A review on variant of visco-elastic polymer media for abrasive flow finishing

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KEYWORDS

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ABSTRACT

Abrasive Flow Finishing (AFF) is a specialized surface finishing method used in a variety of applications, notably for components with complicated geometries and difficult-to-access locations. The improvement of surface finish can lead to enhanced functionality, reliability, and customer satisfaction across various sectors. Wide industrial sectors are associated with AFF like aerospace, automotive, medical, die and mold manufacturing etc. A specifically developed viscoelastic polymer material mixed with abrasive particles forms the basis of AFF. This substance can flow while still applying pressure because of its thick, paste-like consistency. Various carrying mediums are utilized and some require customized media properties, each tailored to unique application requirements. In the process, selecting the right carrying media is crucial to in attaining the best possible surface finish and performance since it affects material removal rates, surface quality, and overall efficiency. The current review paper provides a comprehensive evaluation of the various media options for AFF applications.

1. Introduction

In the realms of manufacturing and design, surface finish is essential since a product's durability, functionality, and appearance are all closely related to the surface quality. A superior surface quality minimizes the risk of failure in important components by eliminating flaws that might cause fatigue or fracture. The AFF process involves, the abrasive medium flowing over and through the component's surfaces as a result of the media reciprocating action. The media reciprocates from the lower media cylinder to the upper media cylinder passing through the component at the work holding fixture as shown in Fig. 1. It is possible to regulate the speed, pressure, and duration of this motion. As the medium flows, its abrasive particles scrape and polish the workpiece surface. The movement eliminates material, smoothing out flaws, burrs, and uneven edges (Kumar et al., 2016).

The carrier media consisting of Abrasive-laden media, also known as self-deformable polymers, is one of the most crucial components of the AFM process. To finish the surface to the nanoscale, it should have three fundamental qualities: self-deformability, good flowability to easily pass-through complex passages, and the capacity to abrade while flowing. The primary purpose of abrasive particles in AFM media is to serve as a cutting tool for material removal from the surface of the work piece. The basic carrier is a high-molecular-weight polymer with primarily elastic characteristics and low viscosity (Jain, 2013). Extrude Hone developed Abrasive Flow Finishing in 1960's to meet the problems of finishing internal surfaces with complicated geometries, difficult-to-reach locations, deburring, radiusing and eliminating recast layer. Various configurations of AFF machines are available based on the particular requirements of the application. Fig. 2 below displays the various Process parameters for the AFF Research Area (Kumar et al., 2024).

The primary configurations of AFF machines are intended to govern how the abrasive media flows through the workpiece, how the workpiece is mounted, and how the media is operated or controlled. Media is inserted from one end of the workpiece through a hydraulically pressurized flow in a one-way AFF. The AFF medium is collected

