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STUDY ON THE PARAMETER OPTIMIZATION INMAGNETIC ABRASIVE POLISHING FORBRASS CUZN33PLATE USING TAGUCHI METHOD

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Abstract*:*

This paper describes a new finishing process using magnetic abrasiveswere newly made to finish effectively brass plate that is very difficult to be polished by the conventional machining processes.Taguchi experimental design method was adopted for evaluating the effect of the process parameters on the improvement of the surface roughness and hardness by the magnetic abrasive polishing.The process parameters are: the applied current to the inductor, the working gap between the workpiece and the inductor, the rotational speed and the volume of powder. The analysis of variance (ANOVA) wasanalyzed using statistical softwareto identify theoptimal conditions for better surface roughness and hardness. Regressions models based on statistical-mathematical approach by using the MINITAB-statistical software for both surface roughness and hardness were obtained.Experimental results indicated that rotational speed is the most significant parameters on change in surface roughness(ΔRa), and for change in surface hardness (ΔHa), volume of powder is the significant one.As a result, it was seen that the magnetic abrasive polishing was very useful for finishing the brass alloy plate.

الخلاصة

يصف هذا البحث طريقة تنعيم جديدة باستخدام مادة حاكة مغناطيسية جديدة صنعت لانهاء سطح لوحة سبيكة البراص التي في الواقع من الصعب جدا ان تصقل باستخدام طرق التشغيل التقليدية. اعتمدت طريقة تاكوجي لتصميم التجارب لتقييم تاثير متغيرات العملية التشغيلية على تحسين خشونة وصلادة السطح بواسطة التنعيم بالحك المغناطيسي. متغيرات العملية التشغيليةهي التيار المجهز للملف والفجوة بين الملف والمشغولة وسرعة دوران الملف واخيرا حجمالمسحوق. تم تحليل التباين باستخدام برنامج احصائي لتحديد الظروف المثلى للحصول على افضل سطح من حيث الخشونة والصلادة.تم الحصول على نموذج رياضي إحصائي باستخدام برنامج الحاسوب MINITAB ، يوضح العلاقة بين المتغيرات وجودة السطح من حيث الخشونة والصلادة. النتائج التجريبية تشير الى ان سرعة الدوران هي الاكثر تاثيرا لاجراء تغيير في خشونة السطح (ΔRa) بينما التغير في صلادة السطح (ΔHa)، حجم المسحوق هو الاكثر تاثيرا. كمحصلة نهائية يمكن الاستنتاج بانة التنعيم بالحك المغناطيسي طريقة جدا كفوئة لانهاء السطوح المصنعة من سبائك البراص.

Keywords:
Magnetic Abrasive polishing (MAP), non-ferromagnetic materials, surface roughness,Taguchi experimental design, magnetic abrasive powder, electromagnetic inductor, flat surface.

1. Introduction

A relatively new finishing method, magnetic abrasive polishing(MAP) or magnetic abrasive finishing(MAF) is one such advanced machining process in which cutting force is primarily controlled by the magnetic field.InMAP, the workpiece is kept between the two poles of a magnet**Fig.1**.The working gap between the workpiece and the magnetis filled with magnetic abrasive particles(MAPs). A magnetic abrasiveflexible brush (MAFB) is formed**Fig.2**, acting as a multipoint cuttingtool, due to the effect of the magnetic field in the working gap.The tool canremove a very small amount of material from a workpieceand better surface can be produced after polishing without damaging its surface. This process can be used to produce efficiently good surface quality of some products such asbearings, precision automotive components, shafts. The method can not only machine ferromagnetic materials such as steel, but can also machine nonferromagnetic materials such as brass.Brass is a soft, very ductile and as a general rule, soft materials are not so easy to machine as harder one [1].Conventional solid polishing tools have high polishing force and some abrasives are harder than brass, which may even damage the materialsurface, resulting in re-working, time-consuming and errorprone. In order to overcome these defects, non-conventionaltechniques are required. Amongst them, Magnetic AbrasivePolishing (MAP) process is developed for these application areas[14].

