

COMPARATIVE ANALYSIS OF DRY AND OILED MAGNETIC ABRASIVE FINISHING TECHNIQUES FOR IMPROVING THE ROUGHNESS OF COMPLEX SURFACES

*Shahd A. Taqi, Saad K. Shather, Wisam K. Hamdan
University of Technology, Baghdad*

Abstract:

The development of modern industries necessitates complexity and the creation of manufactured models to keep pace with advancements. Magnetic abrasive finishing (MAF) is the most prominent finishing technique due to its effectiveness and efficiency without damaging the part. This study fills a research gap by directly comparing dry and lubricated magnetic abrasive finishing (MAF) using hybrid abrasive particles on geometrically complex surfaces, with surface quality evaluated through non-contact laser scanning and SEM. This work investigates the effect of adding lubricating oil to the abrasive grain finishing technique, comparing this finishing with traditional dry finishing. The magnetic abrasive grains used were prepared from a hybrid mixture consisting of two types of abrasive particles: silicon carbide (SiC) and tungsten carbide (WC), with the addition of iron particles to enhance the magnetic attraction force. The tool was magnetized with a permanent neodymium magnet. Three operational variables were controlled at three levels: feed rate, tool rotation speed, and particle size. The surface roughness of the samples was measured before and after the finishing process to assess the improvement. Since the designs of the samples used for the experiments were non-planar, they were difficult to inspect using conventional techniques. Therefore, laser scanning technology, in addition to scanning electron microscopy, was used to assess surface defects. Experimental results showed that the oil-lubricated finishing process performed better than the dry finishing process, with the oil-lubricated finishing process achieving an improvement of approximately 66.4% compared to the dry finishing process, which achieved a 36.9% improvement under the same operating conditions. The experimental results demonstrated that the level of influence of these variables on finishing performance may vary depending on the external operating conditions.

Key words: Magnetic Abrasive Finishing (MAF), lubricating MAF, Dry MAF, complexly designed surfaces, laser scanning technology, and Hybrid Abrasive

INTRODUCTION

Magnetic abrasive particle finishing is one of the most advanced processes that can keep pace with modern products that require unconventional finishing, capable of finishing edges and complex shapes. This technology is characterized by its flexibility, which enables it to finish all available designs, and its precision in improving surfaces without causing damage [1, 2]. MAF is based on the principle of using a magnetic field to generate an attractive force that contributes to the formation of a brush composed of abrasive particles, which serves as the finishing tool. As the tool rotates, the abrasive particles begin to remove surface burrs, improving surface roughness [3]. Although its effectiveness at finishing and enhancing surfaces has been proven in studies, experiments conducted with the addition of lubricating oil to the abrasive particles have not been performed accurately. Such an addition to the process can significantly alter finishing results [4]. This

process can be implemented either using dry magnetic abrasive particles or by adding lubricating oil to the abrasive particles, which reduces friction and limits surface scratches [5, 6]. Despite these advantages, few studies compare dry and lubricated MAF, especially on complex surfaces with medium initial roughness. To bridge this gap, the current study evaluates both techniques using a hybrid abrasive mixture consisting of silicon carbide (SiC) and tungsten carbide (WC), bonded with acrylic resin and mixed with carbonyl iron powder [7, 8]. It is challenging to inspect the surface that has been finished using traditional screening techniques because it is complex and somewhat uneven. Therefore, laser scanning was adopted to obtain the most accurate results [9]. Therefore, the primary objective of this study is to evaluate and compare the performance of dry and lubricated magnetic abrasive finishing (MAF) processes when applied to geometrically complex, non-flat surfaces, using a hybrid

abrasive mixture of silicon carbide (SiC) and tungsten carbide (WC) bonded with acrylic resin and mixed with carbonyl iron powder. The novelty of this work lies in directly comparing both finishing methods using the same process parameters and evaluating them on complicated geometries with high, non-contact surface evaluation techniques, including laser scanning and scanning electron microscopy (SEM). In this combined method, the exhaustive evaluation of the surface quality is more precise and reveals how operational parameters affect the different finishing environments.

