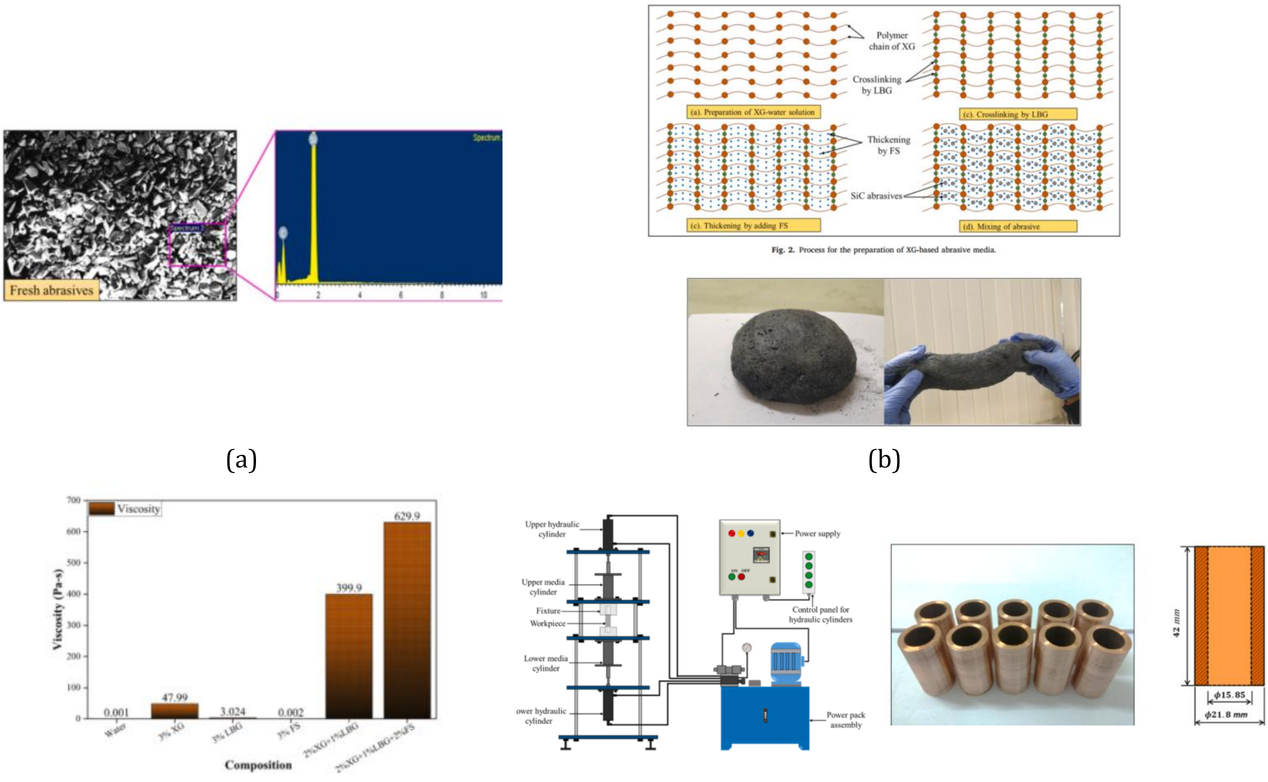
(d) (e)

Fig. 55. (a)Schematic, (b)Shear-thinning, (c)Polymer, (d)Velocity &shear, (d)tubular flow [52].



(a) (b) (c)

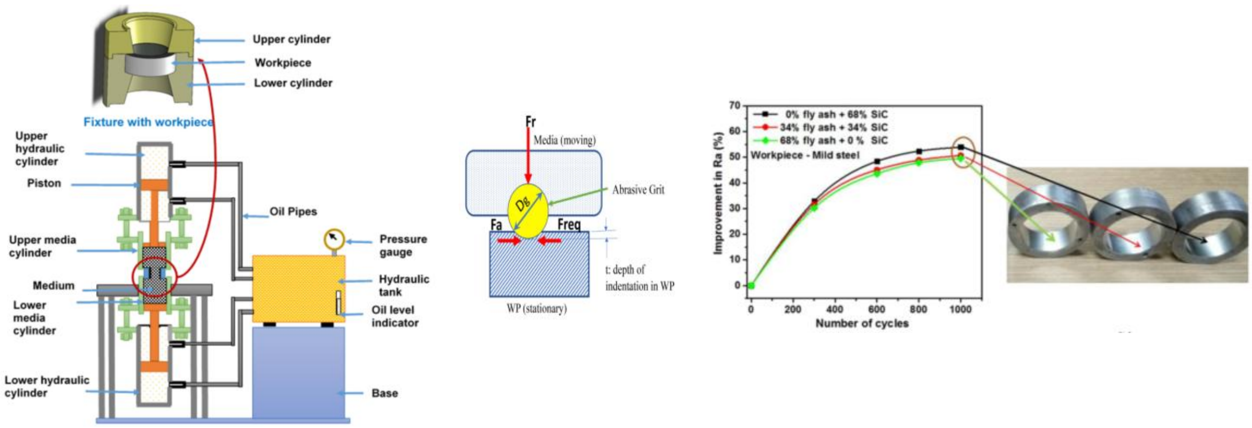
Fig. 56. (a) AFM, (b) Al_2O_3 & CeO_2, (c) Climbing effects and extrusion swell, Velocity and shear [57].