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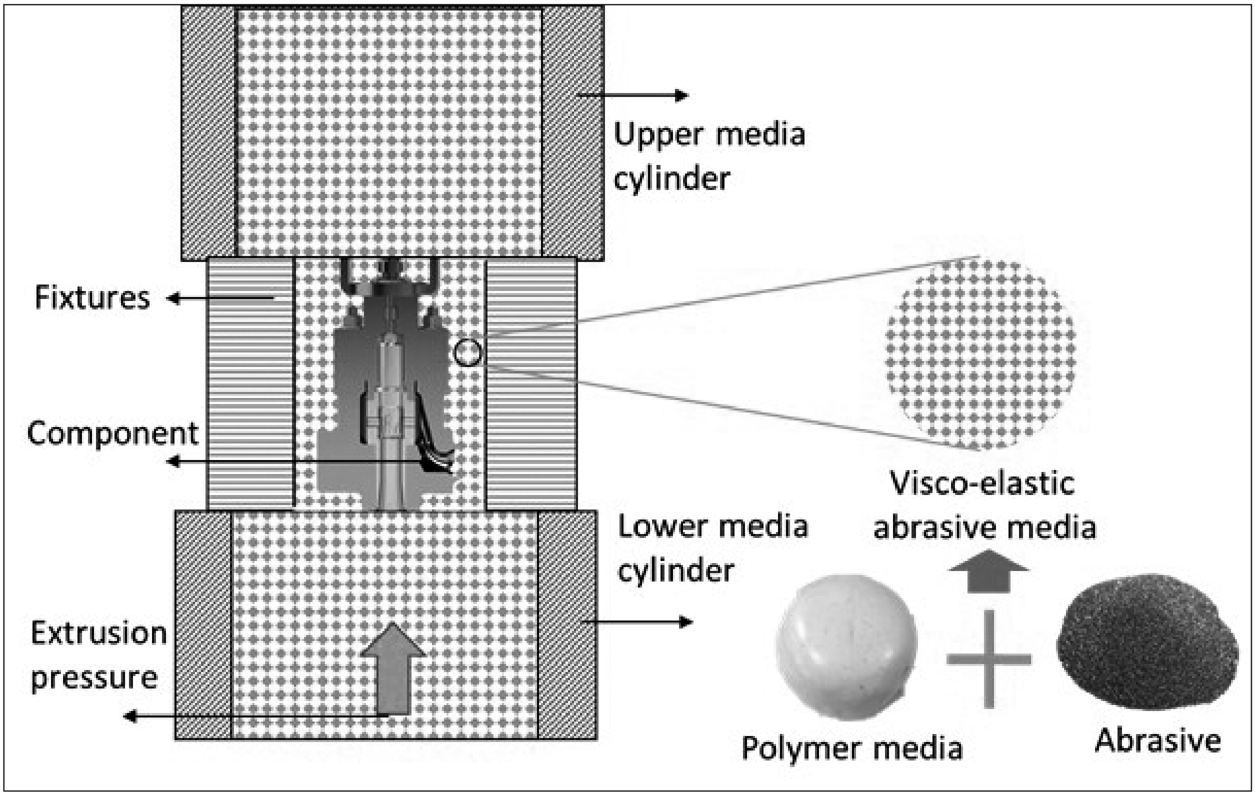

Fig. 1. Working principle of AFF.

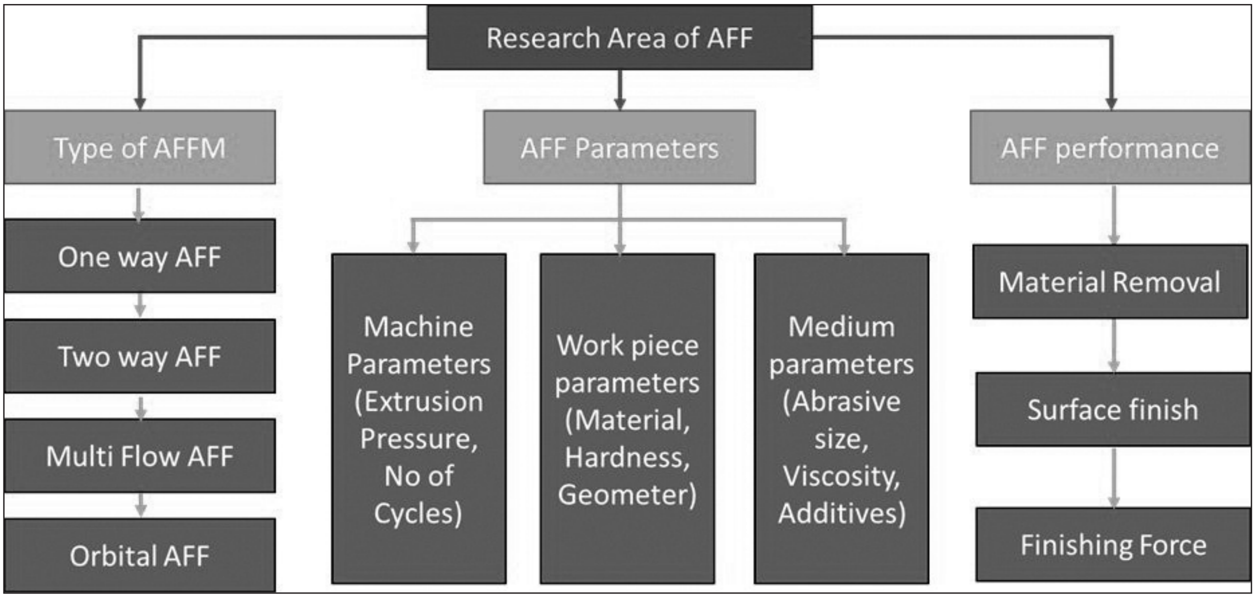

Fig. 2. Classification of AFF research areas.