LITERATURE REVIEW

Magnetic Abrasive Finishing (MAF) is an effective process for enhancing the surface quality of parts, particularly those with difficult-to-access or complex geometrical shapes. The performance of MAF has been the subject of several studies examining how to improve this process. The influence of operational parameters on magnetic air floats (MAF) applied to flat and cylindrical surfaces was analyzed by Singh et al. [10], revealing that the magnetic field strength is a critical parameter controlling the performance of the finishing operation and surface improvement. Uddin et al. [11] emphasized that the material used as an abrasive, such as SiC and Al₂O₃, is a significant factor that influences the performance of the finishing process. Examples include particle size and working gap, which are the main parameters when using Al₂O₃ abrasive, whereas tool speed and abrasive amount prevail when using SiC. Process efficiency has also been achieved through innovations in tool design. Nagdeve et al. [12] proposed a tool that utilized neodymium permanent magnets, resulting in improved abrasive distribution and reduced surface roughness. On the same note, Ahmad et al. [13] suggested a multi-phase Al₂O₃, SiC mixture, which can provide a better hardness-toughness ratio, along with improved finishing of titanium alloys. This concept was further developed by Cheng et al. [14], who utilized abrasive media gel-based fluids to polish stainless steel tubes, demonstrating that the significant variables affecting roughness minimization were the concentration of the particles and the finishing duration.

Several of them have transitioned from MAF to CNC systems. Kumar and Komma [15] demonstrated a low-cost configuration for finishing simple models with the CNC, indicating that machining time and spindle speed are the most critical parameters. Zhao et al. [16] used silicone gel to create flexible magnetic particles that enhanced flexibility and facilitated processing. Their results also indicated that a smaller particle size resulted in a quicker rate of wear, but improved finishing detail.

Wang et al. [17] provided a comprehensive analysis of the MAF on complex surfaces, with an emphasis on the requirements of a versatile motion apparatus and the need to adapt MAF to three-dimensional geometries. Researchers of Sah et al. [18] studied the interactions of process variables, including the number of passes and feed rate, in CNC-based MAF. They justified that it is capable of automated bright finishing.

More recent reviews conducted by Kumar and Komma [19] highlighted the need to incorporate simulation and optimization tools into MAF systems to eliminate human dependency and enhance control. In their comparative study, Singh et al. [20] found that unbonded, binder-bound, and sintered abrasives differed in their servicing properties, as the latter provided better surface improvement and material removal rates. Lastly, Souza et al. [21] developed a hybrid tool composed of gel and paste-based abrasives, which melt during ablation to form a flexible brush that fits different internal geometries. Their practice embraces sustainability in terms of reusability and flexibility in various forms.

Despite the progress in this field, no prior studies have directly compared dry and lubricated magnetic abrasive finishing (MAF) using hybrid abrasive particles on non-flat or geometrically complex surfaces. Most existing works have focused on one technique applied to flat or straightforward geometries. Furthermore, limited attention has been given to the non-contact and highly accurate evaluation of surface quality in such complex cases using laser scanning and SEM. This research paper addresses this gap by comparing dry and oiled MAF at practically the same process setting, using a hybrid abrasive blend, on samples with complex geometries, and assessing high-end investigation tools.

METHODOLOGY

This section is considered the fundamental step in any research project, as it serves as the basis for the study and verifies that it is achieving its objectives. It provides a comprehensive explanation of the tools used, the materials they were made from, and their design.

Design and Manufacture of Working Sample

As industries grow and applications become more complex, it is essential to keep pace with this development by conducting experiments on work samples with designs that accurately reflect these changes. The shape of the work samples to be finished was determined to be non-standard or unconventional. A complex, non-flat shape was chosen whenever possible. SolidWorks (version 23) was used for this task; its computer-aided design program is widely used for designing three-dimensional models across various industrial fields. It offers distinct features when designing shapes, including the ability to simulate them before implementation and facilitate design modifications [22]. Figure 1 shows the design chosen as a working sample.

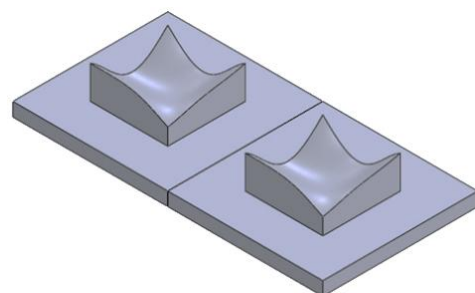


Fig. 1 SolidWorks workpiece design: high-carbon steel

The working sample metal type was chosen to be high-carbon steel as the basic material for conducting research experiments, as it is widely used in industrial applications and is readily available. The use of high-carbon steel was due to its high mechanical properties, such as a high level of hardness, high resistance to wear, and dimensions that cause good performance within the conditions of magnetic abrasive finishing (MAF). Such features render it a proper material to determine the effectiveness of MAF in enhancing the quality of surfaces and providing constant finishing capabilities [23]. The chemical composition of the sample workpiece is shown in Table 1.