Some findings related to MAF process are reported in this paper. The magnetic abrasive finishing (MAF) method was originally introduced in the Soviet Union,sited inYamaguchi, Shinmura [2]. Yamaguchi, Shinmura[2] have examined the microscopic changes in the surface texture of SUS304 stainless steel disk resulting from aninternal magnetic abrasive finishing processusing sintered magnetic abrasive powder of a ferromagnetic substance (Fe_2O_3) and pure aluminum.Yamaguchi,Shinmura[3] have proposed an internal magnetic abrasive finishing process using a pole rotation system to produce highly finished inner surfaces of SUS304 stainless steel tubes.MAF setup has been designed andfabricatedbyV.K. Jain et al. [4]. The performance of the setup has also beenstudied on non-magnetic stainless steel with the use of loosely bounded MAPs (mechanical mixing of ferromagneticpowder and abrasive powder with a small amountof lubricant). It isconcluded that working gapand circumferential speed of workpiece are the parameterswhich significantly influence the material removal, changein surface roughness value(Ra).

The effectiveness and validity of a MAF method to refine rough surfaces and sharp edges of silver steel bars have been investigated by AhmedB. Khairy [5] using sintered mixture of AL_2O_3 and iron powder.Geeng-Wei Changet al.[6]have describedthe process principle and the finishing characteristics of a mechanical mixture of SiCabrasive and ferromagneticparticles with a SAE30 lubricant as unbonded magnetic abrasive within cylindrical magnetic abrasive finishing.T. Moriet al.[7] have examined the magnetic field, acting forces and provides a fundamental understanding of the process mechanism of magnetic abrasive polishing for a non-magnetic material, stainless steel using magnetic abrasive powder that was sintered from an aggregate of iron and alumina particles.

Taguchi design of experiments is applied on magnetic abrasive finishing (MAF) process byDhirendra K. Singhet al.[8] to find out important parameters influencing the surface quality generated using a mechanically mixed homogeneous mixture of silicon carbideabrasives and ferromagnetic iron particles.Experimental results have indicated that for a change in surface roughness (Δ*R*a), voltage and working gap are found to be themost significant parameters followed by grain mesh number and then rotational speed. Modeling and numerical simulationof surface roughness in the MAF process have been performed byS.C. Jayswalet al.[9] and concluded thatthe magnitude of the normal magnetic force is relativelyhigher near the edge of the magnetic pole due to the edge effect.

Dhirendra K. Singhet al.[10]havereported the experimental findings about the forces acting during MAF and provide correlation between the surface finish and the forces.It is concluded thatforces and change in surface roughness (ΔRa) increase with increase in current to the electromagnet (or magnetic flux density) and decrease in the working gap.The working gap is filled with a homogeneous mixture of silicon carbide abrasives and ferromagnetic iron particles in the ratio of 25:75 by weight, respectively.

Ching-Tien Linet al.[11] have employed magnetic abrasive finishing(MAF) to conduct free-form surface abrasion ofstainless SUS304 material operations. The operationswere demonstrated using a permanent magnetic finishingmechanism installed at the CNC machining center. Theoperations were performed using the Taguchi experimentaldesign, considering the effects of magnetic field, spindlerevolution, feed rate, working gap, abrasive, and lubricant.Therefore,the results revealed that MAF provides a highly efficientway of obtaining surface finish.

Experimentswere carried out by L. Koet al.[12] to verify the influence of each condition: volume of powder, height of gap, rotational frequency of the inductor and feed velocity.To improve the surface roughness and impurity, a method of coolant supply and component of abrasive powder (mechanical mixture of powders ofiron $CH_2$50% vol.and $Al_2O_3$50% vol.)are investigated. It is proved that the continuous flow of coolant and the Fe powder without abrasive is effective for surfacequality.

Raghuram, Suhas S. Joshi[13] Have proposed analytical model for the surface roughness in polishing stainless steel work surface. The model was found to agree reasonably well with the experimental results.

Jae-Seob and Tae-Kyung [14]was performedMAP on the magnesiummaterial and design of experimental method using the Taguchi method was applied toevaluate parameter’s effect on the surface roughness using Fe powder and boron nitride as magnetic abrasive powder, it was seen that better surface roughness could be obtained by applying the MAP process.

The second generation magnetic abrasivepolishing process, which consists of electro-magnet array table and magnetic abrasives mixed with silicone gel medium, was developed byJae-Seob, Chang-Min Shin[15]to improve the magnetic force for MAP of AZ31B magnesium alloy. As a result, it isindicated that magnetic force intensity of magnetic table andspindle speed of inductor was significant parameters onimprovement of surface roughness in the second generationMAP process.

