Retraction

Retraction: A Review on Experimental Investigation of Magnetic Abrasive Finishing process (IOP Conf. Ser.: Mater. Sci. Eng. 1145 012066)

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IOP Publishing regrets that our usual quality checks did not identify these issues before publication, and have since put additional measures in place to try to prevent these issues from reoccurring. IOP Publishing wishes to credit anonymous whistleblowers and the Problematic Paper Screener [1] for bringing some of the above issues to our attention, prompting us to investigate further.

[1] Cabanac G, Labbé C and Magazinov A 2021 arXiv:2107.06751v1

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A Review on Experimental Investigation of Magnetic Abrasive Finishing process

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Abstract. Magnetic Abrasive Finishing (MAF) is one of the superfinishing processes that produce nanoscale finishing for both metals and non-metals. Also, the MAF process can be utilized for the finishing of magnetic and non-magnetic materials. The basic mechanism of the MAF process consists of a flexible magnetic abrasive brush (FMAB) is developed using magnetic particles and abrasives. The FMAB acts as a multipoint cutting tool and removes material with the application of indentation and shearing action of abrasives. The literature suggests that the concept of surface finish (SF) and material removal rate (MRR) in MAF is limited to only a few materials. However, the phenomena involved in this process must be studied to improve the process mechanism and surface finish capabilities. In this review paper, the concept of surface finish mechanisms using MAF has been revised to date, the possibility of future research has been named and talked over. Attempts to improve the surface finish of MAF are also talked about.

Keywords: Magnetic abrasive finishing; Flexible magnetic abrasive finishing; Surface finish; Material removal rate.

1. Introduction
In the present era, fine finishing of advanced materials is required to improve the life and quality of the components under fatigue loading. The application of fine finish is required in medical implants and engineering applications. However, the main difficulty with traditional finishing processes is to control finishing forces[1]. The MAF process is one of the non-traditional processes to achieve the nano-level finish. The main advantage of the MAF process is it can easily fabricate on milling and lathe machines for the finishing of flat as well as cylindrical objects[2]. Also, the MAF process can finish both metals and non-metals of complex shapes with suitable fixtures. The removal of material in the MAF process is in the form of microchips using an FMAB. The cutting action of FMAB is easily controlled by magnetic flux density[3]. In this present work, a review on the finishing of different flat surfaces using the MAF process was summarized.

1.1. Mechanism of MAF process
MAF process is a non-traditional machining process, it consists of an FMAB composed of abrasive particles and magnetic particles are used for finishing. Figure 1. Shows the schematic of the MAF process. The FMAB is formed at the end of the electromagnet and is continuously in rotary motion. The cutting action taking place between FMAB and stationary workpiece due to the cutting
action of both axial force and centrifugal action[4]. In the MAF process finishing takes place due to the action of indention and shearing. The indention force occurs due to strong magnetic abrasive chains at the end of FMAB and the removal of material takes place due to relative motion between FMAB and workpiece. In this process, there is the main conflict between a ferromagnetic material and a non-ferromagnetic material. In the case of ferromagnetism, the chain formation is large compare to non-ferromagnetic. Also, adhesion is formed in ferromagnetism, but not in the case of non-ferromagnetic[5]. But these two situations depend on the user's interest and can take advantage of this particular procedure. In MAF, attempts to use a flexible magnetic brush result in a better solution in the case of nanoscale surface treatment.

![Figure 1. MAF process (a) flat surfaces (b) cylindrical surfaces](image)