Table 1
Chemical Composition of Samples

	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Fe
%	0.421	0.216	0.581	0.0206	0.0139	0.0565	< 0.002	0.0245	0.0293	0.0527	Bal

The SolidWorks models were created using a three-axis CNC machine, and HSMWorks software was utilized to convert the designs into code that the machine could understand, thereby enabling the creation of the desired shapes. To generate the magnetic force, neodymium magnets were mounted on the cylinder, which was designed as a finishing tool, generating a constant, highly efficient magnetic field for its small size. At this stage, a roughness inspection is performed on the samples to be used for finishing tests in both dry and lubricated conditions. The samples used in this study were examined using laser scanning technology. This unconventional testing technique involves shining a laser on the reflective surface of work samples [24]. The reflected radiation is received by a special camera, which converts this radiation into readings, graphs, and three-dimensional images of the surface that can be viewed in a computer application called the GENTC program, which stands for Generic Transport Layer Control. The pictures and graphs are then processed using image processing software to produce values that indicate roughness on the surface. During the inspection process, certain technical variables must be considered and addressed to ensure the success of the inspection and obtain accurate results. This analytical approach allows the evaluation of roughness at various resolution levels. Roughness can be evaluated at different levels of resolution. The value of roughness was not measured in a one-point direct reading system of the device; otherwise, the ruling was based on the evaluation of the surface profile produced by the laser scanning system. Given that the decimal variations are tiny, the results can be reasonably rounded to a suitable number of decimal places for clarity and consistency. Figure 2 shows the laser scanning sampling system.

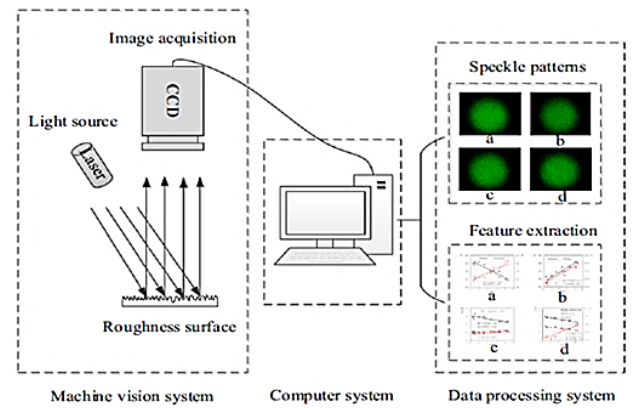


Fig. 2 Laser scanning device diagram

Design and Manufacture of Finishing Tools

The finishing tool is crucial in determining the efficiency of the finishing process, as it controls the direction and intensity of the magnetic field that defines the shape of the finishing brush formed during the process [25]. The tool was designed with a cylindrical end diameter that matched the dimensions of the finished workpiece and a radial shaft that matched the CNC machine used to perform the finishing operations. The required shape was also designed using SolidWorks. The shaft material was selected to match the sample material (high-carbon steel) to ensure mechanical and thermal compatibility, as well as stability of performance during the finishing process. In this investigation, the electromagnetic coil was swapped out with a permanent neodymium magnet, which is lightweight and easy to move for surface finishing. This magnet also provides a high and constant magnetic force without the need for an external source. This makes the system easier to use and maintains a stable finishing process [26, 27]. A cylindrical neodymium (NdFeB) magnet (10 mm diameter, 10 mm height) was selected for its high capacity to generate a strong magnetic field despite its small size [28]. The magnets were symmetrically distributed within the shaft to ensure balance during rotation and avoid vibration or deflection. Figure 3 illustrates the stages of designing the finishing tool used in the MAF stage.

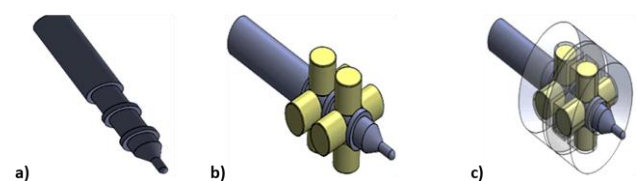


Fig. 3 The design of a finishing tool:
a) The design of the tool with grooves,
b) The tool with the magnetic pieces added,
c) The final shape of the tool

Specifically, Figure 3(a) shows the shape of the tool with grooves, and Figure 3(b) shows the tool with magnetic pieces added. Figure 3(c) shows the final shape of the tool.

Preparation of Magnetic Abrasive Particles

- Selection of the Abrasive Material: In this stage, a combination of two types of abrasive particles was chosen: silicon carbide (SiC) and tungsten carbide (WC). This was done to maximize the benefits of each distinct mechanical property. SiC is characterized by its high hardness and resistance to wear, while WC is characterized by its hardness and durability [29].
- Iron Material: In this stage, iron particles are added to the mixture to enhance its magnetic strength and attract it to the magnetic finishing tools.
- Binding the combination: An acrylic resin is used to bond the iron particles with abrasive particles to form a cohesive mixture whose abrasive and magnetic properties are enhanced [30].