(a) (b)

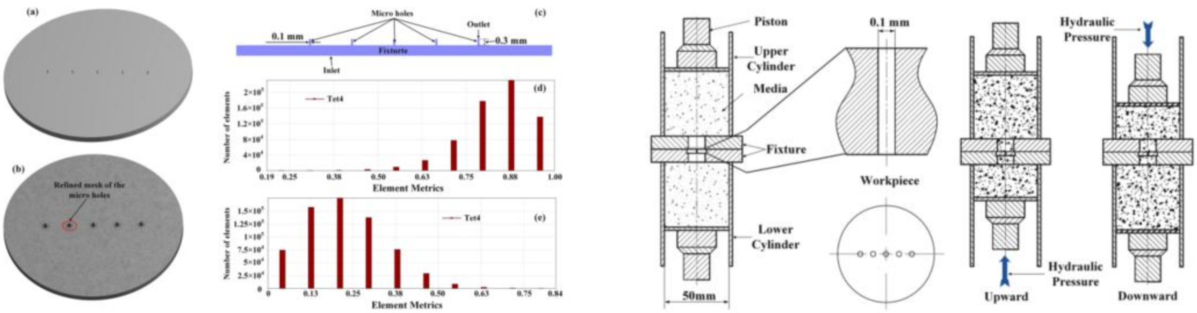
(c) (d) (e)

Fig. 57. (a) XRD, (b) Developed abrasive media, (c) Composition, (d) AFM, (e) Workpiece [65].

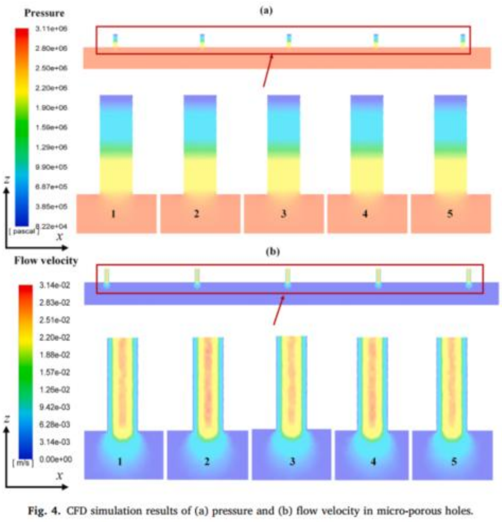


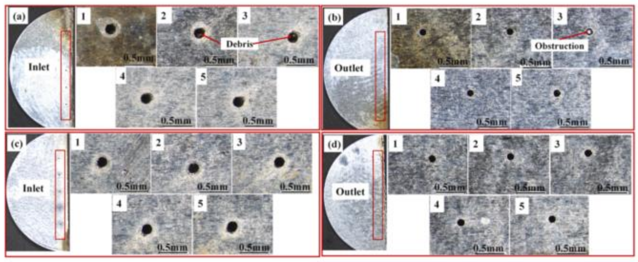
(a) (b) (c)

Fig. 58. (a) AFM, (b) MR mechanism, (c) Ra vs N, (d) [66].



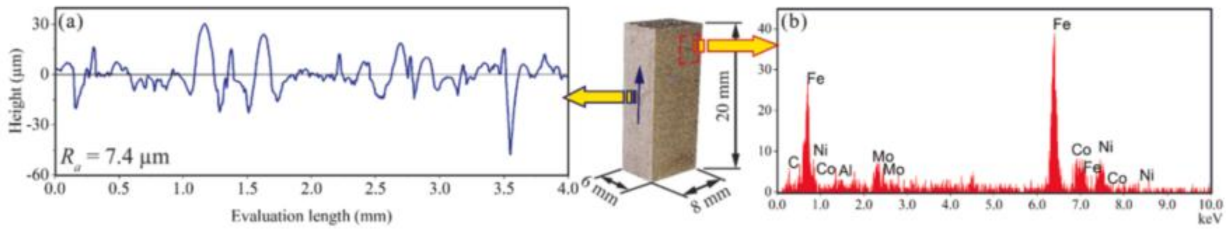
(a) (b)



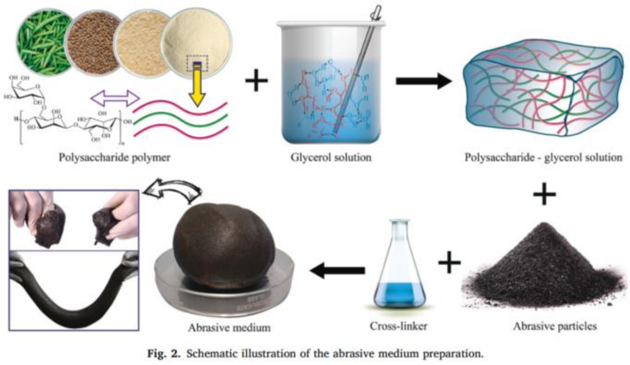


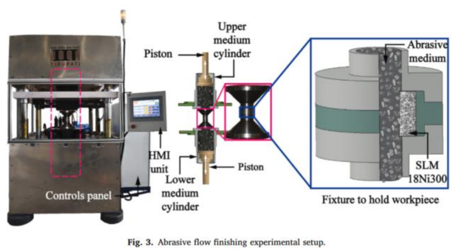
(c) (d)

Fig. 59. (a) Abrasive media, (b) Workpiece and Two-way AFM, (c) Modeling, (d) Hole [67].