In this study, MAP process was performed on the brass material for getting better surface quality. In addition a new magnetic abrasive powder which is a mixture of 33 wt% iron and 67 wt% quartz was prepared. Furthermore, to study the influence of working parameters on the improvement of surface roughness and hardness, experiments using the Taguchi method and L9(3^4) orthogonal array wereadopted**Table3.**

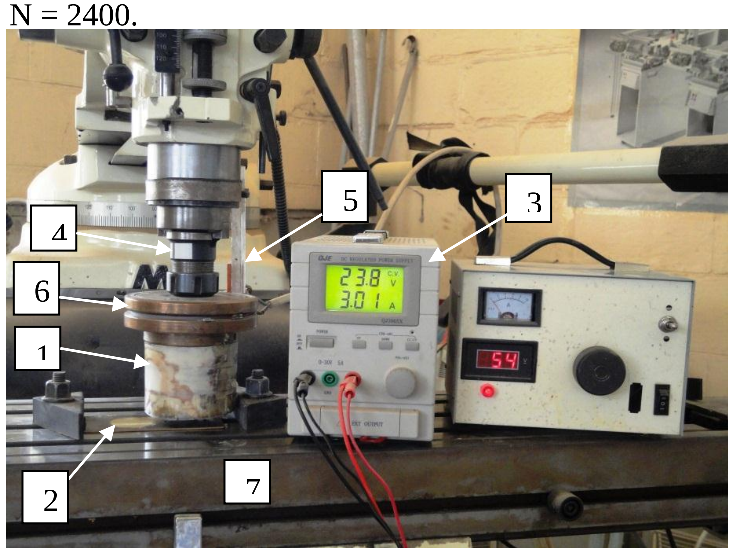
Consequently, it was seen that better surfaceroughness and hardness could be obtained by applying the MAP process.

2. Electromagnetic inductor design

An electromagnetic inductor was designed and manufactured for surfacefinishing on flat work piecesby a milling machine in amachining laboratory of Baghdad University; its general view is shown in**Fig.1**. The electromagnetic inductor (1)is asteel rod wrapped around a coil of wires. According toFaraday's Laws, when the voltage and current are supplied tothe coil, magnetic force is generated between theelectromagnetic pole and the workpiece (2). A continuous current was suppliedto the inductor by D.C. power supply (3). The body of the inductor was fixed on the mandrel with theshank and inserted into the hole of a milling machine spindle (4). The coil waslocated inside the inductor body and the slipbrushes (5) placed on the commentator (6) at top plane ofthe inductor body to connect the coil with the constant current source. The magnetic pole was located at the bottom plane of the inductor,representing the North Pole and the workpiece was the South Pole. The radial grooves were made on the ring pole to createmagnetic field concentrators and equalize the area of the pole.A fixture with work pieces was placed on the table of the milling machine (7). While the inductor rotated, the machine table together with the fixtures and workpiece was fed during the finishing process.As shown in**Fig.2**,Magnetic abrasive particles are attracted on the pole alonglines of magnetic force, forming a flexible magnetic abrasivebrush (1). The brush rotates with the magnetic pole, beingpressed toward the workpiece (2) and then removes the materialin forms of chips. The gap between the pole and the surface ofthe work piece during finishing are referred to as working gapfilledwith the magnetic abrasive powder (3).

The characteristics of the electromagnetic inductor are the following:

- The material of the iron core is: C 15 low carbon steel,
- The cross-section of the iron core is: A= 14 cm^2,
- The length of the iron core is: L = 75 mm,
- The diameter of the copper wire of the magnetic coil is: Ø=1 mm,
- The number of turns is: N = 2400.