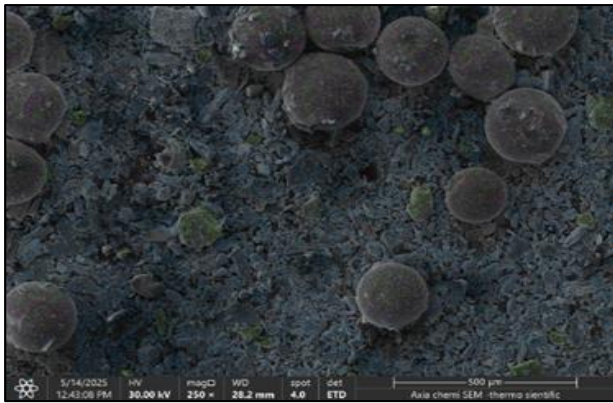
After the combination solidifies, it is mechanically ground to transform it into a homogeneous powder that responds to magnetic forces. Table 2 shows the particle mixing ratios.

Table 2

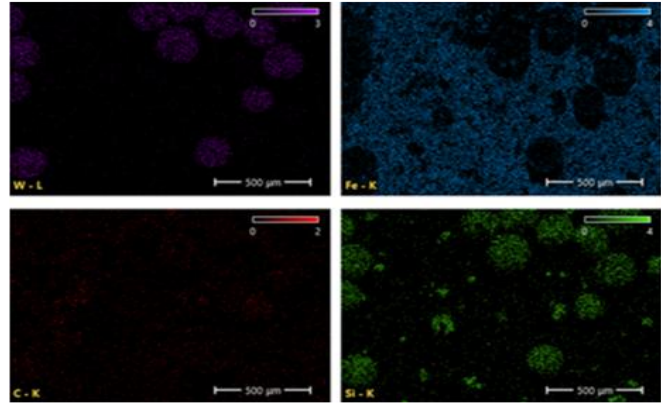
Particle Mixture Ratios

Particle	Mixing ratio
Wc	20% of the total weight
Sic	20% of the total weight
Fe	60% of the total weight

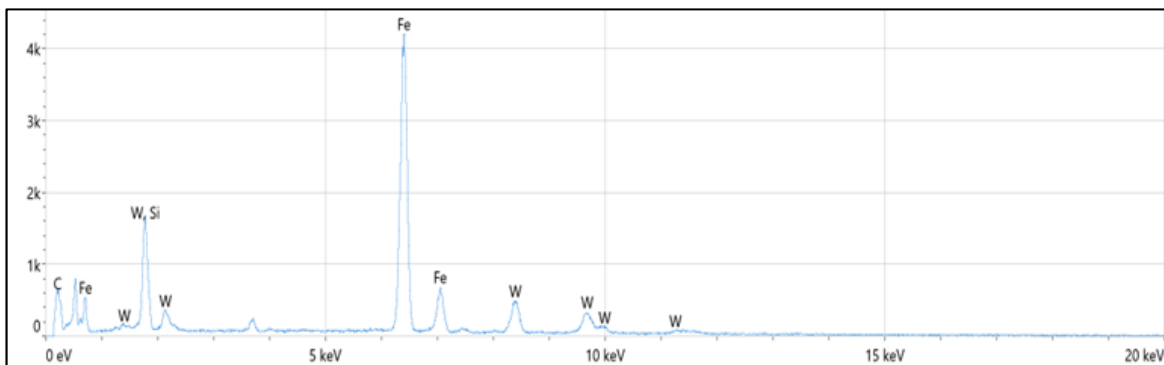
As for the binder, its proportion was set between 10% and 30% of the total weight, which contributed to the formation of a homogeneous and cohesive paste of mixed particles. Figure 4a shows the EDX test that was conducted to show the distribution of particles and the mixture that was made of the abrasive particles with the iron particles before adding the bonding material, Figure 4b shows the surface structure of the particles and how the elements are distributed, and Figure 4c represents the hybrid mixture and the elements that make it up.



a)



b)



c)

Fig. 4 The Results of the EDX Tests

- a) The EDX test shows the distribution of particles,
- b) The surface structure of the particles and how the elements are distributed,
- c) EDX test shows the hybrid mixture and the elements

Defining Variables and Designing Experiments

This study focused on some operational variables that can directly affect performance and efficiency. Three levels were defined for each variable to ensure the comprehensiveness of experiments and to study different levels. These variables were:

- Feed rate, which represents the surface finish time in this study. Since the samples being finished are

uneven surfaces, it is impossible to determine the finishing time [30]. Therefore, the feed rate was determined to complete the surface finish. The following levels were chosen: 35, 70, and 90 mm/min.

