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The Impact of Magnetic Abrasive Finishing (MAF) Process Parameters on the Microhardness of Stainless Steel SUS420 Bubble Cups

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HIGHLIGHTS

- Magnetic abrasive finishing enhanced SUS420 stainless steel bubble cup microhardness
- A 21.20% microhardness increase occurred with the smallest particle size, high voltage, moderate gap and lower rotation speed
- Optimizing parameters enabled substantial microhardness improvement through magnetic abrasive finishing

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ABSTRACT

The optimal performance of bubble cups relies on achieving the appropriate surface quality, a common requirement in various industrial applications. The effectiveness of the Magnetic Abrasive Finishing (MAF) process depends on several factors, including the brush's flexibility, that vary across tools. This study investigates the influence of five key parameters, voltage, finishing time, gap distance, rotating speed, and particle size, on microhardness (MH). Experimental work was based on Taguchi design with L27 trials in Minitab 17, involving five variables with three levels for each. The impact of these parameters on microhardness for stainless steel SUS420 bubble cups is assessed using Taguchi and ANOVA analyses. According to the Taguchi analysis, the main parameters that improve microhardness (MH) most are, in order, gap distance, voltage, time, particle size, and spindle speed. The percentage change in microhardness (%ΔMH) increases with higher voltage and time values and decreases with higher particle size and spindle speed values. This study observes an exception to this trend for the gap distance value of 1.2 mm. The use of smaller particle sizes in the range of (20-63) μm showed the most significant enhancement in microhardness (MH) at 21.20%, whereas larger particle sizes (125-250 μm) exhibited lower enhancement in microhardness (MH) at 4.12%.

1. Introduction

Bubble cups, which are frequently created via the deep drawing process, are widely used in distillation towers, where they are subjected to high pressure and temperature levels. Nonetheless, the presence of faults and the high production costs need to improve the surface quality of bubble cups [1–3]. Increasing metal surface microhardness has many benefits. Improved fatigue, wear, and abrasion resistance enhance component lifespan. Strong scratch and corrosion resistance improves lifespan in severe situations. Stronger surfaces increase load-bearing capacity and mechanical strength. Increased heat resistance helps high-temperature applications. Elevated microhardness improves material dependability, minimizes maintenance, and extends metal-based product lifespan across sectors, improving customer satisfaction and cost-effectiveness [4–8]. Due to some metals having specific properties, conventional finishing techniques like grinding, honing, and lapping are insufficient for achieving a satisfactory finish on these materials. Magnetic abrasive finishing (MAF) and other modern finishing techniques may provide a workable solution by enhancing surface quality and microhardness [9]. In contrast to conventional finishing techniques, magnetic abrasive finishing controls machining forces using a magnetic field. Cost-effective finishing may be achieved by inserting magnetic polishing components into existing machine tools, eliminating the need for expensive, stiff, and error-free equipment. For the MAF method, a spindle chuck firmly holds a cylinder of work material. Whether the workpiece is made of steel or ceramic, it is affected by the magnetic field lines passing through it. Magnetic abrasive particles (MAP) are distributed between the workpiece and the magnet's poles in the working region. The abrasive grains of magneto abrasive brushes are flexible so that they may match the contours of the work surface [10]. Magnetic abrasive particles can be made by combining magnetic particles (ferrous particles) with abrasive materials like aluminum oxide (Al_2O_3), silicon carbide (SiC), or diamond.

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Bounded, semi-bounded, and unbounded MAP models exist. Finishing with magnetic abrasives may be broken down into cylindrical (interior and exterior) and flat [11,12].As shown in Figure 1 (a) and (b).