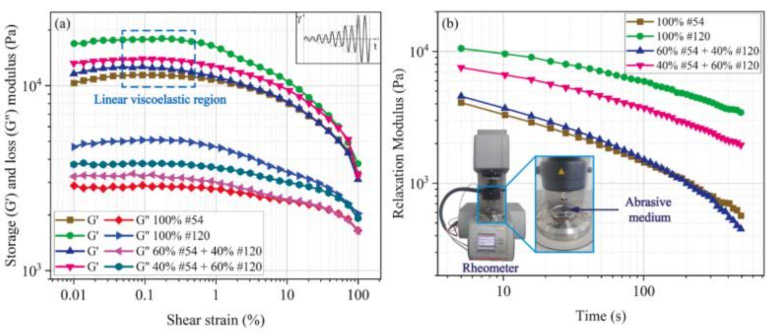


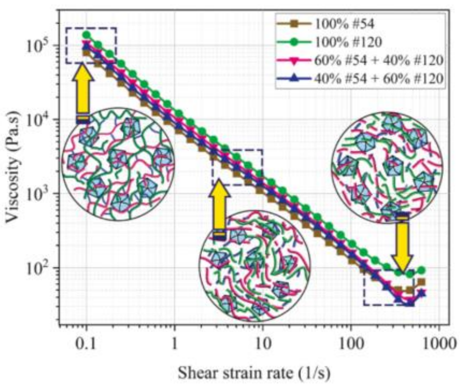
(a)





(b) (c)





(d) (e)

Fig. 60. (a) Initial SR and SLM 18Ni300 steel, (b) Media preparation, (c) AFM, (d) Effects, (e) Effect Viscosity and Shear strain rate [73]

Table 5. AFM review: Abrasive Media; an example 11 articles.

AFM MEDIA						
A.C. Wang, S.H. Weng, 2007 [23]	Developing the polymer abrasive gels	Wire-EDM (WEDM)	Complex hole High abrasive concentration 60% (wt.%) 20 workpieces in 10 working cycles	Commercial abrasive media (very expensive) Vinyl-silicone polymer (or silicone rubber); (will not stick on the workpiece)	RIR (the roughness improvement rate) A-silicone with 60%	SR decreased from 1.8 to 0.28 um Ra RIR: 84% small abrasive sizes can produce smoother SR than large abrasive sizes.
Manas Das, et al., 2007 [25]	MRAFF (Magnetorheological AFM)	The theoretical investigations, normal force, shear stress CFD simulation Magnetic field (T)	Nano-finishing of parts with complicated geometry	Media: Bingham plastic, ferromagnetic and abrasive particles MR, SR (Ra),	SR (Ra), MR	Viscosity and yield stress increase with an increase in the magnetic field, Ra reduction with increased current (A) and number of cycles
M. Ravi Sankar, et al., 2011 [33]	Rheological characterization of styrene-butadiene-based medium R-AFF	nanoscale. Shear rate (Pa), % viscous component in medium, creep compliance with time (τ=100 Pa), plasticizer content in medium on shear viscosity, storage modulus (Pa): 200000 to 600000	Complex shaped components,	Abrasive mixed polymer (medium). Co-polymerized soft styrene butadiene-based polymer, plasticizer and abrasives, static and dynamic rheological properties.	Change in surface roughness; ΔRa, MRR (mg)	Yield shear stress increases, MR increases. The linear viscoelastic range for the creep recovery test is between 50 and 150 Pa. The vicious increases the radial force decreases, MR decrease

3.6 Development of AFM: Ultrasonic-Assisted

Group 6 uses ultrasonic to help.

The use of Ultrasonic-assisted AFM work was found in a research study in 2014. UAAFM (Ultrasonic assisted AFM) additional ultrasonic vibration FEM; 3D model; CFD (Computational fluid dynamics) Frequency, pressure, time, and media flow rate pieces the tasks are Bevel gears and the dependent variables are SR and MR [42].