- Tool rotation speed during the process, at three levels: 350, 500, and 750 rpm.
- Abrasive particle size, with three different sizes used: 200, 300, and 600 µm.

The Taguchi method was employed to design process experiments, aiming to reduce the number of experiments while achieving a balanced distribution of variables [31]. An L9 orthogonal matrix was adopted to distribute the experiments. Table 3 shows the design of the planned practical experiments.

Table 3
The Design of the Finishing Experiments

No.	Tool rotation speed (rpm)	Feed rate (mm/min)	Particle size (µm)
1	350	35	200
2	350	70	300
3	350	90	600
4	500	35	300
5	500	70	600
6	500	90	200
7	750	35	600
8	750	70	200
9	750	90	300

These experiments were conducted twice: the first for the finishing process of dry magnetic abrasive particles, and the second for the addition of lubricating oil to the magnetic abrasive particles. The samples were examined after finishing, and the results of these tests are included in the next section.

RESULTS OF PRACTICAL EXPERIMENTS

This section presents the results of the finishing experiments, which were obtained by examining the surface of the samples using laser scanning technology and conducting SEM examinations. However, before starting the finishing experiments, the results of the samples examined before finishing will be presented to accurately analyze the abrasion that will be determined for the samples. Surface roughness before finishing was 4.329 µm.

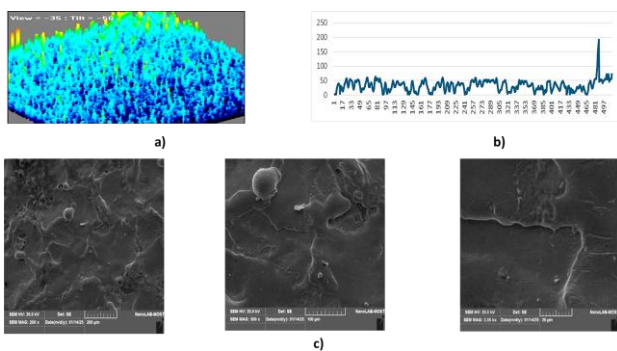


Fig. 5 Sample Surface Before Finishing
a) Surface Roughness Diagram from Laser Scanning,
b) Surface Ridges from Laser Scanning,
c) SEM Scan with Magnification

Figure 5 shows a scanning electron microscope (SEM) examination of a sample surface before the finishing process is applied to determine the nature of microscopic changes that may occur after the finishing process, where (a) Surface Roughness Diagram from Laser Scanning, (b) Surface Ridges from Laser Scanning.

Graphical explanation of roughness: the (X-axis) is the number of peaks detected within the inspected area, and the (Y-axis) is the height of the peaks expressed in µm, and (c) SEM Scan with Magnification.

After completing the magnetic finishing experiments, accurate surface roughness measurements were performed on the samples to evaluate the efficiency of the finishing process under each operational condition. Table 4 presents the final roughness (Ra) results for each experiment after completion, under both dry and lubricated conditions.

Table 4
The Results of The Finishing Process Experiment for the Dry and Lubricated Phases

No.	Dry finishing			Lubricated finishing		
	New SR (µm)	Δ Ra	Total Improvement %	New SR (µm)	Δ Ra	Total Improvement %
1	3.329	1	23.1	2.397	1.932	44.6
2	2.929	1.4	32.3	1.904	2.426	56.1
3	3.629	0.7	16.2	2.871	1.458	33.7
4	2.729	1.6	36.9	1.455	2.874	66.4
5	3.829	0.5	11.6	3.024	1.305	30.1
6	3.419	0.910	21.1	2.482	1.847	42.7
7	3.829	0.500	11.6	2.875	1.454	33.6
8	3.356	0.973	22.5	2.265	2.065	47.7
9	3.029	1.300	30.1	1.818	2.512	58.1

Figure 6 includes the results of a sample subjected to the dry finishing process. It contains a 3D map of the sample surface generated using laser scanning, a graph illustrating the change in roughness, and a scanning electron microscope (SEM) image that highlights the characteristics of the residual burrs on the surface after finishing, where (a) Surface Roughness Diagram from Laser Scanning, (b) Surface Ridges from Laser Scanning. Graphical explanation of roughness: the (X-axis) is the number of peaks detected within the inspected area, and the (Y-axis) is the height of the peaks expressed in µm, and (c) SEM Scan with Magnification.