2. Literature
[6] investigated the finishing capabilities of different magnetic particles by varying their different mesh sizes in the finishing of the Cylindrical MAF process. They used unbound abrasives and magnetic particles with different mesh sizes for experimentation. They finished HRC 55 material using both steel grits and iron grits along with SiC abrasives. The researchers observed that steel grit gives a better finish and MRR compared to iron grit. [7] investigated the finishing mechanism of AISI 440C steel using the Cylindrical MAF process. The experiments were carried out using the design of experiments by varying different abrasives slurries of Al₂O₃ and SiC along with workpiece speed and working gap. They observed that using SiC abrasive slurry, the speed at 355 rpm and 2mm working gap getting better results compared to Al₂O₃ slurry. They also observed that the maximum SF that can achieve using this process is 0.27μm. [8] studied the finishing mechanism of the electrochemical MAF process while finishing AISI- 420 material. The experimentation was carried out with process parameters rotational speed, vibrational frequency, current to study on SF. They observed that the SF is proportional to electrolyte concentration and MRR is mostly affected by magnetic flux. The surface and edge finishing capabilities of the MAF process were investigated by [9]. They investigated the process parameters influence on edge finishing of silver steel bars. They observed that nano level finish up to 50nm in the cycle time of 3 minutes.[10] studied the influence of process parameters on removing of burrs in the MAF deburring process. The researchers studied the deburring capabilities of the MAF process by changing various process parameters like working gap, rotational speed, etc. They observed that abrasive size and speed are significant variables to reduce burr height.[11] investigated the basic mechanisms of the MAF process by varying different process parameters while finishing SUS 304. They studied the variants in the MAF process and the formation of FMAB by varying different abrasives and iron particles. The authors explained the different finishing forces and the area of application of forces on the workpiece,[12] studied the mechanism of the MAF process while finishing the SS304 hollow pipe. The authors conducted experiments using an RSM-based central composite design and the simulation was carried out with Maxwell software. Based on
simulation results magnetic flux density is the most significant process parameter of SF and based on experimental results 89.6% SF improvement was observed after MAF finishing. The MAF process finishing characteristics with varying frequency of magnetic field was investigated by[13]. The authors used different cutting fluids to study the SF capabilities of the MAF process. They also observed that by varying tool angle the SF is changes rapidly and the increase in the speed of the tool with low frequency is preferable for nano-level surface finish. [14] studied the finishing of SS 316L material using the MAF process. They carried out experimentation using orthogonal arrays to study the variation of SF and MRR. The maximum SF and MRR at optimum condition are 81.28% SF improvement and MRR of 107.31mg. [15] studied the performance of the polishing tool in the internal finishing of the MAF process. The authors conducted both theoretical and experimental analysis and the maximum MRR and SF observed at the optimum condition of process parameters are 15μm/min and 0.258 μm. Simulation studies on SF in the MAF process for irregular surfaces were investigated by [16]. They conducted both numerical and experimental studies by varying different process parameters. As a result, they observed that SF depends on magnetic flux and fine grit size of abrasives. Nano level surface finishing capabilities of the MAF process were investigated by[17]. They conducted numerical studies with different electromagnetic materials with existing permeant magnets. Based on simulation results, they conducted experimental studies while finishing ss304 material and the maximum SF observed is 22nm. Pei- Y[18] investigated the MRR mechanism of the MAF process for finishing additively prepared parts. Then authors conducted experiments with fixed magnetic tool and flexible magnetic tool. They observed that large size abrasives used for rough finishing and small size abrasive better for fine finish but for higher MRR large size abrasives are preferable. The MAF based aluminium sheet finishing was investigated by[19]. The authors carried out experimentation by varying one parameter at a time to study SF improvement. Based on experimental results, working gap and finishing time are most significant process parameters on SF improvement. [20] carried out simulation studies on finishing capabilities of vibration based MAF process. The authors conducted both simulation and experimental studies with different process parameters influence on SF. Based on results, the SF improved with vibrations compared to conventional MAF process.

2.1 Process Parameters selection in MAF Process

Based on the literature the most preferable process parameters and their range decide the finishing capabilities of the MAF process in achieving the nonlevel finish. Based on past researchers the most influencing process variables in the MAF process are voltage, abrasive size, electromagnet speed, working gap, and flux density[21]. Whereas, process responses are mostly discussed in the literature SF and MRR. Figure 2 shows the cause & effect diagram of the MAF process.

![Figure 2. Cause and effect diagram for MAF](image)

Figure 3 explains the variation of SF and MRR for various process parameters speed, feed, gap, and abrasive size for AISI 304 material explained by [22]. From figure 3(a) as the speed increases the 0SF increases up to a certain speed then decreases because due to high-speed indentation force is increases and SF declines. Similarly, as the speed increases the MRR increases proportionally because at high speeds the indentation and shearing forces are increase MRR. From figure 3(b) as the feed increases the SF and MRR both decrease proportionally. As the feed increases the time for application
of finishing forces decreases due to this just rubbing action takes place on the surface. From figure 3(c) as the gap increases the SF increases and MRR decreases proportionally. As the gap increases the amount of formation of FMAB chains increases. As the gap increases the SF increases but MRR decreases due to the indentation effect. From figure 3(d) as the abrasive percentage increases the amount of iron, particles reduce in FMAB due to this the SF declines but the MRR increases slightly because of the rubbing action of abrasives.