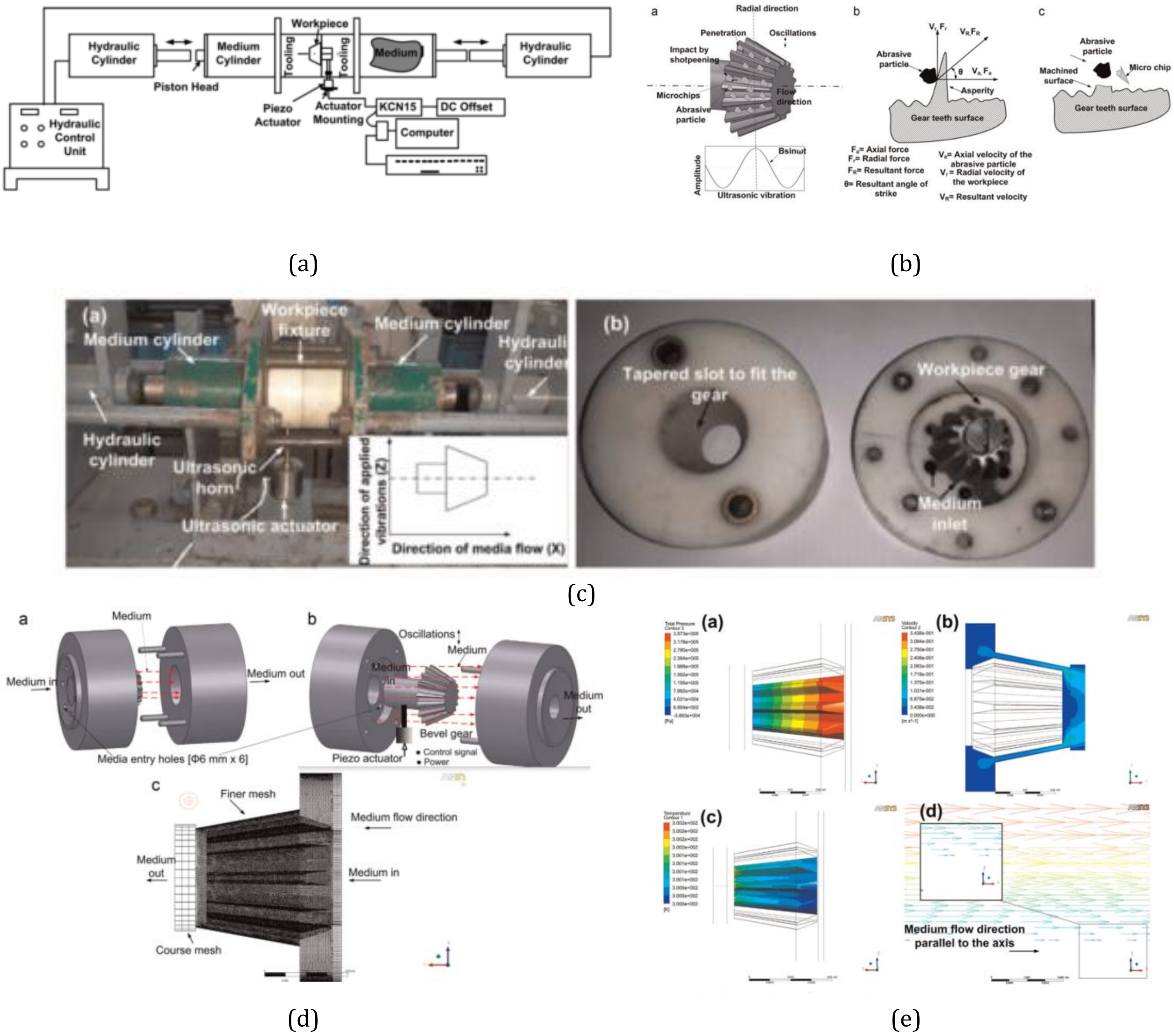


Fig. 61. (a) Schematic of UAAFM set-up, (b) A bevel-gear, (c) UAAFM set-up, (d) Workpiece, (e) Simulation results, (f) EN8 bevel-Gear [42].

Table 6. AFM review: Ultrasonic-assisted

Reference	**Changing**	**Parameters**	**specimens**	**Abrasive media**	**Responses**	**Inference**
Ultrasonic-assisted						
G. Venkatesh, et al., 2014 [42]	UAAFM (Ultrasonic assisted AFM) additional ultrasonic vibration	FEM; 3D model; CFD (Computational fluid dynamics) Frequency, pressure, time, and media flow rate	Bevel gears		SR MR	Finishing is more effective than conventional AFM in terms of time and SR improvement. Simulation; velocity and pressure profiles. rapid improvement, while MRR is almost unchanged.

3.7 AFM Review Summary

Summary of the results of reviewing all articles as shown in Table 7 and Figure 59.

Table 7. AFM review summary.

	12	20	2	2	17	30	6	8	8	10	1	1
	AFM [x]		Rotational WP AFM		Modeling [x]		Magnetic-assisted [x]		AFM Media		Ultrasonic-assisted	
1998	[3]	1			[1], [2]	2						
1999					[4], [5], [6]	3						
2000	[7]	1			[8]	1						
2001					[9]	1						
2002							[10], [11]	2				
2003												
2004	[14]	1			[12], [13]	2	[15]	1				
2005												
2006	[18], [19]	2			[16], [17], [20], [21]	4						
2007					[22]	1			[25]	1		
2008	[26], [27], [28]	3			[24], [30]	2						
2009	[31]	1	[32]	1	[29]	1						
2010												
2011									[33]	1		
2012	[34], [36]	2					[35], [37]	2				
2013					[38]	1						
2014	[39]	1			[40], [41]	2					[42]	1
2015	[45]	1			[43]	1	[44]	1				
2016					[46]	1						
2017												
2018	[50], [51]	2			[47]				[48], [49]	2		
2019					[53], [54], [55], [56], [58]	5			[52]	1		
2020	[61], [63]	2	[60]	1	[59], [62]	2			[57]	1		
2021							[64]	1	[65], [66]	2		
2022							[68]	1	[67]	1		
2023	[69], [70],[72]	3			[71]	1			[73]	1		
2024												