at the exit and reinserted from the entrance after extrusion. The two-way configuration involves moving the AFF medium back and forth between two cylinders that contain the medium in opposite directions, with a workpiece fixture positioned in between. The medium in Multi-flow AFF is transferred back and forth between four cylinders that contain medium and are positioned opposite to one another. The orbital AFF process uses a medium to move back and forth between two hydraulically operated mediums that have a displacer arrangement and cylinders. The workpiece receives orbital vibrations in the displacer's transverse direction (Howard & Cheng, 2013). The right combination of AFF process parameters is required to be selected to achieve the necessary material removal and surface finishing. They can be divided into three groups:

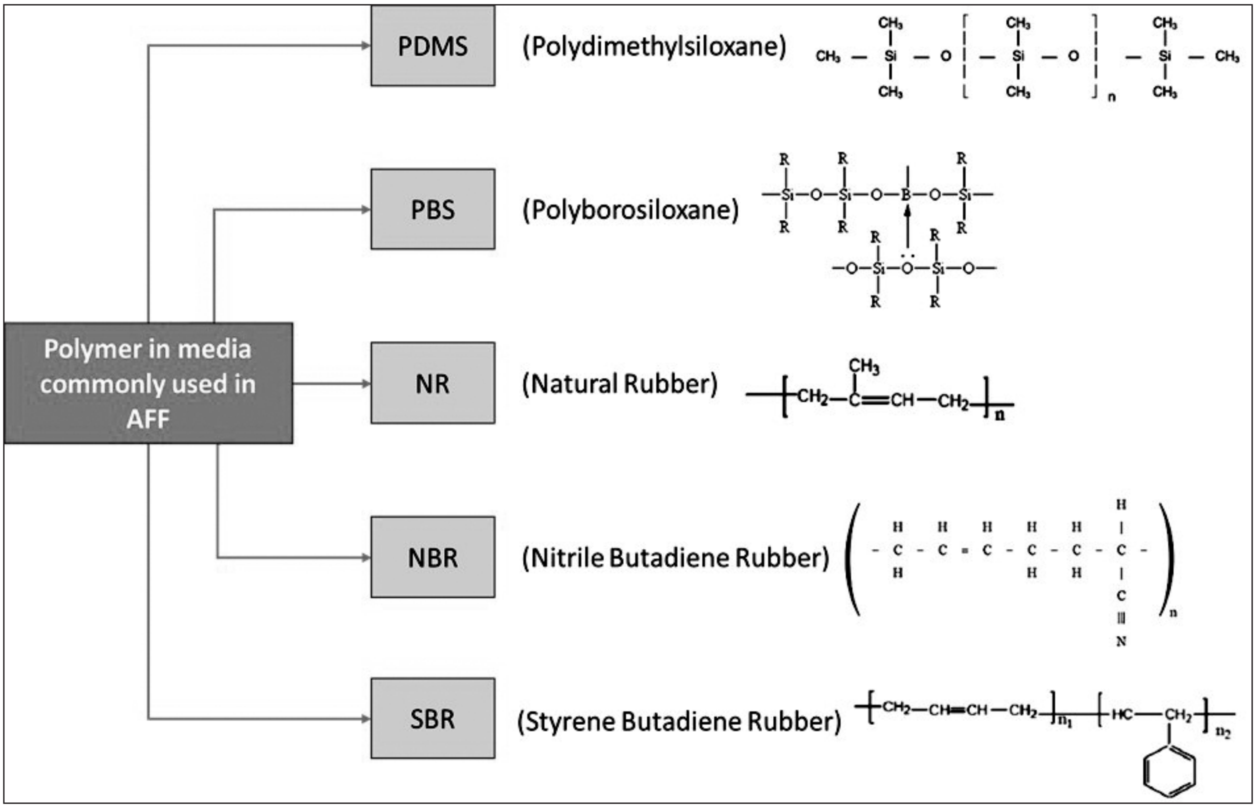

Fig. 3. Commonly used carrier media in AFM.