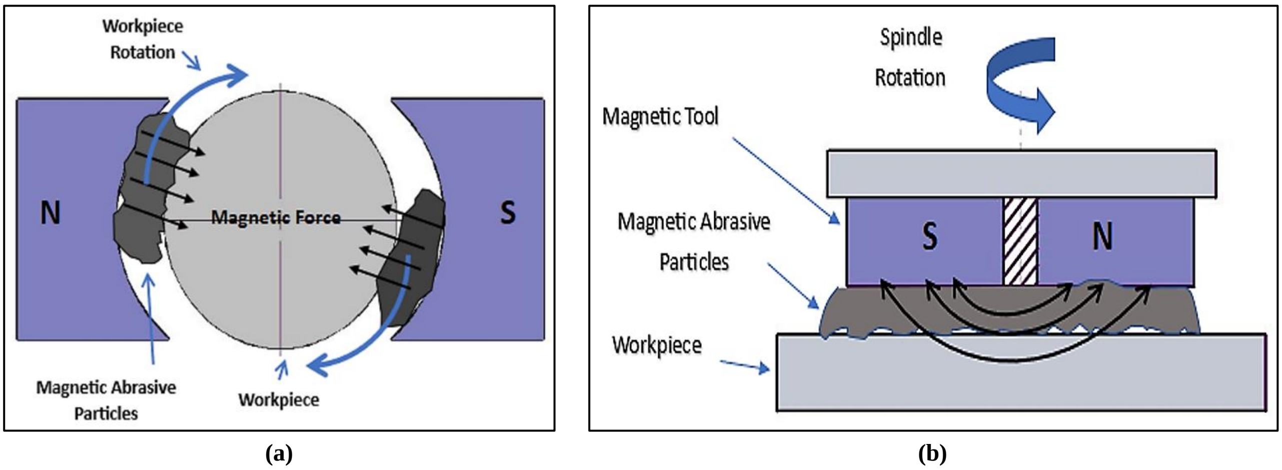

Figure 1: (a) Cylindrical external MAF process, (b) Flat MAF process

Several previous studies machined stainless steel metals of different classifications with various numbers of input parameters. Firstly, the effect of five parameters (current, machining gap, speed, abrasives concentration, and time) on microhardness in the MAF process was studied by Ahmad et al. [6]. Singh et al. [12]improved the microhardness surfaces of specimens by four input parameters (mesh size, speed, time, and abrasive weight). Microhardness was studied by Ahmed et al. [13]. After Single Point Incremental Forming (SPIF), the MAF process was utilized as a finishing process with four input parameters (speed, feed rate, gap, and current). Nahy and Kadhum [14] proposed studying six input parameters (oil viscosity, powder quantity, gap distance, pole diameter, rotational speed, and Current). Zhang et al. [15] proposed using the MAF process as a flexible finishing technique to polish the samples generated by the selective laser melted (SLM) process with different slope angles and studied the MAF process effect on the microhardness of the sample surfaces. Teng et al. [16] studied the microhardness as a response factor of the MAF process after machining the workpieces by selective laser melted (SLM) process with varying one parameter (abrasive type). Mousa [17] studied the improvement of the hardness of stainless steel plate 321 by the MAF process with five input parameters (groove number, voltage, speed, time, and powder volume). Amineh et al. [18] studied the effects of four input parameters of the MAF process (gap, time, abrasive mesh size, and speed). They studied their effect on the microhardness of specimens to remove recast layers.

The machining processes involved in modern industries need to produce high-level quality products of bubble cups during the magnetic abrasive finishing process. This study aimed to investigate the effect of five parameters on the microhardness of bubble cups by using magnetic abrasive finishing techniques to produce high-level quality products. The parameters of interest include (supply voltage, finishing time, gap distance, rotational speed, and magnetic abrasive particle size). Using the Taguchi design methodology and ANOVA allows for efficient experimentation and analysis, enabling us to identify the optimal parameter settings that minimize surface roughness variation and enhance the surface quality of bubble cups.

2. Methodology

2.1 Experimental Setup

Figure 2 shows this study's experimental setup. A drilling machine, magnetic pole, sample fixation, workpiece, power supply, and abrasive powder are included. The magnetic pole used was with 6000 turns of 0.75 mm copper wire. This coil was mounted on a 15-mm-diameter, 100-mm-long carbon steel shaft. The tool head was 20 mm in diameter and 30 mm long, with 2 mm grooves along the wall and base to increase magnetic force at the center, particle retention, rotational speed, and a homogeneous machining surface. Bubble cups were chopped into tiny pieces for this study's trials. Table 1 shows the chemical composition of the stainless steel 410 cup. The studies used 2:2:1 iron powder, resin, and AL_2O_3 abrasive powder. After 24 hours in a 250°C furnace, the mixture solidified. The solidified slurry was milled at 350 rpm for 90 minutes to separate particles. Following are the materials specifics and the experimental setup:

1) Metal powder of Iron electrolytic 300 mesh 98% R:11 S:16-33 CAS NO: 7439-89-6.
2) Typical liquid resin properties (25℃): in Table 2.
3) Extremely pure aluminum oxide (specially fused alumina) containing at least 99.5% AL_2O_3.
4) Finally, add one drop of Methyl ethyl Ketone Peroxide with CAS NO: 1338-23-4.