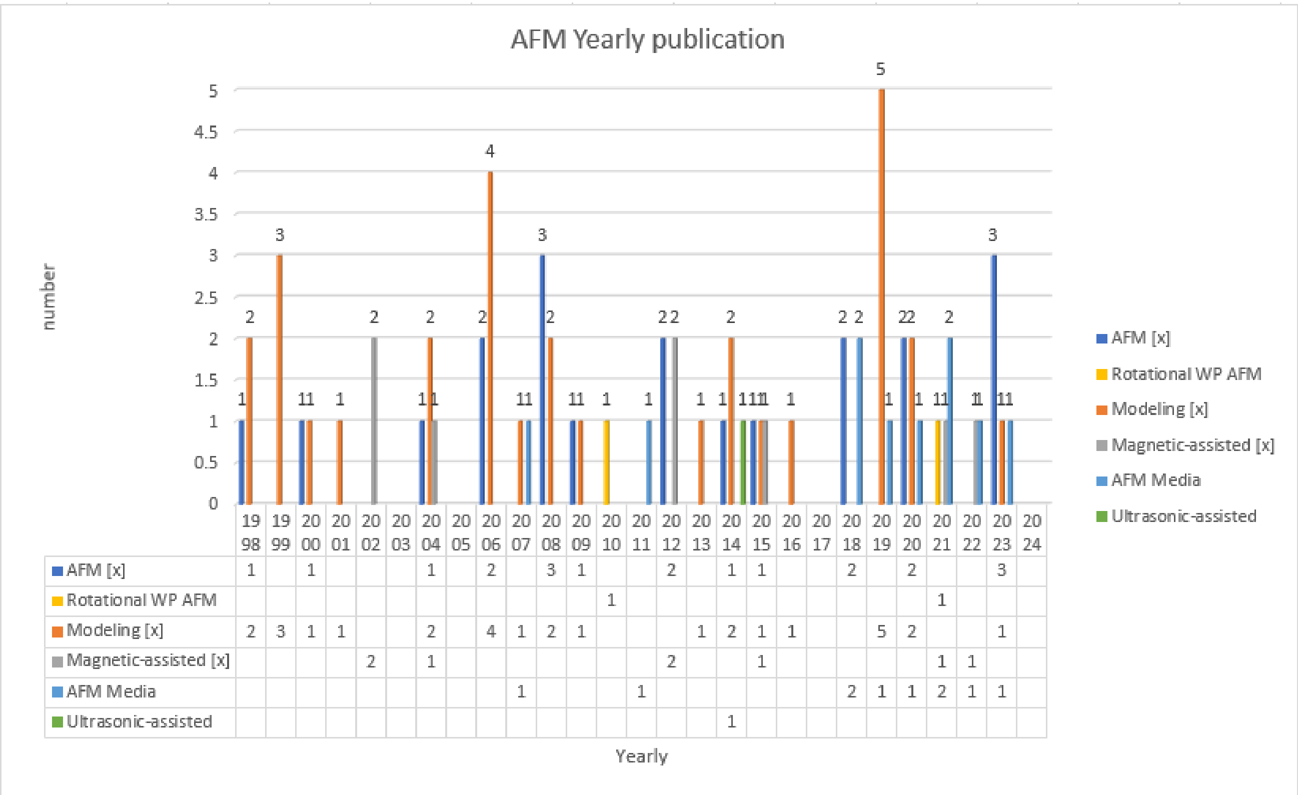


Fig. 62. AFM yearly publication.

4. CONCLUSIONS

From doing a Literature Review on Abrasive Flow Machining, it was found that the articles are summarized in order of the year of study. And can be grouped into 6 main groups: Group 1 is a research study that works on a one-way, two-way AFM machine, etc. Group 2 has the addition of workpiece rotation. Group 3 has done a simulation and compared it with the experiment. Group 4 adds a magnetic field to help. Group 5 studies abrasives mixed with polymers and various carriers. And Group 6 uses ultrasonic to help. and summarize the number of articles from 1998 to 2023 in Table 7 and Figure 59.

Discover the research and development ramifications in more detail. To increase the efficiency of tools and equipment in polishing work. For example, both the rotation of the workpiece is used. Use a magnetic field in some experimental work, the vibration of the tool was used to help with polishing, etc. Makes it possible to find trends in each subgroup. There will be research and development to reduce gaps or research problems to get more detailed and accurate results. However, there must be promotion of research funds. and new knowledge to help bring about rapid changes to meet the needs and be in line with the industrial sector. In the world's leading industries.

Research gap analysis in Abrasive Flow Machining (AFM) involves identifying areas within the field that have not been adequately explored or require further investigation. By identifying these gaps, researchers can determine the direction for future studies and contribute to the advancement of AFM. Here are some potential research gaps or trends in AFM:

1. Optimization of Process Parameters:
   - While significant progress has been made in optimizing AFM process parameters, there is still a need for further research to explore the interaction effects and optimal parameter settings for specific materials and geometries.
   - Investigating the influence of process parameters on surface finish, material removal rates, and deburring effectiveness across a wider range of materials and workpiece geometries would help enhance the understanding and optimization of AFM.
2. Surface Integrity and Material Property Analysis:
   - Further research is needed to understand the impact of AFM on the surface integrity and material properties of different materials.
   - Investigating the effect of AFM on residual stresses, microstructure, fatigue properties, and corrosion resistance would provide insights into the long-term performance and durability of AFM-finished components.
3. Modeling and Simulation:
   - Advanced modeling and simulation techniques can aid in predicting and optimizing AFM outcomes.
   - There is a research gap in developing comprehensive models that incorporate the rheological behavior of the abrasive media, material deformation, and heat transfer during AFM.
   - Developing accurate numerical models and simulation tools can help optimize process parameters, predict surface finish, and reduce experimentation time and costs.
4. Advanced Media Formulations:
   - While there have been advancements in abrasive media formulations, further research can explore new materials or additives that enhance the cutting and polishing capabilities of the media.
   - Investigating the impact of media characteristics, such as particle size distribution, shape, and hardness, on material removal rates and surface finish could lead to improved AFM performance.
5. Sustainability and Environmental Considerations:
   - There is a growing need to address sustainability and environmental concerns in AFM.
   - Research could focus on developing environmentally friendly abrasive media, optimizing media consumption, and minimizing waste generation during the AFM process.