**Figure 3.** Variation of SF and MRR with (a) Speed (b) Feed (c) Working gap (d) Abrasive size

Figure 4 explains the variation of % of SF improvement and MRR for various process parameters speed, feed, gap, and abrasive size explained for SS 316L by [23]. From figure 4(a) as the speed increases the SF and MRR follow an increasing trend up to 400 RPM then decreases because due to high speed only rubbing action takes place between FMAB and workpiece. From figure 4(b) as the feed increases the SF and MRR both decrease proportionally. As the feed increases the time for application of finishing forces decreases due to this just rubbing action takes place on the surface. From figure 4(c) the trend shows for SF and MRR increases proportionally to the gap. As the gap increases the amount of formation of FMAB chains increases. As the gap increases the influence of both finishing forces increases due to this both SF and MRR increases. From figure 4(d) as the abrasive size increases, both SF and MRR increases initially then decreases. As the abrasive size increases the finishing capabilities of abrasives increases up to a certain abrasive size after that SF decrease.

**Figure 4.** Variation of SF and MRR with (a) Speed (b) Feed (c) Working gap (d) Abrasive size
2.2 Morphology of MAF finished surfaces

Figure 5 shows the SEM images of MAF processed Al 2024 alloy. It has been observed the improvement in the surface finish was achieved after the MAF process. The abrasive scratches were visible on the workpiece (Figure 5(b)). Figure 6 shows a fine finish of the MAF processed MS plate. A nano-level finish is also observed after the MAF process (Figure 6(b))[24].

Figure 5. Al 2024 alloy (a) before (b) after MAF finish

Figure 6. MS plate (a) before (b) after MAF finish

2.3 Summary of key observations of flat surfaces using MAF process

Table 1 and Table 2 summarizes the contributions of various authors on the finishing of flat and Cylindrical surfaces using the MAF process.

| Work Material          | Abrasives Used          | Input Parameters                        | Key Observations                                                                 | Ref. |
|------------------------|-------------------------|-----------------------------------------|----------------------------------------------------------------------------------|------|
| Magnesium alloy, Stainless steel Brass | Magnetic abrasives | Amplitude: 1 mm, frequency: 6 Hz, Feed: 17 mm/min, B: 0.8 T, WG: 2 mm | 1. It is observed that the MRR of magnesium alloys is better compared to the other two materials. 1. It is observed that high mesh size and size ratio of abrasives and magnetic particles are good for high surface finish | [25] |
| Copper alloy           | AS: 180–210, I: 3.0–3.5A, Al₂O₃, Feed rate: 0.01–0.045mm/rev. | | 1. MAF-processed tools had improved the life 50% higher than untreated tools. | [26] |
| Ti-6Al-4V alloys       | Steel grit and magnetic particles along with abrasives: 40g, S: 600 RPM, WG: 2 mm | | 1. Normal forces and torque, mostly affected by | [28] |
| Copper alloys          | Diamond, Upper disk and lower disk WG: 1.5–2.5 mm, | | | |

Table 1. Summarized MAF process for Flat Surfaces.
Al$_2$O$_3$ Abrasive percentage: 10-30%, S: 200-400 RPM  
WG: 1-3 mm,  
Abrasives percentage: 10-40% wt.,  
AS: 400-1200  
Feed: 1-5 mm/min,  
S: 100-600 RPM.

1. For hard materials, high magnetic flux density and low working gap, and low speed are preferable.  
2. For soft material low magnetic flux, high working gap, and high speed are preferable.  

C61400 & SS 202  
Al$_2$O$_3$  
Abrasives percentage: 10-30%  
WG: 1-3 mm,  
AS: 400-1200  
Feed: 1-5 mm/min,  
S: 100-600 RPM.

1. It is observed that optimum parameters are a low working gap, low feed, and high electromagnetic speed is preferable.  

Aluminum alloy  
Al$_2$O$_3$  
Abrasives Powder wt.: 0.35-1.75 g,  
WG: 0.5-2.5 mm, Feed rate: 10-50 mm/minute,  
S: 100-2100 RPM.