Fig(1): photograph of the magnetic abrasive polishing

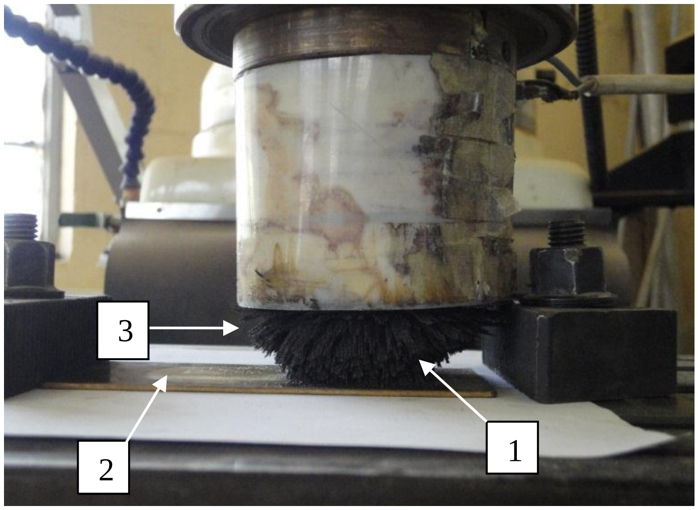


Fig (2): Magnetic brush formed between the electromagnet pole (north) and the non ferromagneticworkpiece (south)

3. Materialsand tests condition

A series of experiments were made to finish a non-ferromagnetic material, brass alloywhose properties is shown in **Table1**. The workpieces are divided to nine flat plate pieces as shown in **Fig.3;** each one has dimensions of 130mm in length, 60mm in width, and 1.5 mm thickness. The average of measured roughness and Micro-Vickers hardnessof the surface before operation is Ra = (1.046 – 1.065)µm andHa = (98–99.8)HV, respectively.

Table 1: Properties of brass alloy CuZn33

UNS No	AS No	Common Name	BSI No	ISO No	JIS No	Copper %	Zinc %	Lead %
C26800	268	Yellow brass (65/35)	CZ107	CuZn33	C2680	64.0-68.5	~ 33	< 0.15
Plate sheet strip	Temper	Tensile strength kg/mm^2	Vickers hardness	Shear strength kg/mm^2		Density kg/mm^3		
	Coled worked	38-39	89-105	28		8400-8730		

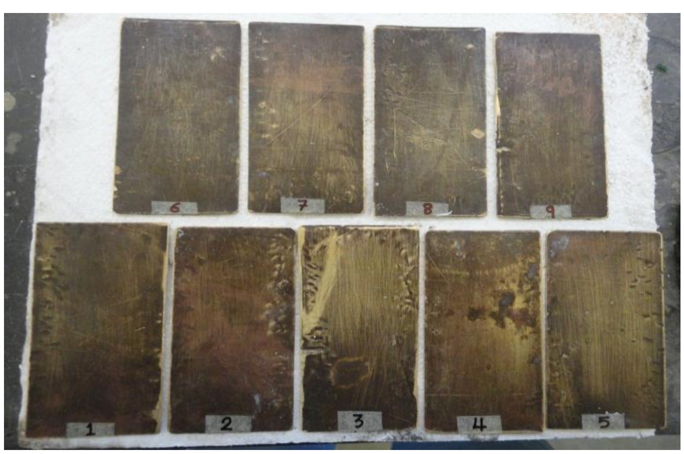


Fig (3):photograph of the nine brass workpieces before MAP

4. The magnetic abrasive powder

Fig.4 shows aschematic view of a sintered magnetic abrasive particle.In this study, the magnetic abrasives were typicallymixed with 40wt% iron powder and 60wt% quartz. The abrasives were then compressed into a cylindrical modeand sintered in a vacuum furnace at(1200°C). Following the sintering process, the magneticabrasives were crushed into small particles with diametersof approximately 150 µm, and the magnetic abrasivesbecame well mixed. During finishing, iron powder andquartz were difficult to separate since they werecohered after sintering. **Fig.5**shows the magnetic abrasives under a scanning electronic microscope (SEM, JSM-6360LV type) which are spherical with no sharp edge that may scratch the soft brass material.

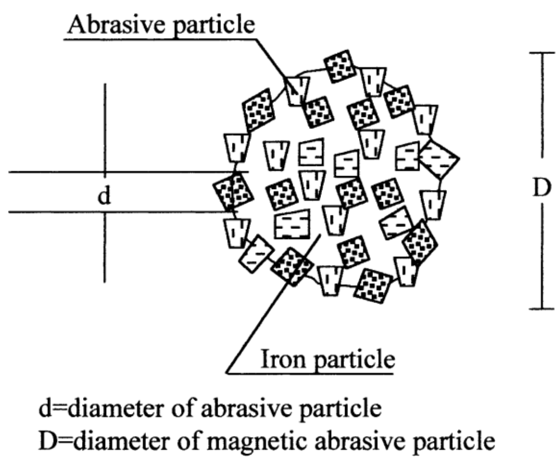


Fig (4): Schematic view of a sintered magnetic abrasive particle used inmagnetic abrasive polishing