6. Hybrid Machining Approaches:
    - Exploring the potential of combining AFM with other machining techniques, such as electrical discharge machining (EDM) or laser machining, can lead to innovative hybrid machining approaches.
    - Investigating the synergistic effects of combining AFM with other processes can optimize material removal rates, enhance surface quality, and expand the capabilities of AFM.
7. Real-time Monitoring and Control:
    - Developing advanced real-time monitoring and control systems for AFM can enhance process stability and repeatability.
    - Investigating the use of sensors, machine vision, and feedback control mechanisms can improve process monitoring, automate parameter adjustments, and reduce reliance on manual interventions.

Conducting research in these identified gaps can provide valuable insights into the optimization, modeling, material effects, and sustainability aspects of AFM. Addressing these gaps will contribute to the development of more efficient, reliable, and versatile AFM processes and broaden the scope of its applications for conceptual design, and engineering design.

REFERENCES

[1] J. J. Hann and P. S. Steif, "Abrasive wear due to the slow flow of a concentrated suspension," *Wear*, vol. 219, pp. 177-183, 1998.

[2] K. L. Petri, R. E. Billo, and B. Bidanda, "A Neural Network Process Model for Abrasive Flow Machining Operations," *Journal of Manufacturing Systems*, vol. 17, no. 1, pp. 52-64, 1998.

[3] R. E. Williams and V. L. Melton, "Abrasive flow finishing of stereolithography prototypes," *Rapid Prototyping Journal*, vol. 4, no. 2, pp. 56-67, 1998.

[4] R. K. Jain and V. K. Jain, "Simulation of surface generated in abrasive flow machining process," *Robotics and Computer-Integrated Manufacturing*, vol. 15, pp. 403-412, 1999.

[5] R. K. Jain, V. K. Jain, and P. M. Dixit, "Modeling of material removal and surface roughness in abrasive flow machining process," *Machine Tools and Manufacture*, vol. 39, pp. 1903-1923, 1999.

[6] R. K. Jain, V. K. Jain, and P. K. Kalra, "Modeling of abrasive flow machining process: a neural network approach," *Wear*, vol. 231, pp. 242-248, 1999.

[7] V. K. Jain and S. G. Adsul, "Experimental investigations into abrasive flow machining (AFM)," *Machine Tools and Manufacture*, vol. 40, pp. 1003-1021, 2000.

[8] R. K. Jain and V. K. Jain, "Optimum selection of machining conditions in abrasive flow machining using neural network," *Journal of Materials Processing Technology*, vol. 108, pp. 62-67, 2000.

[9] R. K. Jain and V. K. Jain, "Specific energy and temperature determination in abrasive flow machining process," *Machine Tools and Manufacture*, vol. 21, pp. 1689-1704, 2001.

[10] S. Singh, H. S. Shan, and P. Kumar, "Wear behavior of materials in magnetically assisted abrasive flow machining," *Materials Processing Technology*, vol. 128, pp. 155-161, 2002.

[11] S. Singh and H. S. Shan, "Development of magneto abrasive flow machining process," *Machine Tools and Manufacture*, vol. 42, pp. 953-959, 2002.

[12] V. K. Gorana, V. K. Jain, and G. K. Lal, "Experimental investigation into cutting forces and active grain density during abrasive flow machining," *Machine Tools and Manufacture*, vol. 44, pp. 201-211, 2004.

[13] R. K. Jain and V. K. Jain, "Stochastic simulation of active grain density in abrasive flow machining," *Materials and Processing Technology*, vol. 152, pp. 17-22, 2004.

[14] J.-D. Kim and K.-D. Kim, "Deburring of burrs in spring collets by abrasive flow machining," *Advanced Manufacturing Technology*, vol. 24, pp. 469-473, 2004.

[15] S. Jha and V. K. Jain, "Design and development of the magnetorheological abrasive flow finishing (MRAFF) process," *Machine Tools and Manufacture*, vol. 44, pp. 1019-1029, 2004.

[16] V. K. Gorana, V. K. Jain, and G. K. Lal, "Forces prediction during material deformation in abrasive flow machining," *Wear*, vol. 260, pp. 128-139, 2006.

[17] N. K. Jain, V. K. Jain, and S. Jha, "Parametric optimization of advanced fine-finishing processes," *Advanced Manufacturing Technology*. DOI: 10.1007/s00170-006-0682-4, 2006.

[18] H.-J. Tzeng, B.-H. Yan, R.-T. Hsu, and Y.-C. Lin, "Self-modulating abrasive medium and its application to abrasive flow machining for finishing microchannel surfaces," *Advanced Manufacturing Technology*. DOI: 10.1007/s00170-006-0423-8, 2006.

[19] H.-J. Tzeng, B.-H. Yan, R.-T. Hsu, and H.-M. Chow, "Finishing effect of abrasive flow machining on micro slit fabricated by wire-EDM," *Advanced Manufacturing Technology*. DOI: 10.1007/s00170-006-0632-1, 2006.

[20] V. K. Corana, V. K. Jain, and G. K. Lal, "Prediction of surface roughness during abrasive flow machining," *Advanced Manufacturing Technology*, vol. 31, pp. 258-267, 2006.