parameters related to the machine, workpiece and medium (Cheema et al., 2012). Force per unit contact area determines extrusion pressure. Pressure affects the force applied per unit area of the AFF medium as well as the friction between the cylinder and its piston. The power unit that can be operated mechanically or hydraulically for extrusion value ranges from 7 Bar to 200 Bar, according to the experimental investigation (Jain & Adsul, 2000). A key element in achieving the necessary surface finish is the number of cycles. The final requirement determines its value. Because abrasive particles have sharp cutting edges and workpiece surfaces have higher surface peaks, it has been noted in the literature that more improvements in surface finish and material removal rate occur during the initial cycles of the AFF process (Jain et al., 1999). The workpiece material's ductility and hardness have a big impact on the AFF process's performance and surface finishing outcomes. The geometry, the initial surface finish and the volume of the workpiece are also one of the important considerations in the workpiece parameters (Loveless et al., 1994). The type of viscoelastic polymer and quantity of blending oil used determine the viscosity of the AFF medium. AFF medium with a higher viscosity causes more material to be removed from the workpiece and creates a uniform surface by strengthening the bond between the abrasive particles and the polymer. Reduced polymer-abrasive particle bonding results in abrasive particles rotating on the workpiece surface rather than sliding, which lowers the material removal rate and results in a poor surface finish. This is caused by a lower viscosity of the AFF medium (Kumar et al., 2024). Because smaller abrasive particles result in a smaller depth of indentation in the workpiece, a decrease in surface roughness and MRR has been observed with a decrease in abrasive particle size (Sankar et al., 2011). The AFF process variables such extrusion pressure, cycle time, viscosity, abrasive grain size and other parameters effects the output responses specifically, surface finish and material removal rate. Many researchers have carried out experimental investigations with controllable input parameters to achieve effective surface finish (Siddiqui & Hameedullah, 2010).

2. Materials

The material consideration of media is an important criterion that are used presently in AFF application. During selection of the medium, it was also kept in mind that the medium should be stable mechanically. A considerable level of shearing stress will arise during the movement of the medium in the AFF process. The material begins to deteriorate during the flow as a result of shearing stress, the medium will be unable to function as a binder for the abrasive particles. This underscores the significance of the mechanical stability of the medium. The medium must simultaneously remain inert to both the abrasive particles and the workpiece, making the chemical properties a critical consideration. While selection of the carrier, it is essential to ensure that the medium consists of mechanical stability and is chemically compatible with both the abrasive particles and the processing oil (Kar et al., 2009a). The list of representation of commonly used carrier media with its respective chemical structure in AFF is as shown in Fig. 3.

2.1. PDMS – Polydimethylsiloxane

PDMS is an organic silicone characterized by its viscoelastic properties, making it appropriate for engineering applications. The material exhibits significant alterations in its properties based on temperature and flow rate. At elevated temperatures or high flow rates, it functions as a viscous liquid; conversely, at lower temperatures or reduced flow rates, it acts as an elastic solid. Polymers containing an R2Si-O unit are commonly referred to as silicones, whereas the repeating unit Si-O is known as siloxane. In the case of PDMS, the inherent flexibility of the siloxane backbone allows the chains to readily organize and reorganize, positioning the methyl groups at their surfaces and interfaces. The adjustment of the cross-link ratios between the curing agent and the base elastomer facilitates the precise modification of the mechanical and chemical characteristics of PDMS (Genoves et al., 2023). PDMS is utilized in AFF because of its viscoelastic characteristics and adjustable rheological properties. This enables adaptation to complex geometries and ensures uniform abrasive contact, which is essential for attaining high-quality surface finishes in detailed components. Research suggests that media composed of PDMS can diminish surface roughness to the nanometer scale, rendering it exceptionally appropriate for sectors including aerospace, biomedical, and micro-manufacturing (Mangesh, 2023).

2.2. PBS – Polyborosiloxane

PBS with high molecular weight acts as a viscoelastic material, which possesses both viscous and elastic components. PBS is recognized for its temperature stability, chemical inertness, and customizable abrasiveness, distinguishing it from traditional media. The intriguing viscoelastic characteristics, along with the high mobility of the siloxane backbone and the reversible inter-molecular interactions, enable PBSs to be utilized as impact-resistant protective materials. These characteristics render it particularly suitable for high-precision sectors, including aerospace, automotive, and biomedical manufacturing. The Abundant boron (Si−O−B(OH)2) terminal groups in PBSs facilitate the creation of reversible physical cross-links via hydrogen bonding. This characteristic enables PBSs to demonstrate a viscous fluid behaviour over extended time periods while exhibiting a rigid mechanical response when subjected to rapid extensional strain (Li et al., 2019).