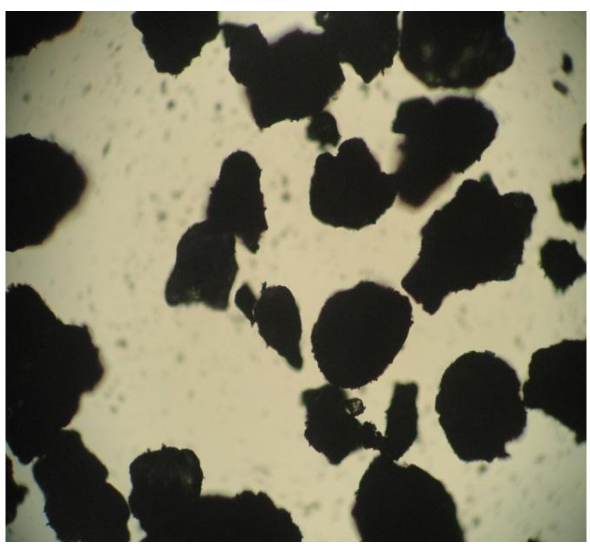


Fig (5):SEM (X 100) of magnetic abrasives

5. Experimental set-up

The schematic diagram of a plane magnetic abrasive finishingapparatus is shown in**Fig.6**.In this processand during the design of the setup the parameters that have been considered are the effect of change the working air gap (1.0 -2.0)mm,the magnetic flux density in the working gap isvaried by changing input current to the electromagnetfrom 1.5Ampto 3.5 Amp, the volume of powder (2 - 4) $cm^3$and the change of inductor rotational speed (175-525) rpm using constant feed rate 30 mm/min.

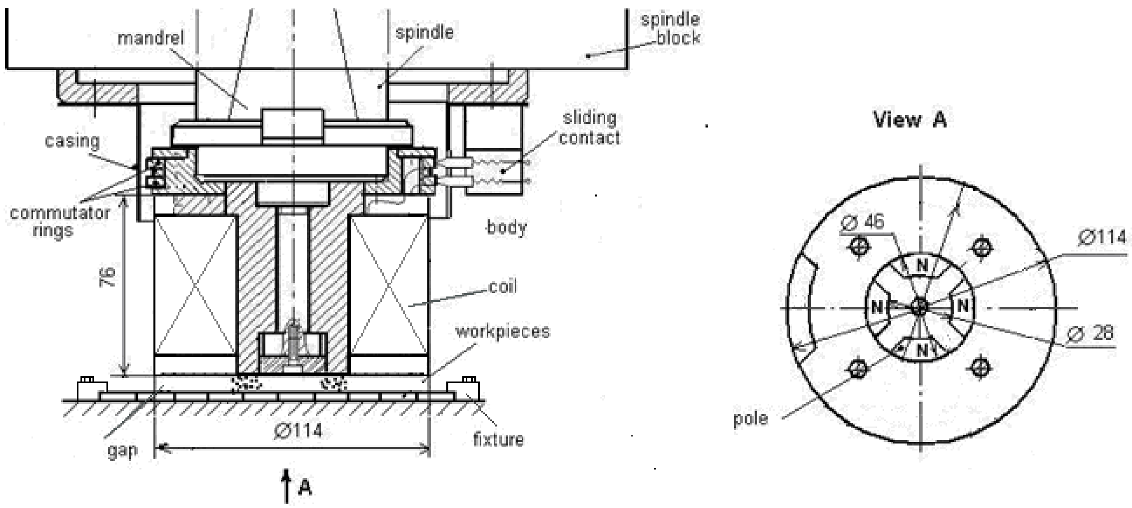


Fig (6): Schematic view of plane magnetic abrasive polishing

6. Experimental design based on Taguchi method

Taguchi method has been widely used in engineering analysis,and is a powerful tool to design a high quality system.Moreover, Taguchi method employs a special design of orthogonalarray to investigate the effects of the entire machiningparameters through small number of experiments. Recently,the Taguchi method was widely employed in several industrialfields and research works [7], [10].