[21] N. K. Jain, V. K. Jain, and K. Deb, "Optimization of process parameters of the mechanical type advanced machining processes using genetic algorithms," *Machine Tools and Manufacture*, vol. 47, pp. 900-919, 2007.

[22] A. M. Wani, et al., "Simulation for the prediction of surface roughness in magnetic abrasive flow finishing (MAFF)," *Journal of Materials Processing Technology*, vol. 190, pp. 282-290, 2007.

[23] A. C. Wang and S. H. Weng, "Developing the polymer abrasive gels in AFM processes," *Journal of Materials Processing Technology*, vols. 192-193, pp. 486-490, 2007.

[24] U. Caydas and A. Hascalik, "A study on surface roughness in abrasive waterjet machining process using artificial neural networks and regression analysis method," *Journal of Materials Processing Technology*, vol. 202, pp. 574-582, 2008.

[25] M. Das, et al., "Fluid flow analysis of magnetorheological abrasive flow machining (MRAFF) process," *Machine Tools & Manufacture: Design, Research, and Application*, vol. 48, pp. 415-426, 2008.

[26] K. K. Kar, et al., "Performance evaluation and rheological characterization of newly developed butyl rubber-based media for abrasive flow machining process," *Journal of Materials Processing Technology*, 2008.

[27] M. R. Sankar, et al., "Experimental investigations into rotating workpiece abrasive flow finishing," *Wear*, vol. 267, pp. 43-51, 2009.

[28] V. K. Jain, et al., "Investigations into abrasive flow finishing of complex workpieces using: FEM," *Wear*, vol. 267, pp. 71-80, 2009.

[29] L. Fang, et al., "Movement patterns of ellipsoidal particle in abrasive flow machining," *Journal of Materials Processing Technology*, vol. 209, pp. 6048-6056, 2009.

[30] L. Fang, et al., "Temperature as a sensitive monitor for efficiency of work in abrasive flow machining," *Wear*, vol. 266, pp. 678-687, 2009.

[31] A. C. Wang, et al., "Uniform surface polished method of complex holes in abrasive flow machining," *Transactions of Nonferrous Metals Society of China*, vol. 19, pp. 250-257, 2009.

[32] M. R. Sankar, et al., "Rotational abrasive flow finishing (R-AFF) process and its effects on finished surface topography," *Machine Tools & Manufacture*, vol. 50, pp. 637-650, 2010.

[33] M. R. Sankar, et al., "Rheological characterization of styrene-butadiene based medium and its finishing performance using rotational abrasive flow finishing process," *Machine Tools & Manufacture*, vol. 51, pp. 947-957, 2011.

[34] J. Kenda, et al., "Surface Integrity in Abrasive Flow Machining of Hardened Tool Steel AISI D2," *Procedia Engineering*, vol. 19, pp. 172-177, 2011.

[35] J. Kang, et al., "High-speed Internal Finishing of Capillary Tubes by Magnetic Abrasive Finishing," *Procedia CIRP*, vol. 1, pp. 414-418, 2012.

[36] D. Bahre, et al., "Investigation of one-way abrasive flow machining and in-process measurement of axial forces," *Procedia CIRP*, vol. 1, pp. 419-424, 2012.

[37] P. D. Kamble, et al., "Use of magneto abrasive flow machining to increase material removal rate and surface finish," *Mechanical, Automobile & Production Engineering*, vol. 2, pp. 249-262, 2012.

[38] E. Uhlmann, et al., "Development of a material model for visco-elastic abrasive medium in abrasive flow machining," *Procedia CIRP*, vol. 8, pp. 351-356, 2013.

[39] G. Venkatesh, et al., "Finishing of bevel gears using abrasive flow machining," *Procedia Engineering*, vol. 97, pp. 320-328, 2014.

[40] M. Swat, et al., "Improved process control and model of axial forces of one-way abrasive flow machining," *Procedia CIRP*, vol. 14, pp. 19-24, 2014.

[41] J. Kenda, et al., "Modeling and energy efficiency of abrasive flow machining on tooling industry case study," *Procedia CIRP*, vol. 13, pp. 13-18, 2014.

[42] G. Venkatesh, et al., "On ultrasonic assisted abrasive flow finishing of bevel gears," *Machine Tools & Manufacture*, vol. 89, pp. 29-38, 2015.

[43] E. Uhlmann, et al., "CFD simulation of the abrasive flow machining process," *Procedia CIRP*, vol. 31, pp. 209-214, 2015.

[44] S. Kumar, et al., "Nanofinishing of freeform surfaces (knee joint implant) by rotational-magnetorheological abrasive flow finishing (R-MRAFF) process," *Precision Engineering*, vol. 42, pp. 165-178, 2015.

[45] T. Bremerstein, et al., "Wear of abrasive media and its effect on abrasive flow machining results," *Wear*, vols. 342-343, pp. 44-51, 2015.

[46] E. Uhlmann, et al., "A pragmatic modeling approach in abrasive flow machining for complex-shaped automotive components," *Procedia CIRP*, vol. 46, pp. 51-54, 2016.

[47] M. S. Duval-Chaneac, et al., "Characterization of maraging steel 300 internal surface created by selective laser melting (SLM) after abrasive flow machining (AFM)," *Procedia CIRP*, vol. 77, pp. 359-362, 2018.