1. It is observed that 150 µm of the size of abrasive and voltage has a high influence on the finishing process.  

Stainless Steel 202  
Al$_2$O$_3$  
V: 6-18 V,  
S: 60-120 RPM,  
AS: 90-300 µm

1. It is observed that SF is better after the MAF process compared to conventional machining.  

Stainless steel 304  
Al$_2$O$_3$  
V: 30-50 V, S: 180-540 RPM,  
Abrasives percentage: 20-30%  
V: 50 V, S: 1440 RPM,  
Abrasives percentage: 30%

1. It is observed that SF improvement of 83%.  

Table 2. Summarized MAF process for Cylindrical Surfaces

| Work Material       | Abrasives Used | Input Parameters | Key Observations                                      | Ref. |
|---------------------|----------------|------------------|-------------------------------------------------------|------|
| Additively manufactured tube | SiC            | S: 10-100 RPM, Vibration: 17.5-19 Hz, Feed :200 mm/min | 1. It is observed that SF initial reduces then increases after 60°  
2. Maximum MRR observed at horizontal position. | [33] |
| Stainless steel     | Unbounded Fe powder, Al$_2$O$_3$ with servospin-12 oil | WS: 205 RPM, S: 1600 RPM, feed :0.48 mm/rev,  | 1. It is observed that simultaneously both internal and external SF is observed | [34] |
| SS430 tube          | SiC            |                  |                                                       | [35] |
| Material          | Abrasive | Workpiece Speed | Spindle Speed | Magnetic Flux | Abrasive Size | Working Gap |
|-------------------|----------|-----------------|---------------|---------------|---------------|-------------|
| AISI 440C         | SiC      | S: 150 RPM, B: 0.5 T, AS: 50-100 µm, WG: 2-4 mm | 1. It is observed that 50% improvement in SF observed compared to the initial surface [36] |
| Stainless steel (SUS 304) | Iron powder | S: 50-400 RPM, I: 1-2 A, B: 1.04 T, A: 12 V, WS: 200-600 RPM, Freq: 5 KHZ, AS: 400-1200 | 1. It is observed that the behaviour of FMAB depends on magnetic flux density. 2. Abrasives with fine grains improves SF compared to rough grains [37] |
| SKD11, HRC61     | Al₂O₃    | WS: 180-780 RPM, B: 0.85 T, I: 0.5-2.5 A, Freq: 2-8 Hz, WS: 400-2000 RPM, I: 10 A, V: 12 V, WG: 0.002 m, Frequency: 5 KHZ, AS: 400-1200 | 1. It is observed that microcracks and recast layers are easily removed using the MAF process. [38] |
| Aluminum alloy 6061 | SiC      | WS: 200-600 RPM, B: 0.4-0.8 T, AS: 400-1200 | 1. It is observed that the hybrid application of ECM in MAF improves SF. [39] |
| AISI304 (non-magnet) | SiC      | WS: 180-710 RPM, I: 0.5-2.5 A, Vibration: 2-6 Hz, WG: 1 mm, WS: 200-600 RPM, B: 0.4-0.8 T, Abrasive percentage: 20-30% | 1. The SF effects on electrolyte concentration and MRR affects the magnetic flux. [40] |
| SS – AISI 420    | SiC, Al₂O₃, diamond powder | 1. It is observed that the SF improves with the application of vibrations to the MAF process. [41] |
| SS 304           |          | 1. It is observed that using SiC abrasive slurry, the speed at 355 rpm and 2mm working gap getting better results compared to Al₂O₃ slurry. [42] |

Where I= Current, V= Voltage, S= Spindle speed, WS= Workpiece speed, AS= Abrasive size, WG = Working gap, B= Magnetic flux

3. Conclusion and future scope

In this review paper, the finishing of flat & cylindrical surfaces using the MAF process is discussed in detail.

- Based on the literature speed, working gap, and voltage are the major influencing process parameters in this process. Whereas SF improvement and MRR are the responses.
- It is observed from the literature that a small working gap, increase in voltage, greater mesh number of grain size and high rotational speed are feasible for high SF.
- Hybridization of the MAF process is required to get an additional benefit to the process performance. The processes like Ultrasonic assisted MAF, Double disk MAF processes, etc. are developed in recent years.
- It is observed a very limited work related to forces and thermal aspects during the MAF process was discussed in the literature. There is a scope to study these aspects.
- To enhance the process capabilities of MAF process optimization of process parameters is needed. Some advanced optimization techniques such as Jaya Algorithm, Genetic algorithm, etc. may be used.

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