The experimental design was according to an L9 orthogonalarray based on the Taguchi method, while using the Taguchiorthogonal array would markedly reduce the number ofexperiments.The L9 orthogonal array had four columns and 9rows. Thus, four machining factors can be apportionedto the columns and the rows designate 9 experiments withvarious combination levels of the machining parameters.In this study, fourpossible parameters which arerotational speed of inductor (P_1),coil current (P_2), volume of powder (P_3), working gap (P_4),considered and used to conductexperiments. In the experiment, four factors with eachthree levels were selected respectively as**Table2**. Two observed values of change in surface roughness (ΔRa) and Micro-Vickers hardness (ΔHa),were examined. The levels of each machining parameterswere set in accordance with the L9 orthogonal array, based on the Taguchi experimentaldesign method as **Table3**. In this work, the experimentally observed (ΔRa)and (ΔHa)value are "the higher the better".

Table (2): Parameters and their Levels

Parameters	Units	Levels
Rotational speed (P_1)	rpm	175 - 350 - 525
Coil current (P_2)	Amp	1.5 - 2.5 - 3.5
Volume of powder (P_3)	cm^3	2.0 – 3.0 – 4.0
Working gap (P_4)	mm	1.0 - 1.5 - 2.0

Table (3): Orthogonal array $L_9(3^4)$ forexperiments parameters

Exp.	Parameters			
	Rotational speed (P_1) (rpm)	Coil current (P_2) (Amp)	Volume of powder (P_3) (cm^3)	Working gap (P_4) (mm)
1	175	1.5	2	1.0
2	350	2.5	3	1.0
3	525	3.5	4	1.0
4	350	1.5	4	1.5
5	525	2.5	2	1.5
6	175	3.5	3	1.5
7	525	1.5	3	2.0
8	175	2.5	4	2.0
9	350	3.5	2	2.0

7. Experimental procedure

Theworkpieces whichare divided to nine pieces,each one is fixed in the slot of thefixture respectively in such a way that center of the workpiece coincideswith the center of the north pole of the magnet. The requiredgap between the flat-faced pole and workpiece is set withthe help of slip gauges. Again after setting the gap, both theflat-faced magnet and workpiece are checked with referenceto the table of the machine. The magnetic abrasiveparticles are prepared just before the startof each experiment with different amount of volume (cm^3). The workpieces are cleanedat the end of each experiment, the fixture andworkpieces are taken out from the MAF setup.To obtain more accurate experiment results, aftercleaning the workpiece, we measured the surface roughness and Micro-Vickers hardnessboth in the central and side of the workpiece at 6 randompointsbefore and after magnetic abrasive finishing, which were identified in **Fig.7** and later thevalues were averaged.The differences in thesetwo Raand Ha values (before and after MAF) at the same locationare called(ΔRa) and (ΔHa), respectively.The change in surface roughness value (ΔRa)is determined by measuring Ra (center line average value, by Surface roughness tester (TR-220)) as shown in**Fig.8**with a cut-off length of 0.8 mm. The measurement has been done by movingthe stylus in the same area perpendicular to the lays obtainedin the process. Also, the same procedure is used to measure the change in Micro-Vickers hardnessvalue (ΔHa) by micro hardness tester (MICROMET), as shown in **Fig.9**.

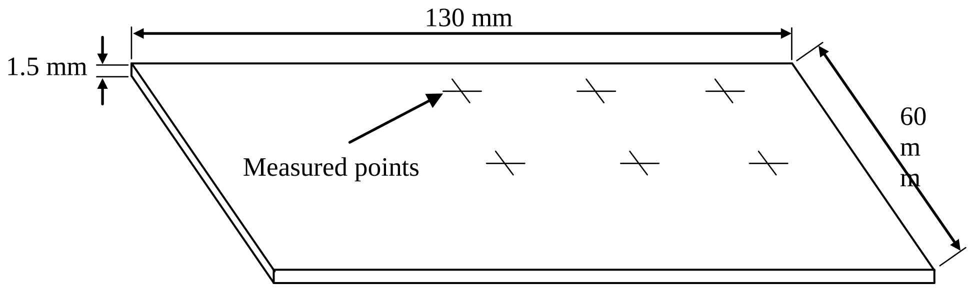


Fig (7): Measuring points on the material surface.