2.3. NR – Natural Rubber

NR has a degradation temperature of approximately 375°C, the media shows a two-step degradation with higher thermal stability. NR exhibits a lower tear strength due to its relatively lower degree of chemical branching, while it demonstrates a superior tear modulus and low hysteresis loss. The material exhibits a softer consistency in comparison to other materials due to the combined influences of mastication, oil processing, temperature, and other factors. Consequently, less effort is needed to deform it during the compression process (Kar et al., 2009a). NR is distinguished by its exceptional elasticity, resilience, and tensile strength, rendering it an ideal choice for applications involving AFF. The material exhibits high elasticity, tensile strength, energy absorption and shear characteristics, enabling it to exert regulated pressure on abrasive particles, thereby improving the uniformity of material removal and surface finish (Fletcher & Fioravanti, 1996).

2.4. NBR – Nitrile Butadiene Rubber

NBR, also known as nitrile rubber, is a synthetic copolymer of acrylonitrile and butadiene. While the butadiene component in the material provides elasticity. Because of the increased polarity and glass-transition temperature, rubber with a higher nitrile content typically has greater strength. For a range of component concentrations, the NBR's elongation at break is high. The modulus values also show a positive trend. Due to the special properties of NBR material in a variety of applications where oil

Table 1
Review on the previous research in AFF utilizing variable type of media.

Media type	Researcher, Year, [reference]	Media composition	Work piece material	Remarks
PDMS – Polydimethylsiloxane	Zhang et al. (2023)	PDMS + (SiC, abrasive grits ranged from 15 µm to 25 µm) % of Weight ratio 57 : 43	Stainless steel and Aluminum	Surface roughness has improved from Ra 2.35 µm to Ra 0.55 µm
	Howard and Cheng (2014)	PDMS + (SiC, abrasive grits of 24, 40, 400) % of Weight ratio 65 : 35	Titanium alloy 6Al4V	Surface roughness has improved to Ra 0.2 µm to 0.5 µm from Ra 1.21 µm
	Sarkar and Jain (2015)	PDMS + (SiC abrasive grits of 1000) % of Weight ratio 50 : 50	Stainless steel and Ti-6Al-4V	Surface roughness has improved to range of Ra 0.042 µm to 0.062 µm
	Manjunath et al. (2020)	PDMS + (SiC abrasive grits of 60, 220, 400, 800) % of Weight ratio 50 : 50	Aluminum	Surface roughness has improved to Ra: 0.35 µm from Ra 0.712 µm
PBS – Polyborosiloxane	Hull et al. (1992)	PBS + (Diamond and SiC abrasive size of 0.25 to 1200 µm) % of volume 66	Not disclosed	The medium's behavior at varying temperatures, abrasives, and strain rates size of the particles are explored
	Bremerstein et al. (2015)	PBS + (SiC abrasive of abrasive size of 17, 525, 745 µm) % of Weight ratio 41.6 : 58.4	Austenitic stainless steel	Surface roughness Ra has improved in the range of 0.1 µm to 0.5 µm from Ra 8 µm
	Davies and Fletcher (1995)	PBS + (SiC abrasive grits of 60, 100) % of Weight ratio 50 : 50	Die steel	Rheological properties of the media has been studied.

NR – Natural Rubber	Rajesha et al. (2011)	NR + (SiC abrasive size: 200 µm) Ratio of abrasive to polymer: 0.67; 1.0; 1.5	Brass	Final surface roughness (Ra) values typically ranging from 0.2 µm to 1.0 µm.
	Hashmi et al. (2021)	NR + (SiC abrasive grits 120, 220, 320)	3D printed ABS (Acrylonitrile Butadiene Styrene) parts	Final surface roughness (Ra) improved from 21.93 µm to 0.88 µm.
	Kar et al. (2009)	NR + (SiC abrasive sizes of 12, 18, 37, 68, 187 µm)	Aluminum and EN-8	Through Silicon Carbide abrasive 220 mesh size, surface roughness (Ra) of 3.87 µm is achieved from 5.03 µm for Aluminum, whereas roughness (Ra) of 1.10 µm is achieved from 1.24 for EN-8.
NBR – Nitrile Butadiene Rubber	Dhull et al. (2021)	Media + (SiC, Al_2O_3 abrasive grits of 100, 200, 300) Abrasive Ratio 2:1 1:1 1:2	Aluminum, Brass, Cast Iron	The percentage of improvement in surface roughness is found higher in hybrid AFM processes. The surface roughness is reduced from 1.4 µm to 0.07 µm.
	Vaishally (2020)	NBR + SiC	Not disclosed	SiC abrasives (800 and 2000 mesh sizes), achieved surface roughness improvement from 0.32 µm to 0.09 µm.
SBR - Styrene Butadiene Rubber	Sankar et al. (2010)	SBR + (SiC abrasives size of 53 µm)	Aluminum	Initial Surface Roughness (Ra): 0.65 µm is reduced to 15% after optimization of process parameters.
	Gao et al. (2013)	SBR + (Al2O3 abrasives size of 80 µm and SiC abrasives size of 350 µm)	Titanium alloy	Final surface roughness (Ra) improved from 6.32 µm to 0.59 µm
	Ansari et al. (2023)	SBR + SiC	Alloy Steel	A better surface finish of 110 nm and 124 nm is achieved.