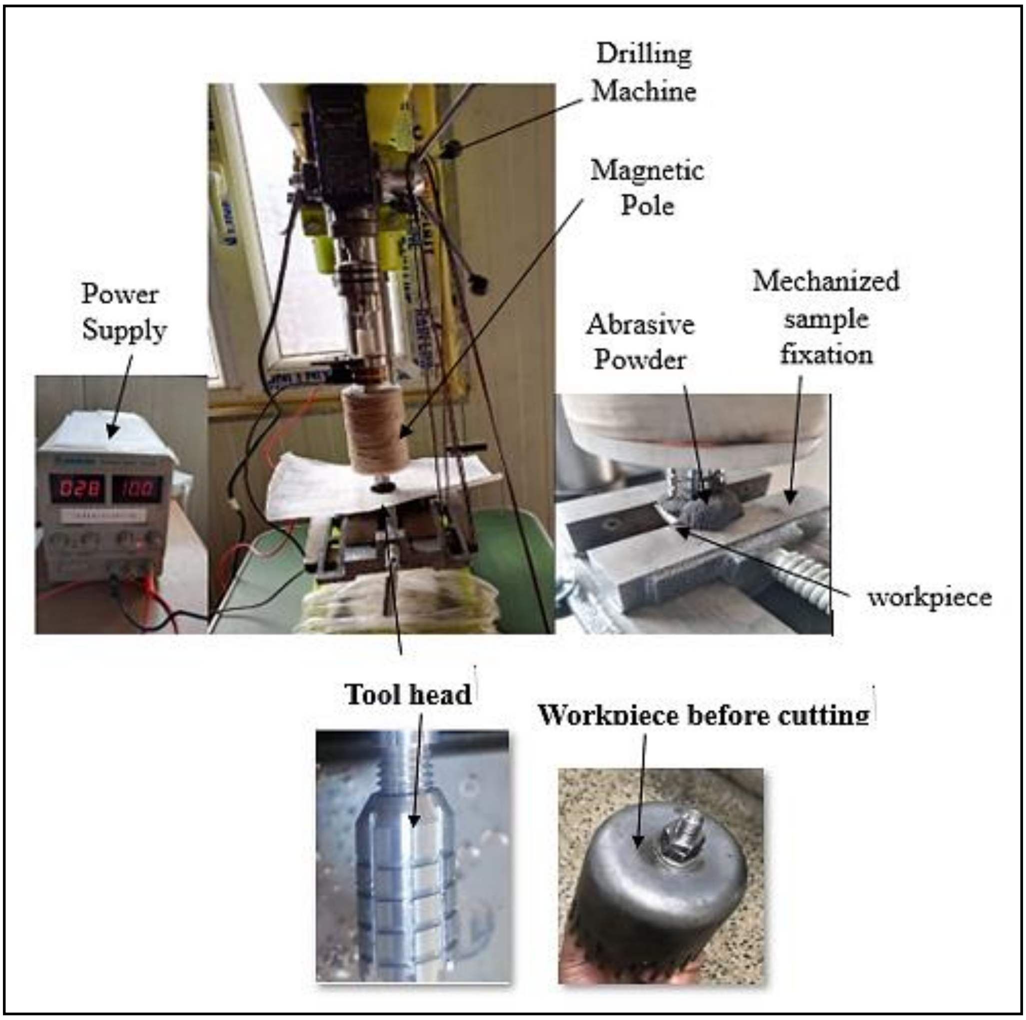

Figure 2: Experimental Setup

Table 1: Chemical Composite of Stainless Steel 410

W	Sn	Mo	Cu	Ni	V	Mn	Cr	Fe
0.04%	0.02%	0.04%	0.12%	0.27%	0.04%	0.63%	14.4%	84.45%

Table 2: Resin Properties

Percent solids	61-70%
Viscosity – Brookfield, cps spindle 3@60 rpm	450-700 cps
Appearance	Clear, yellowish
Acid value	18-24
Specific Gravity	1.04 ± 0.02
Pounds per Gallon	9.2
Flash Point Range,℃	33

2.2 Experimental Procedure

Table 3 displays the selected triad of values for each of the five parameters: voltage, duration, gap distance, spindle speed, and particle size. The experimental design utilized the Taguchi L27 orthogonal array methodology in conjunction with Minitab-17. The constraints for each parameter were determined based on the most prevailing and commonly observed limitations in recent studies [19–27]. The amount of abrasive powder used in each experiment equals 2 grams.

Table 3: MAF Process Parameters

Voltage (V)	Time (min)	Gap distance (mm)	Spindle speed (r.p.m)	Particles size (µm)
A1=10	B1=10	C1=0.8	D1=220	E1=125-250 = 187.5
A2=20	B2=15	C2=1.2	D2=580	E2=63-125= 94
A3=30	B3=20	C3=1.6	D3=1150	E3=20-63= 41.5

2.3 The Microhardness Measurement

The method used for computing the percentage of improvement in microhardness is measured by taking an average for three device readings before and after finishing the process in Nanotechnology and Advanced Materials Research Center/University of Technology. The indentation was done with a weight equal to 250 grams for 15 seconds with device information: Digital Micro Vickers Hardness Tester, Model: TH715, SN: 0006, TIME (Bei Jing TIME High Technology Ltd). The values of $\Delta MH\%$ were computed as explained in Equation 1 [28]

$$\Delta MH\% = \frac{MH\ after - MH\ before}{MH\ before} \times 100\% \quad (1)$$

2.4 Taguchi Design

To optimize product and process performance, reducing variability and enhancing quality is essential. Taguchi's designs employ fractional factorials to facilitate comprehensive research with minimal effort. This strategy conserves time and resources while yielding valuable insights. Robustness is achieved by mitigating the impact of external factors, particularly those beyond control [29]. Taguchi designs are helpful in many different areas, including manufacturing, engineering, and product creation. These methods are helpful to businesses because they help cut costs, improve performance, and increase customer happiness [30,31]. The experimental plans of the tests designed by Taguchi's L27 orthogonal array are recorded in Table 4 below.

Table 4: Taguchi L27 Orthogonal Array

Exp. No.	Voltage (V)	Time (min)	Gap distance (mm)	Spindle speed (r.p.m)	Particle size (μm)
1	A1	B1	C1	D1	E1
2	A1	B1	C1	D1	E2
3	A1	B1	C1	D1	E3
4	A1	B2	C2	D2	E1
5	A1	B2	C2	D2	E2
6	A1	B2	C2	D2	E3
7	A1	B3	C3	D3	E1
8	A1	B3	C3	D3	E2
9	A1	B3	C3	D3	E3
10	A2	B1	C2	D3	E1
11	A2	B1	C2	D3	E2
12	A2	B1	C2	D3	E3
13	A2	B2	C3	D1	E1
14	A2	B2	C3	D1	E2
15	A2	B2	C3	D1	E3
16	A2	B3	C1	D2	E1
17	A2	B3	C1	D2	E2
18	A2	B3	C1	D2	E3
19	A3	B1	C3	D2	E1
20	A3	B1	C3	D2	E2
21	A3	B1	C3	D2	E3
22	A3	B2	C1	D3	E1
23	A3	B2	C1	D3	E2
24	A3	B2	C1	D3	E3
25	A3	B3	C2	D1	E1
26	A3	B3	C2	D1	E2
27	A3	B3	C2	D1	E3

3. Results and Discussion

The microhardness values were measured before and after the MAF process for all experiments and are in Table 5. It can be seen that all experiments have an improvement in microhardness. The range of the percentage increase (4.12-21.20)% was notable. From the experimental results shown in Table 5, The most substantial enhancement in microhardness was observed (27), with a remarkable increase of 21.20%. This improvement was achieved through the use of the smallest particle size (offering more cutting edges), a high voltage (resulting in greater magnetic force), a moderate gap size (providing optimal magnetic force), and a lower rotational speed (creating higher cutting force).