Fig(8): Surface roughness tester, Time Group Inc. (TR-220)

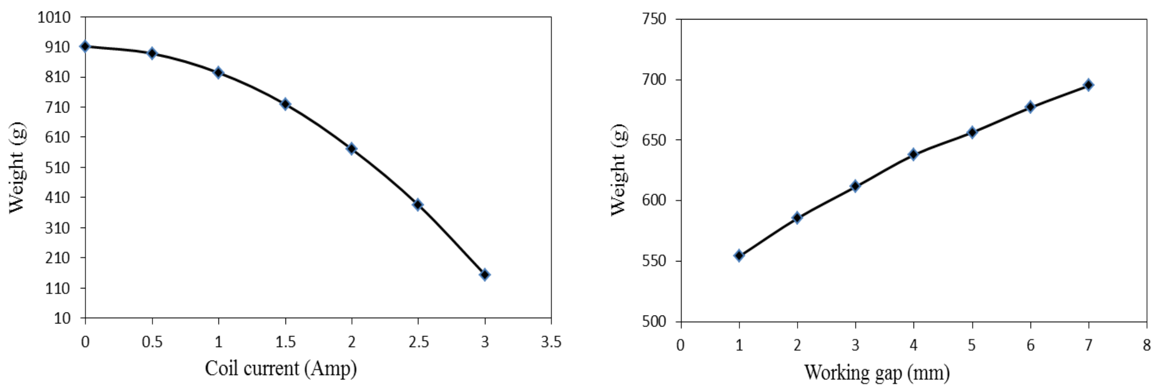
Fig (9): Micro hardness tester (MICROMET)

8. Results and discussion

A magnetic attraction forces can be observedby using a sensitive balance with known weightas shown in **Fig.1**.It is clear from the figures(a, b, and c) that the increasing flux density (by increasing voltage) in a specified air gap decreases the weight reading which mean increases magnetization that results in increased magnetic force.A relationship shown in **Fig.11a**between the weight on the balance and electric current (D.C.) to the magnet has been established.

(a) (b) (c)

Fig(10):photograph shows the decrease of weight with the increase of coil current



(a) (b)

Fig (11):(a) Variation in weight with coil current at a specified working gaps; **(b)**Variation in weight with working gap at a specifiedcoil current.

It is also observedfrom**Fig.11b** that the weight increaseswith increasing in air gapfor a specified amount ofcurrent. So that the increased gap increases total area through which flux lines flow, and therefore flux density decreases. Hence, magneticattractions force decreases and a larger weight sensed by the balance.

The Taguchi experimental design involved three stages.First, a Taguchi orthogonal array L9 was used forexperiments to ensure consideration of the most significantfactors and levels, therefore, optimizing the surface finishin MAP. This investigation considered four parameters:Rotational speed(P_1),Coil current (P_2),Volume of powder (P_3), and Working gap (P_4) as in **Table 2**. Secondly, afterthe data collection, analysis of variance (ANOVA) wasanalyzed using statistical software to identify the significanceof the factors considered in this study. Finally, theoptimal operation condition was generated and theconfirmatory tests were conducted.

Experiments were conducted following the **Table 3** andthen the measured results were analyzed.Using these data, the MINITAB-statistical software has been employed to analyze the experimental findings. Following linear regression models for bothchanges in surface roughness (ΔRa) and change inMicro-Vickers hardness (ΔHa)have been evolved:

$$\Delta Ra = 0.753 + 0.00029P_1 - 0.00283P_2 + 0.004P_3 + 0.00267P_4 \quad (1)$$

$$\Delta Ha = 5.99 - 0.00257P_1 + 0.70P_2 + 3.85 P_3 - 0.433P_4 \quad (2)$$

The accepted absolute values of the percentage errors between the results obtained by the regression model and the experimental(as listed in **Table 4** and**Table 5**), show that the linear regression model (**Eq.(1)**and**Eq.(2)**) is very valid model for this experiments.

Table 4: Experimental results and calculated for surface roughness.