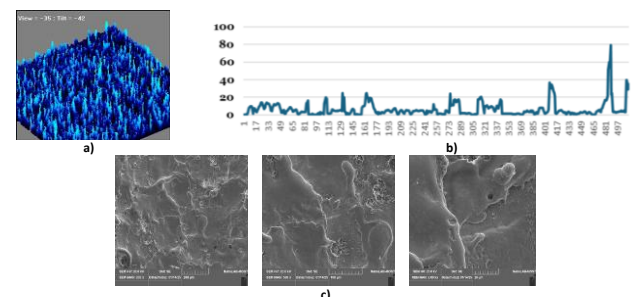


Fig. 6 Sample Surface After Finishing Dry:
a) Surface Roughness Diagram from Laser Scanning,
b) Image of Surface Ridges from Laser Scanning,
c) SEM Scan with Magnification

Figure 7 shows similar results for a sample finished using the lubricated mixture, allowing for a visual comparison between the two conditions and demonstrating the effect of the presence of lubricating oil in improving process efficiency and reducing roughness residue on the treated

surface, where (a) Surface Roughness Diagram from Laser Scanning, (b) Surface Ridges from Laser Scanning.

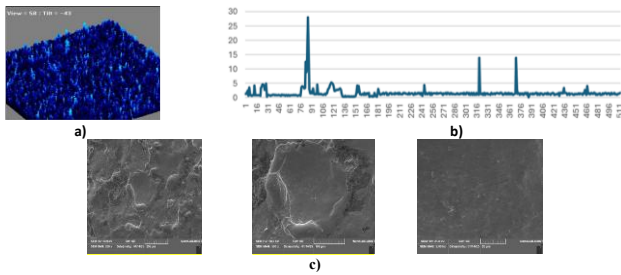


Fig. 7 Sample Surface After Lubricated Finishing:
a) Surface Roughness Diagram from Laser Scanning,
b) Image of Surface Ridges from Laser Scanning,
c) SEM Scan with Magnification

Graphical explanation of roughness: the (X-axis) is the number of peaks detected within the inspected area, and the (Y-axis) is the height of the peaks expressed in μm , and (c) SEM Scan with Magnification.

Analysis of Experimental Results

The results analysis phase aims to interpret the data obtained from the practical experiments and link them to the study objectives, thereby determining the effectiveness of magnetic abrasive finishing technology in improving the quality of complex surfaces. This phase extends beyond presenting numbers; it encompasses descriptive, visual, and statistical analysis of the process outputs, facilitating an understanding of the behavior of operational variables and their role in determining finishing performance in both dry and lubricated conditions. This analysis includes three main phases:

- Qualitative Analysis: This stage interprets the data from the experimental results and links them to the study objectives to determine the effectiveness of the magnetic abrasive finishing technology in improving the quality of complex surfaces.
- Descriptive Analysis: Table 4 shows the final roughness results (New SR), roughness difference (ΔRa), and overall improvement percentage (%) for each experiment after applying the dry and lubricated finishing processes. Comparing the values between the two conditions reveals the following: In general, the final roughness (Ra) values were lower in the lubricated finish than in the dry finish, demonstrating the effectiveness of using lubricating oil in improving surface quality. In all nine experiments, a higher percentage of improvement was recorded in the lubricated condition, with the highest improvement reaching 66.4% in Experiment 4 when lubricated, compared to 36.9% in the same experiment without lubrication. The improvement in the dry condition ranged from 11.5% to 36.9%, while in the lubricated condition, it ranged from 30.1% to 66.4%, supporting the hypothesis that lubrication contributes effectively to increased finishing efficiency.
- Microscopic and Visual Inspection: The data indicate that the use of lubricating oil helped reduce the resistance between the particles and the surface,

resulting in smoother and more consistent removal of surface burrs. From the figures displaying the results of the experimental samples in Figures 6 and 7, it is evident that the samples finished using the lubricated finishing technique had more uniform surfaces and fewer surface burrs, reflecting the improved process efficiency of the lubricated finishing technique. Microscopic images also show that surface defects in samples finished using the oiled finishing technique are improved, resulting in a uniform structure, unlike dry finishing, which exhibits surface scratches and cracks. Additionally, Figure 8 presents a comparison between the results of the dry and oiled finishing processes, illustrating the difference in surface roughness.