The improvement of microhardness in the present work is reasonable compared to other works, as shown in Table 6. However, other works used a different number of parameters with different ranges. It is important to remember that the limits are still governed by the successful performance of the tool adapted and the optimal experiment. Therefore, the close improvement of the present work with others' improvements indicates the good ranges chosen for the parameters and the procedure despite using five input parameters.

Table 5: Taguchi design, Parameters, and Microhardness Results

Exp. No.	Voltage (V)	Time (min)	Gap distance (mm)	Spindle speed (r.p.m)	Particle size (μm)	Microhardness before finishing (μVH)	Microhardness after finishing (μVH)	Percentage change in microhardness ∆μH (%)
1	10	10	0.8	220	125-250	169.901	180.044	5.97
2	10	10	0.8	220	63-125	202.333	218.843	8.16
3	10	10	0.8	220	20-63	178.390	191.680	7.45
4	10	15	1.2	580	125-250	205.167	223.488	8.93
5	10	15	1.2	580	63-125	204.836	226.262	10.46
6	10	15	1.2	580	20-63	189.315	210.632	11.26
7	10	20	1.6	1150	125-250	221.882	231.024	4.12
8	10	20	1.6	1150	63-125	211.791	223.948	5.74
9	10	20	1.6	1150	20-63	169.927	183.351	7.90
10	20	10	1.2	1150	125-250	219.300	233.445	6.45
11	20	10	1.2	1150	63-125	179.233	193.805	8.13
12	20	10	1.2	1150	20-63	187.269	205.434	9.70
13	20	15	1.6	220	125-250	197.327	207.391	5.10
14	20	15	1.6	220	63-125	214.782	226.488	5.45
15	20	15	1.6	220	20-63	184.970	197.733	6.90
16	20	20	0.8	580	125-250	187.745	206.989	10.25
17	20	20	0.8	580	63-125	182.861	204.439	11.80
18	20	20	0.8	580	20-63	194.651	221.260	13.67
19	30	10	1.6	580	125-250	173.819	185.986	7.00
20	30	10	1.6	580	63-125	187.333	202.694	8.20
21	30	10	1.6	580	20-63	194.689	216.397	11.15
22	30	15	0.8	1150	125-250	198.378	219.406	10.60
23	30	15	0.8	1150	63-125	171.548	191.276	11.50
24	30	15	0.8	1150	20-63	185.628	212.785	14.63
25	30	20	1.2	220	125-250	176.471	205.977	16.72
26	30	20	1.2	220	63-125	164.105	193.808	18.10
27	30	20	1.2	220	20-63	187.674	227.461	21.20

Table 6: Compares the percentage decrease in %ΔMH with other works

Input Parameters	Improved %ΔMH	Ref.
Viscosity, powder quantity, pole diameter, rotation speed, and current	2.82 with oil	[14]*
Spindle speed and feed rate.	18–40.	[32]
Speed, current, time, and powder volume	21.8	[33]*
The radius of the hole, the angle of a core, the angle of the pole, and the radius of a pole	13	[34]
Number of grooves, finishing time, utting speed, voltage, andvolume of powder.	10.7-14.6	[17]
Voltage, time, gap distance, speed, and particle size	4.12-21.20	This study

Hint: * means that the percentages were calculated from data and/or graphs in the reference.

From Taguchi analysis results, the gap distance parameter had the main or maximum parameter effect on microhardness that has rank (1) as shown in Table 7, followed by voltage, time, particle size, and spindle speed. As can be seen in this table, the levels of the parameters are equivalent to the levels of the experiment (27) already achieved, as shown in Table 5. In Figure 3, the first part shows a consistent increase in the percentage change in microhardness (%ΔMH) as the voltage was raised, as noticed in previous studies [17][13]. The increase in %ΔMH leads to a large rigidity of abrasive chains that exert a stronger impact on the specimen's surface when the applied magnetic flux increases. So, a large magnetic force with a proper gap distance raised MH surfaces. Longer *finishing time* enhanced %ΔMH with a certain proper gap distance (magnetic force), where as Mousa [17] found the opposite with a big gap distance (low magnetic force). Gap distances (1.2, 0.8, 1.6) mm clearly influence %ΔMH. Among these, the 1.2 mm gap distance yielded the most favorable result because this gap distance facilitated optimal brush flexibility and effective abrasive force and abrasive movement. Although the 0.8 mm narrow gap produced high magnetic force, it constrained abrasive movement, while the 1.6 mm wide gap resulted a reduction in %ΔMH due to the increased distance between the pole and workpiece, weakening the rigidity of the chain of abrasives. As the spindle speed increased, the improvement in %ΔMH became less, as found in Ayad et al., Alkarkhi and Mousa [13,33,17], because the centrifugal force increased, pushing the abrasives further away from the tool center.