resistance is necessary. Long chain surface modified montmorillonite could be used to enhance the mechanical characteristics of NBR. The material is frequently employed in industrial settings where resistance to fuel, oil, and chemicals is necessary. NBR's higher acrylonitrile (ACN) content and intercalation increase the likelihood of hydrogen bonding. The filler–polymer interactions are responsible for the modified clay-filled samples' increased modulus. The interactions allow the polymer to absorb more energy, which is then used to further decoil the chains, resulting in a higher elongation at break. The addition of hard filler particles is another factor contributing to the filled rubber's higher modulus when compared to gum (Jones & Park, 2019; Balachandran & Bhagawan, 2012).

2.5. SBR – Styrene Butadiene Rubber

SBR is one of the commercial material, as the result of random copolymerization causing repeating monomer units in a mixture of roughly 25% styrene and 75% butadiene to be randomly arranged along the polymer chain. The degradation temperature of SBR is roughly 490°C which indicates the thermal stability of the material. The length of the chain, number of side groups, branching, and cross-linking all affect the physical characteristics of the polymer (strength and flexibility). The polymer is stronger when it has a longer chain and polar side groups (polymer chains lose their flexibility). To give the medium flexibility and low density, the base polymer is made up of two monomers: butadiene, which is the only main chain, and styrene, that is branched. It is frequently used in wide industrial applications like footwear production and the automotive sector. Breaking the molecular bonds through mechanical and thermal breakdown while the base polymer passes through a two-roll mill can lower its viscosity. During AFF, these polymers' dominant elastic properties aid the medium in exerting the radial force. The viscous component is represented by plasticizer and other additives, whereas the polymer chain is the predominant elastic component (Zhan et al., 2011; Kar et al., 2009b).

3. Background on AFF With Various Media

The media used in AFF plays a critical role in determining the effectiveness, efficiency, and surface quality achieved during the process. The process relies heavily on the choice of media, which directly influences the process performance. Based on the previous research on different media the overview of the AFF utilizing variable types of media is shown in Table 1.

4. Conclusions

The following subsequent conclusions can be derived from the literature review on the experimental results with respect to various abrasive polymer media:

- The design of the machine configurations, fixtures and process parameters particularly selection of the finishing medium, represent significant challenges and are critical factors influencing its overall performance.
- Based on the comparative study and essential properties of various types of media the major advantages of individual media are known. PDMS known for its flexibility, chemical stability, and customizable viscosity, also enables precise control over abrasive flow, making it ideal for delicate, complex geometries.PBSis highly viscoelastic and offers superior thermal stability, enhancing its performance in applications requiring consistent flow behaviour at high temperatures. NR is flexible, affordable, and exhibits good wear resistance. NBR is resistant to oil and has better stability. BR provides good abrasion resistance and is relatively affordable, making it useful for AFF applications where cost efficiency is a priority.
- From the current survey, it has been observed that different media has shown predominant effect on the achievable surface roughness. Furthermore, enhanced result can be obtained by combinations or hybridizing the variable media. Also, indigenous synthesis and development of effective media is essential for continues supply chain of consumables to industries as per the AFF application.
- The adoption of environmentally friendly media, which minimizes ecological impact while ensuring superior finishing outcomes, is increasingly gaining popularity.

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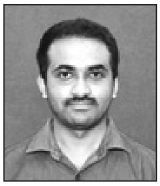

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