[48] A. C. Wang, et al., "A study on the abrasive gels and the application of abrasive flow machining in complex-hole polishing," *Procedia CIRP*, vol. 68, pp. 523-528, 2018.

[49] M. R. Sankar, et al., "Nano-finishing studies using elastically dominant polymers blend abrasive flow machining medium," *Procedia CIRP*, vol. 68, pp. 529-534, 2018.

[50] C. Peng, et al., "Study on improvement of surface roughness and induced residual stress for additively manufactured metal parts by abrasive flow machining," *Procedia CIRP*, vol. 71, pp. 386-389, 2018.

[51] E. Uhlmann and S. Robkamp, "Surface integrity and chip formation in abrasive flow machining," *Procedia CIRP*, vol. 71, pp. 446-452, 2018.

[52] H. Wei, et al., "Development of novel guar gum hydrogel-based media for abrasive flow machining: shear-thickening behavior and finishing performance," *International Journal of Mechanical Sciences*, vols. 157-158, pp. 758-772, 2019.

[53] Y. Fu, et al., "A new predictive method of the finished surface profile in abrasive flow machining process," *Precision Engineering*, vol. 60, pp. 497-505, 2019.

[54] H. Wei, et al., "On establishment and validation of a new predictive model for material removal in abrasive flow machining," *Machine Tools & Manufacture*, vol. 138, pp. 66-79, 2019.

[55] S. Han, et al., "Residual stress profiles induced by abrasive flow machining (AFM) in 15-5PH stainless steel internal channel surfaces," *Journal of Materials Processing Technology*, vol. 267, pp. 348-358, 2019.

[56] C. Bouland, et al., "Abrasive flow machining of laser powder bed-fused parts: numerical modeling and experimental validation," *Journal of Materials Processing Technology*, vol. 273, p. 116262, 2019.

[57] Z. Zhang, et al., "Preparation and application of a novel water-based viscoelastic polishing fluid for abrasive flow machining," *Procedia CIRP*, vol. 89, pp. 282-287, 2020.

[58] P. Ali, et al., "Experimentation and modeling of CNT additive abrasive media for micro finishing," *Measurement*, vol. 151, p. 107133, 2020.

[59] C. W. Kum, et al., "Prediction and compensation of material removal for abrasive flow machining of additively manufactured metal components," *Journal of Material Processing Technology*, vol. 282, p. 116704, 2020.

[60] J. Zhao, et al., "Investigation of the optimal parameters for the surface finish of K9 optical glass using a soft abrasive rotary flow polishing process," *Journal of Manufacturing Processes*, vol. 49, pp. 26-34, 2020.

[61] R. Baraiya, et al., "In-situ simultaneous surface finishing using abrasive flow machining via novel fixture," *Journal of Manufacturing Processes*, vol. 50, pp. 266-278, 2020.

[62] K. Korzyńska, et al., "Flow burnishing with glass microspheres and its impact on the surface condition of 2017A alloy elements," *Journal of Manufacturing Processes*, vol. 58, pp. 1297-1303, 2020.

[63] S. Han, et al., "Surface integrity in abrasive flow machining (AFM) of internal channels created by selective laser melting (SLM) in different building directions," *Procedia CIRP*, vol. 87, pp. 315-320, 2020.

[64] V. K. Sharma, "Modeling and analysis of a novel rotational magnetorheological abrasive flow finishing process," *International Journal of Lightweight Materials and Manufacture*, vol. 4, pp. 290-301, 2021.

[65] N. Dixit, V. Sharma, and P. Kumar, "Experimental investigations into abrasive flow machining (AFM) of 3D printed ABS and PLA parts," *Rapid Prototyping Journal*, vol. 28, no. 1, pp. 161-174, 2022.

[66] G. A. Gupta, et al., "Rheological characterization of newly developed by fly-ash mixed polymeric media and its finishing performance through abrasive flow machining," *Cleaner Engineering and Technology*, vol. 2, p. 100085, 2021.

[67] B. Zhang, et al., "Machining uniformity and property change of abrasive media for micro-porous structures," *Journal of Manufacturing Processes*, vol. 307, p. 117675, 2022.

[68] B. Zhang, et al., "Study on rheological behaviors of media and material removal mechanism for abrasive flow machining (AFM) microstructures and corresponding simulations," *Journal of Manufacturing Processes*, vol. 73, pp. 248-259, 2022.

[69] S. M. Basha, et al., "Development and performance evaluation of galactomannan polymer based abrasive medium to finish atomic diffusion additively manufactured pure copper using abrasive flow finishing," *Additive Manufacturing*, vol. 61, p. 103290, 2023.

[70] I. A. Ansari, et al., "Effect of ground tire rubber media’s viscoelasticity and flow passage geometry on the abrasive flow finishing of helical gear," *Journal of Manufacturing Processes*, vol. 101, pp. 219-233, 2023.

[71] B. Zhang, et al., "Theoretical and numerical analysis on finishing mechanism by rheological properties and flow behaviors of abrasive media in micro-porous structures," *Journal of Manufacturing Processes*, vol. 99, pp. 513-526, 2023.

[72] X. Dong, et al., "Fine finishing of internal surfaces using cassava starch medium," *Journal of Materials Processing Technology*, vol. 315, p. 117918, 2023.

[73] S. M. Basha, et al., "Experimental investigation on deballing and surface finishing of selective laser melted 18Ni300 steel using polymer rheological abrasive medium," *Wear*, vol. 523, p. 204813, 2023.