Small abrasive particle size in this work showed the highest (%ΔMH) and reduced continuously as the particle size grew. Therefore, the smaller abrasive particle size has more cutting edges than those with larger particles and the smaller particle size improved the brush flexibility [12]. In previous studies, a larger range of particles size was adapted and obtained opposite behaviour with microhardness. Therefore in this study, the maximum effect on microhardness can be observed with particle sizes of ((20-63), (63-125), and (125-250)) µm.Within the chosen ranges of the parameters and from Taguchi analysis as appeared in Table 7, the optimum parameters obtained are the level 3 in the voltage range (30V), level 3 of time (20 min), gap distance (level 2 (1.2 mm), spindle speed (level 1, 220 rpm) and particle size with level 3 (20-63 µm). The Equation 2 shows the (%ΔMH) regression equation. From ANOVA analysis- General Linear Model (%ΔMH) versus voltage (V), time (min), Gap distance (mm), Spindle Speed (rpm) and particle size (mm) are given in Table 8. that shows the results of Analysis of Variance.

The Regression Equation model

$$\%\Delta MH = 0.09872 - 0.02095V(10) - 0.01266V(20) + 0.03361V(30) - 0.01849T(10) - 0.00446T(15) + 0.02295T(20) + 0.00576G(0.8) + 0.02456G(1.2) - 0.03032G(1.6) + 0.00689S(220) + 0.00430S(580) - 0.01120S(1150) - 0.01523P(125\text{-}250) - 0.00145P(63\text{-}125) + 0.01668P(20\text{-}63) \quad (2)$$

where : (V): Voltage, (T): Time,(G): Gap distance,(S): Spindle Speed,(P): Particle size.

Table 7: Most parameter contribution in microhardness from the means

Level	Voltage (v)	Time (min)	Gap distance(mm)	Spindle speed (r.p.m)	Particle size (µm)
1	0.07777	0.08023	0.10448	0.10561	0.08349
2	0.08606	0.09426	0.12328	0.10302	0.09727
3	0.13233	0.12167	0.06840	0.08752	0.11540
Delta	0.05457	0.04143	0.05488	0.01809	0.03191
Rank	2	3	1	5	4