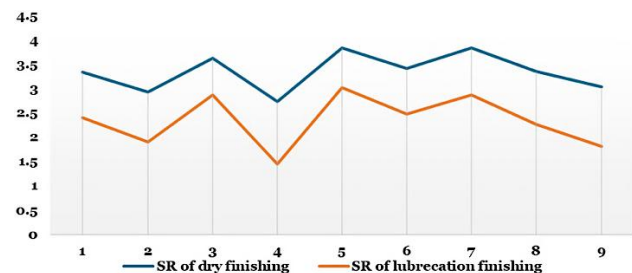


Fig. 8 Comparison of the Results of The Two Finishing Types

CONCLUSIONS

- 1) Magnetic abrasive finishing technology has proven effective in improving the quality of complex surfaces, with all experiments showing a decrease in surface roughness values after treatment, both in the dry and lubricated state.
- 2) The use of lubricating oil significantly enhanced the performance of the finishing process. The improvement in roughness increased in all experiments when using oil, reaching its maximum in the fourth experiment, with an improvement of 66.4% compared to 36.9% in the same experiment without lubrication.
- 3) Optical examinations (laser and scanning electron microscopy (SEM)) showed a clear improvement in surface smoothness in samples finished using the lubricated mixture. This was accompanied by a reduction in burr height and greater uniformity in roughness distribution, compared to the dry state, which exhibited finer surface irregularities and cavities.
- 4) The best finishing results were achieved with 300- μm particles, indicating that the medium size provides an ideal balance between removal capacity and finishing accuracy.
- 5) The difference in the effect of variables depending on the working environment (dry or lubricated) indicates that the importance of these factors is not fixed but rather varies depending on the surface nature and processing conditions. This must be considered when designing future finishing processes.
- 6) The results of this research can be used as a basis for using MAF technology in industrial applications that require precise finishing of surfaces with complex geometric configurations, with the recommendation to

use a lubricated environment to achieve optimal performance.