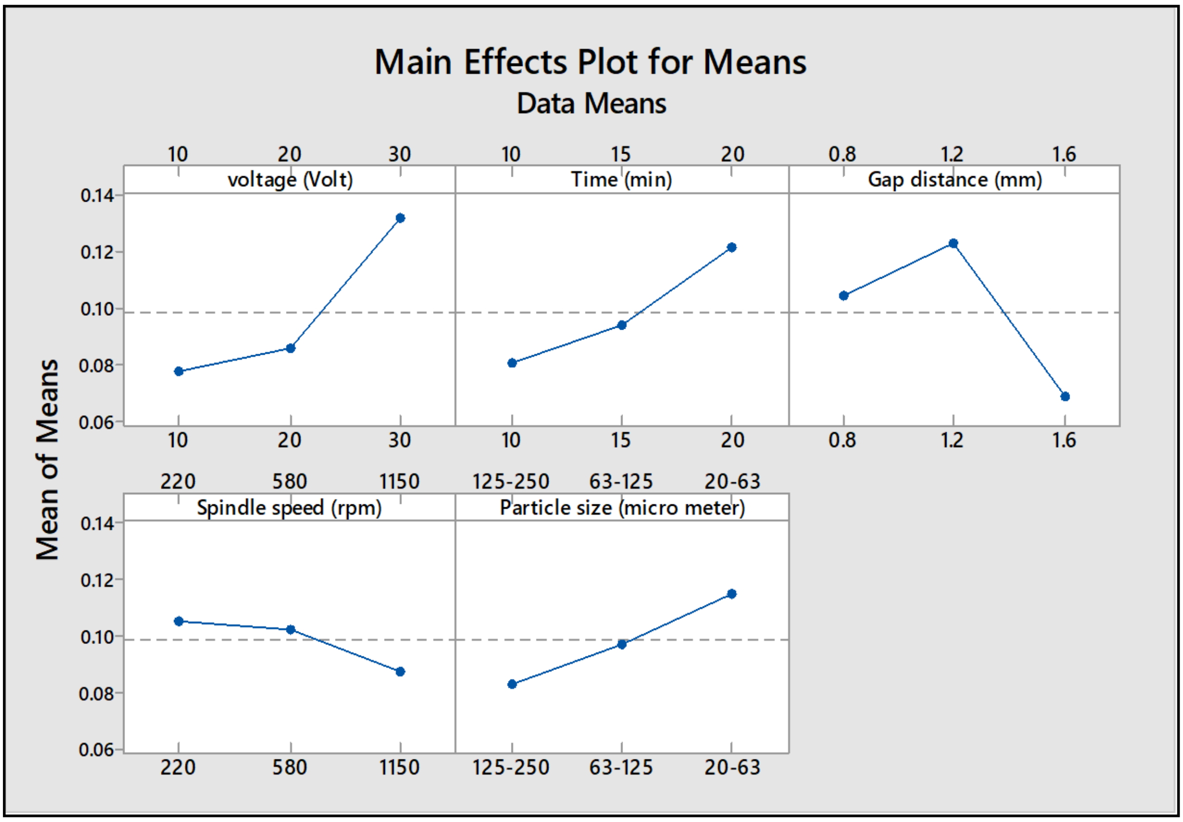

Figure 3: Means of Microhardness

Table 8: Analysis of Variance for %ΔMH

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution percentage
Voltage (V)	2	0.015564	0.007782	156.55	0.000	35%
Time (min)	2	0.007994	0.003997	80.41	0.000	18%
Gap distance (mm)	2	0.014000	0.007000	140.82	0.000	31%
Spindle speed (rpm)	2	0.001722	0.000861	17.33	0.000	4%
Particle size (µm)	2	0.004611	0.002305	46.38	0.000	10%
Error	16	0.000795	0.000050			
Total	26	0.044686				
Model Summary	S = 0.0070504	R-sq = 98.22%	R-sq(adj) = 97.11%	R-sq(pred) =94.93%		

The ANOVA analysis is illustrated in Figure. 4, elucidating the interactions among input factors for %ΔMH. The top row initially elaborates on the behavior of %ΔMH concerning three voltage levels in correlation with other parameters. Voltage interacts with time, gap distance, and speed but does not interact with particle size. The second row shows the behavior of %ΔMH regarding three-time levels in conjunction with other parameters, where time interacts with gap distance and speed. The third row illustrates the interaction of gap distances with the speed parameter. In the last row, it's noted that spindle speed levels do not interact with the particle size.

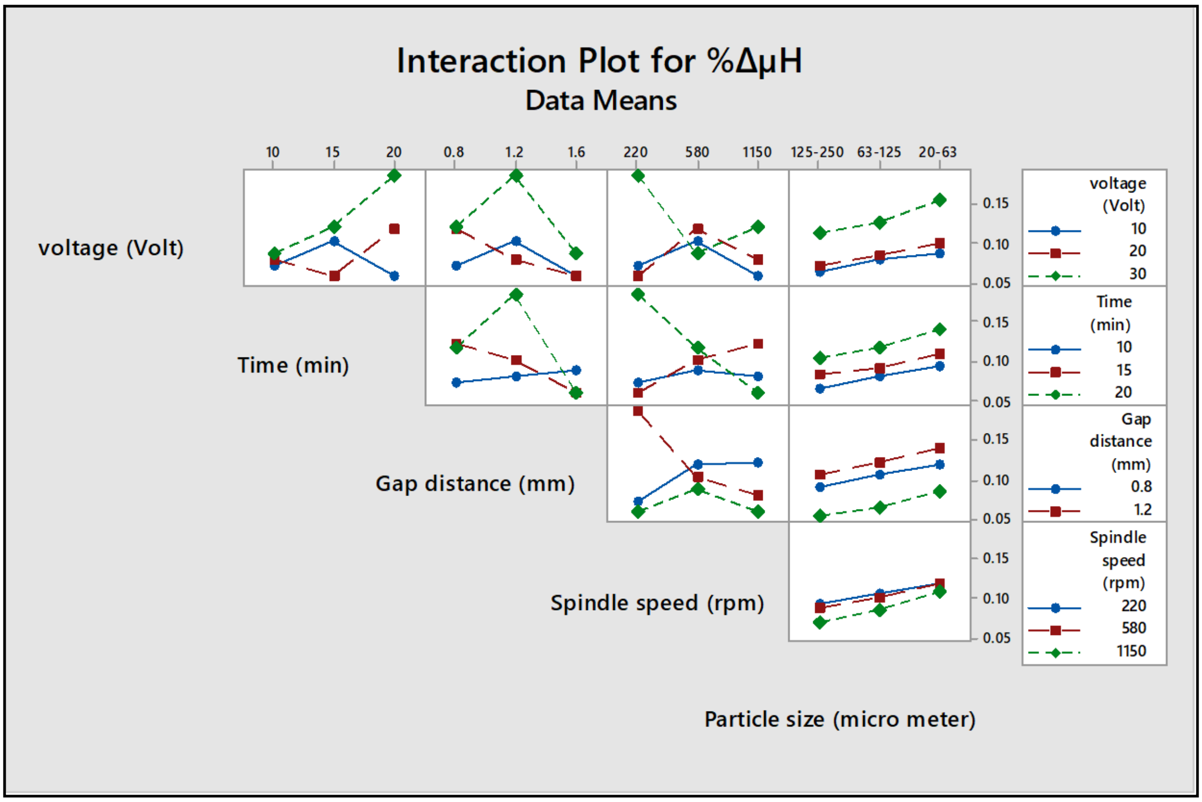

Figure 4: Interaction plot for %ΔMH

4. Conclusion and Future Work

This study examined the microhardness of stainless steel SUS420 bubble cups at the MAF process for bubble cups. Brush flexibility, which changes depending on the tools' electromagnetic design, affects the MAF process's performance. By analyzing the experimental data using Taguchi Analysis in Minitab 17, the study determined the relative effects of each parameter on the microhardness as:

1. The best parameters of %ΔMH in the current experimental setting are in experiment 27, which can differ from one design to another.
2. The small abrasive particle size gives good results in %ΔMH with a 1.2 mm gap distance.
3. The analysis showed that the parameters' order affected the (%ΔMH) from the largest to the smallest in order (gap distance, voltage, time, particle size, and spindle speed).
4. The optimum parameter values obtained from Taguchi analysis are given: level 3 in the voltage range (30V), level 3 of time (20 min), gap distance (level 2 (1.2 mm), spindle speed (level 1, 220 rpm) and particle size with level 3 (20-63 µm).

5. The very small gap needs higher speed, lower voltage, and/or smaller particle sizes of abrasives to increase the brush's flexibility and vice versa.
6. The (%ΔMH) was raised with higher values of (voltage and time) and lowered with higher values of (particle size and spindle speed), with another proper parameter excepting the value of 1.2 mm of gap distance at this work.
7. The optimum percentage increase of microhardness obtained was 21.2%.
8. The study of many input parameters is significant to optimize the MAF process. Still, it is important to expand the levels of the parameters to obtain clearer behavior and determine the limit of each, which is useful for future works that concern designing and manufacturing MAF machines in industrial productions.

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Author Contribution

Conceptualization, A. Ahmed and S. Shather; formal analysis, A. Ahmed and S. Shather.; resources, A. Ahmed and S. Shather.; writing—original draft preparation, A. Ahmed and S. Shather.; writing—review and editing, A. Ahmed and S. Shather.; supervision, S. Shather. All authors have read and agreed to the published version of the manuscript.

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The data supporting the current research results are accessible upon request from the corresponding author.

Conflicts of Interest:

The researchers declare that there's no conflict of interest.

Reference

[1] S. Mohamed, Types and Design of the Towers Tray, Faculty Of Petroleum & Mining Engineering, (2013)1–14.

[2] A. Zoesch, T. Wiener, and M. Kuhl, Zero defect manufacturing: Detection of cracks and thinning of material during deep drawing processes, Procedia CIRP, 33 (2015) 179–184.https://doi.org/10.1016/j.procir.2015.06.033

[3] Engel V. How to design and optimize Bubble Cap Trays, Part 2, ©WelChem GmbH • 2020.

[4] H. S. Mahdi , K. N. Sallomi and H. H. Ismail, Improvement of Microhardness and Corrosion Resistance of Stainless Steel by Nanocomposite Coating, Al-Khwarizmi Eng. J., 10 (2016). https://alkej.uobaghdad.edu.iq/index.php/alkej/article/view/201

[5] D. Bartkowski, A. Bartkowska, and D. Przestacki, Microstructure, Microhardness, Corrosion and Wear Resistance of B, Si and B-Si Coatings Produced on C45 Steel Using Laser Processing, Metals, 10 (2020) 792. http://dx.doi.org/10.3390/met10060792

[6] S. Ahmad, R. M. Singari, and R. S. Mishra, Tri-objective constrained optimization of pulsating DC sourced magnetic abrasive finishing process parameters using artificial neural network and genetic algorithm, Mater. Manuf. Process., 36 (2021) 843–857. https://doi.org/10.1080/10426914.2020.1866196

[7] O. Othman, Improvements in out-of-roundness and microhardness of inner surfaces by internal ball burnishing process Improvements in out-of-roundness and microhardness of inner surfaces by internal ball burnishing process, J. Mater. Process. Technol.,196 (2008) 120-128.https://doi.org/10.1016/j.jmatprotec.2007.05.028

[8] M. Abdallha, S. Al-zubaidi, and A. H. Kadhum, Effect of Magnetic Abrasive Finishing Process on the Surface roughness of CuZn28 With New Pole Geometry, J. Mech. Eng. Res. Dev.,43 (2020) 256–264.

[9] N. Sihag, P. Kala, and P. M. Pandey, Chemo assisted magnetic abrasive finishing: Experimental investigations, Procedia CIRP, 26 (2015) 539–543. https://doi.org/10.1016/j.procir.2014.07.067

[10] El-Hofy H., Advanced Machining Processes, Nontraditional and Hybrid Machining Processes, Production Engineering Department Alexandria University, Egypt, The McGraw-Hill Companies, 2005.

[11] R. Kumar, D. K. Singh, and S. Gangwar, ScienceDirect Advances in Magnetic Abrasive Finishing for Futuristic Requirements - A Review, Mater. Today Proc., 5 (2018) 20455–20463. https://doi.org/10.1016/j.matpr.2018.06.422

[12] Singh, S., Gupta, V., and Sankar, M. R., Magnetic Abrasive Finishing Process," B. Adv. Abras. Based Mach. Finish. Process. Mater. Forming, Mach. Tribol. Springer, Cham., pp. 183–210, 2022, doi: https://doi.org/10.1007/978-3-030-43312-3_8..

[13] B. Ayad , S. K. Shather, W. K. Hamdan, Improve the Micro-hardness of Single Point Incremental Forming Product Improve the Micro-hardness of Single Point Incremental Forming Product Using Magnetic Abrasive Finishing, Eng. Technol. J. 38 (2020) 1137-1142. https://doi.org/10.30684/etj.v38i8A.906

[14] A. M. Nahy and A. H. Kadhum, Optimizing the micro-hardness of a surface by magnetic abrasive finishing Optimizing the micro-hardness of a surface by magnetic abrasive finishing, IOP Conf. Ser.: Mater. Sci. Eng., 870 (2020) 012018 . https://doi.org/10.1088/1757-899X/870/1/012018