REFERENCES

- [1] Qian, C. et al. (2021) 'A review on magnetic abrasive finishing', *The International Journal of Advanced Manufacturing Technology*, 112(3), pp. 619-634.
- [2] Ibrahim, A.F., Shather, S.K. and Hamdan, W.K. (2014) 'Modeling the Abrasive Flow Machining Process (AFM) on Aluminum Alloy', *Iraqi J. Mech. Mater. Eng.*, 32(3), pp. 629-642.
- [3] Zou, Y. et al. (2021) 'Development of a New Finishing Process Combining a Fixed Abrasive Polishing with Magnetic Abrasive Finishing Process', *Machines*, 9(4), p. 81.
- [4] Houshi, M.N. (2016) 'A Comprehensive Review on Magnetic Abrasive Finishing Process', *Advanced Engineering Forum*, 18, pp. 1-20.
- [5] Ahmed, B.A., Shather, S.K. and Hamdan, W.K. (2020) 'Improve the Micro-hardness of Single Point incremental forming product using magnetic abrasive finishing', *Eng. Technol. J.*, 38(8), pp. 1137-1142.
- [6] El-Hofy, H. (2005) *Advanced machining processes: nontraditional and hybrid machining processes*. 1st edn. McGraw-Hill.
- [7] Ahmed, A.M.S. and Saad, K. (2024) 'The impact of magnetic abrasive finishing (MAF) process parameters on the microhardness of stainless steel SUS420 bubble cups', *Eng Technol J*, 42(6), pp. 615-623.
- [8] Singh, S., Gupta, V. and Sankar, M. (2020) 'Magnetic Abrasive Finishing Process', in, pp. 183-210.
- [9] Shimizu, M. et al. (2015) 'Multi-dimensional Assessment of Precision Machined Surface Texture Based on Laser Speckle Pattern Analysis', *9th CIRP Conference on Intelligent Computation in Manufacturing Engineering - CIRP ICME '14*, 33, pp. 251-256.
- [10] Singh, R.K., Singh, D.K. and Gangwar, S. (2018) 'Advances in Magnetic Abrasive Finishing for Futuristic Requirements – A Review', *Materials Processing and characterization, 16th-18th March 2018*, 5(9, Part 3), pp. 20455-20463.
- [11] Uddin, M.S., Santos, V. and Marian, R. (2019) 'Interplay of Process Variables in Magnetic Abrasive Finishing of AISI 1018 Steel Using SiC and Al₂O₃ Abrasives', *Journal of Manufacturing and Materials Processing*, 3(2), p. 29.
- [12] Nagdeve, L., Dhakar, K. and Kumar, H. (2020) 'Development of novel finishing tool into Magnetic Abrasive Finishing process of Aluminum 6061', *Materials and Manufacturing Processes*, 35(10), pp. 1129-1134.
- [13] Ahmad, S., Singari, R.M. and Mishra, R.S. (2021) 'Development of Al₂O₃-SiO₂ based magnetic abrasive by sintering method and its performance on Ti-6Al-4V during magnetic abrasive finishing', *Transactions of the IMF*, 99(2), pp. 94-101.
- [14] Cheng, K.-C. et al. (2021) 'Characteristics of the Polishing Effects for the Stainless Tubes in Magnetic Finishing with Gel Abrasive', *Processes*, 9(9), p. 1561.
- [15] Kumar, R. and Komma, V.R. (2023) 'Development of Experimental Setup and Parametric Study of Magnetic Abrasive Finishing Process of Plane Workpieces', *NanoWorld Journal*, 9 (Spl 1), pp. 220-224.
- [16] Zhao, X. et al. (2024) 'Characteristics of magnetic elastic abrasive particles and their effect on tool passivation', *The International Journal of Advanced Manufacturing Technology*, 132(3), pp. 1193-1215.
- [17] Wang, L. et al. (2024) 'A Review of Magnetic Abrasive Finishing for the Internal Surfaces of Metal Additive Manufactured Parts', *Journal of Manufacturing and Materials Processing*, 8(6), p. 261.
- [18] Sah, M.K., Vijaya, A. and Singh, H. (2025) 'Experimental study of the surface finishing of CNC magnetic abrasive finishing based on ANN', *Canadian Metallurgical Quarterly*, 64(3), pp. 1351-1363.
- [19] Kumar, R. and Komma, V.R. (2024) 'Recent advancements in magnetic abrasive finishing: a critical review', *Engineering Research Express*, 6(1), p. 012504.
- [20] Singh, Amardeep et al. (2024) 'Comparative assessment of abrasives in magnetic abrasive finishing: An experimental performance evaluation', *Journal of Magnetism and Magnetic Materials*, 604, p. 172312.
- [21] Souza, A.M. et al. (2023) 'Hybrid Polishing Tool for Internal Finishing of Complex Part Interiors in Magnetic Abrasive Finishing', in H. Kohl et al. (eds) *Sustainable Manufacturing as a Driver for Growth*. Cham: Springer Nature Switzerland, pp. 701-709.
- [22] DEVELOP3D (2012) 'SolidWorks 2012 – Software review'.
- [23] Zhao, G. et al. (2018) 'Mechanical Properties of AISI 1045 Steel Subjected to Combined Loads of Tension and Torsion', *Experimental Techniques*, 42(4), pp. 393-406.
- [24] Shao, M. et al. (2023) 'A review of surface roughness measurements based on laser speckle method', *Journal of Iron and Steel Research International*, 30(10), pp. 1897-1915.
- [25] N, V.P., A, V. and T, A.G. (2020) 'Performance Characteristics of Magnetic Abrasive Finishing (MAF) of Al 4061', *International Journal of Engineering Research & Technology*, 9(2).
- [26] Ahmed, B.A. and Jabbar, M.S. (2023) 'Investigation of surface roughness in modern finishing process using permanent magnet', *Kufa Journal of Engineering*, 14(4), pp. 11-22.
- [27] Heng, L., Kim, Y.J. and Mun, S.D. (2017) 'Review of super-finishing by the magnetic abrasive finishing process', *High Speed Mach*, 3(1), pp. 42-55.
- [28] Nagdeve, L. et al. (2018) 'On the effect of relative size of magnetic particles and abrasive particles in MR fluid-based finishing process', *Machining Science and Technology*, 22(3), pp. 493-506.
- [29] Al-Dulaimi, T. (2018) 'Analysis and Design of a Stationary Magnetic Abrasive Finishing System', *University of Waterloo* [Preprint].
- [30] Patil, M.G., Chandra, K. and Misra, P.S. (2012) 'Magnetic Abrasive Finishing – A Review', *Advanced Materials Research*, 418-420, pp. 1577-1581.
- [31] Krishnaiah, K. and Shahabudeen, P. (2012) *Applied design of experiments and Taguchi methods*. PHI Learning Pvt. Ltd.

Shahd A. Taqi (corresponding author)

University of Technology, Baghdad

Baghdad Governorate, Iraq

e-mail: pme.20.87@grad.uotechnology.edu.iq

Saad K. Shather

University of Technology, Baghdad
Baghdad Governorate, Iraq
e-mail: saad.k.shather@uotechnology.edu.iq

Wisam K. Hamdan

University of Technology, Baghdad
Baghdad Governorate, Iraq
e-mail: wisam.k.hamdan@uotechnology.edu.iq