[15] J. Zhang, A. Chaudhari, and H. Wang, Surface quality and material removal in magnetic abrasive fi nishing of selective laser melted 316L stainless steel, J. Manuf. Process., 45 (2019) 710–719. https://doi.org/10.1016/j.jmapro.2019.07.044

[16] Y. Cui et al., Study on magnetic abrasive finishing process of AlSi10Mg alloy curved surface formed by selective laser melting, Int. J. Adv. Manuf. Technol., 118 (2022) 3315–3330. https://doi.org/10.1007/s00170-021-08138-4

[17] S. M. Mousa, Improvement the Hardness of Stainless Steel 321 by Magnetic Abrasive Finishing Process, Al-Nahrain J. Eng. Sci., 20 (2017) 838–845.https://nahje.com/index.php/main/article/view/307

[18] S. K. Amineh, A. F. Tehrani, and A. Mohammadi, Improving the surface quality in wire electrical discharge machined specimens by removing the recast layer using magnetic abrasive finishing method, Int. J. Adv. Manuf. Technol., 66 (2013) 1793-1803.http://dx.doi.org/10.1007/s00170-012-4459-7

[19] J. Kang, A. George, and H. Yamaguchi, High-speed internal finishing of capillary tubes by magnetic abrasive finishing, Procedia CIRP, 1 (2012) 414–418. http://dx.doi.org/10.1016/j.procir.2012.04.074

[20] P. Saraeian, H. Soleimani Mehr, B. Moradi, H. Tavakoli, and O. Khalil Alrahmani, Study of Magnetic Abrasive Finishing for AISI321 Stainless Steel, Mater. Manuf. Process., 31 (2016) 2023–2029. http://dx.doi.org/10.1080/10426914.2016.1140195

[21] S. K. Shather, and M. Alaqeeli, Influence Of Silicon Carbide (Sic) Abrasive On Surface Roughness And Metal Removal Rate During Magnetic Abrasive Finishing, Glob. J. Eng. Sci Res. Manag., 6 (2019) 8-20.

[22] A. Wahab, H. Singh, A. Meena, and I. Ahamad, Experimental investigation on magnetorheological finishing process parameters, Mater. Today Proc., 48 (2021) 1892-1898. http://dx.doi.org/10.1016/j.matpr.2021.09.355

[23] J. Liu and Y. Zou, Study on Elucidation of the Roundness Improvement Mechanism of the Internal Magnetic Abrasive Finishing Process Using a Magnetic Machining Tool, J. Manuf. Mater. Process., 7 (2023) 49. https://doi.org/10.3390/jmmp7010049

[24] Y. M. Hamad, Improvement of Surface Roughness Quality for Stainless Steel 420 Plate Using Magnetic Abrasive Finishing Method, J. Al-Khwarizmi Eng. J., 6 (2010) 20.

[25] L. Nagdeve, K. Dhakar, and H. Kumar, Development of novel finishing tool into Magnetic Abrasive Finishing process of Aluminum 6061, Mater. Manuf. Process., 35 (2020) 1129–1134. https://doi.org/10.1080/10426914.2020.1767295

[26] M. Vahdati and S. A. Rasouli, Evaluation of Parameters Affecting Magnetic Abrasive Finishing on Concave Freeform Surface of Al Alloy via RSM Method, Adv. Mater. Sci. Eng., 2016. https://doi.org/10.1155/2016/5256347

[27] Y. Zou, H. Xie, Z. Yulong, and T. Liaoning, Study on surface quality improvement of the plane magnetic abrasive finishing process Study on surface quality improvement of the plane magnetic abrasive finishing process, Int. J. Adv. Manuf. Technol., 109 (2020) 1-15. https://link.springer.com/article/10.1007/s00170-020-05759-z

[28] A. Collaborative, How to Calculate Percentage Change, 2007–2008, 2008.

[29] T. Stapenhurst and A. Bendell, Taguchi Methods, Oper. Res. Soc. Japan, 41 (1990)887-889. https://doi.org/10.2307/2583510

[30] A. Azadeh, S. S. Miri-Nargesi, S. M. Goldansaz, and N. Zoraghi, Design and implementation of an integrated Taguchi method for continuous assessment and improvement of manufacturing systems, Int. J. Adv. Manuf. Technol., 59 (2012)1073–1089. https://doi.org/10.1007/s00170-011-3549-2

[31] J. Limon-Romero, D. Tlapa, Y. Baez-Lopez, A. Maldonado-Macias, and L. Rivera-Cadavid, Application of the Taguchi method to improve a medical device cutting process, Int. J. Adv. Manuf. Technol., 87 (2016) 3569–3577. , https://doi.org/10.1007/s00170-016-8623-3

[32] A. Alaskari, A. Albannai, B. Althaqeb, and T. Liptakova, Improving the surface quality of 60 / 40 brass using flexible magnetic burnishing brush formed with permanent magnets, Manuf. Lett., 24 (2020) 113–122. https://doi.org/10.1016/j.mfglet.2020.04.002

[33] N. K. Alkarkhi, Study on the parameter optimization in magnetic abrasive study on the parameter optimization inmagnetic abrasive polishing forbrass cuzn33plate using taguchi method, Iraq. J. Mech. Mater. Eng., 12 (2012) 596-615.

[34] B. L. Mahdi and A. H. Kadhum, The effect of magnetic system geometry on the quality of the surface in MAF, Thesis for: Master, 2022. https://doi.org/10.13140/RG.2.2.29031.73128