Exp.	Before (Ra_1)	After (Ra_2)	ΔRa (µm) (Experiment)	ΔRa (µm) (calculated)	Error (%)
1	1.065	0.252	0.813	0.81018	0.34748
2	1.059	0.203	0.856	0.8621	0.712
3	1.061	0.144	0.917	0.91402	0.32552
4	1.057	0.192	0.865	0.87026	0.6081
5	1.046	0.131	0.915	0.91018	0.52678
6	1.064	0.249	0.815	0.80985	0.6319
7	1.063	0.141	0.922	0.91835	0.39642
8	1.060	0.239	0.821	0.81802	0.36358
9	1.064	0.213	0.851	0.85794	0.8149

Table 5: Experimental results and calculated for Micro-Vickers hardness.

Exp.	Before (Ha_1)	After (Ha_2)	ΔHa (HV) (Experiment)	ΔHa (HV) (calculated)	Error (%)
1	98.9	112.3	13.4	13.8572	3.4123
2	98.5	117.5	19	17.9575	5.4868
3	99	120.6	21.6	22.0577	2.1192
4	98.6	119.1	20.5	20.891	1.9073
5	98.3	111.4	13.1	13.4412	2.6049
6	99	118.4	19.4	18.8907	2.625
7	99.8	116.8	17	16.3747	3.6779
8	98	119.6	21.6	21.8242	1.0381
9	98.1	112.2	14.1	14.3745	1.9468

Generally, a generic changes in surfaceroughness(ΔRa) andMicro-Vickers hardness (ΔHa)are used to quantify the present variation in Taguchimethod. In this study, the larger-the-better type of(ΔRa) and (ΔHa)were selected as the quality characteristic for analyzing, sincethe more change in surface roughness and micro hardness means bettersurface roughness and hardness which increase the efficiency of MAP. Both the experiment and calculated (ΔRa) and (ΔHa)results were illustrated in **Table 4** and**Table5**. (Ra_1)and (Ha_1) are the surface roughness and Micro-Vickers hardness valuesbefore (MAP), respectively. (Ra_2)and (Ha_2) aretheimproved values of surface roughness and Micro-Vickers hardness after polishing theworkpiece, respectively. In Taguchi method, the highest possible change in surfaceroughness(ΔRa) and Micro-Vickers hardness (ΔHa)for the resultsare desirable.

As shown in **Fig.12**, thelevel corresponding with the highest (ΔRa) was chosenas the optimum level. They were at rotational speed (525 rpm),coil current (1.5Amp), volume of powder (4cm^3), andworking gap (2 mm), respectively. The optimal combination ofthese factor levels can minimize the process variability andimprove better surface roughness.

Fig.13 shows the highest (ΔHa) was chosen for the optimum level. They were at rotational speed (175 rpm), coil current (3.5Amp), volume of powder (4cm^3), and working gap (1.0mm), respectively.

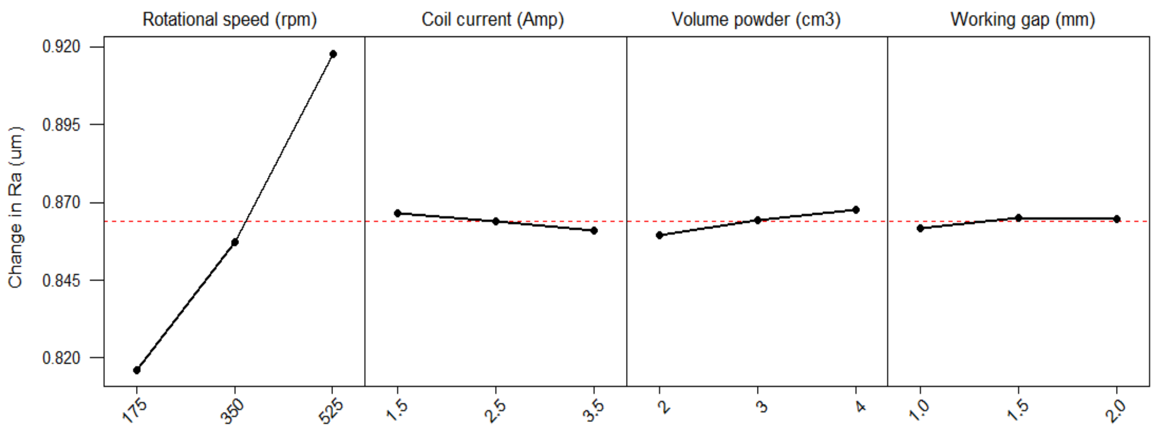


Fig (12): Influence of parameters on the experimental ΔRa values of brass plate.

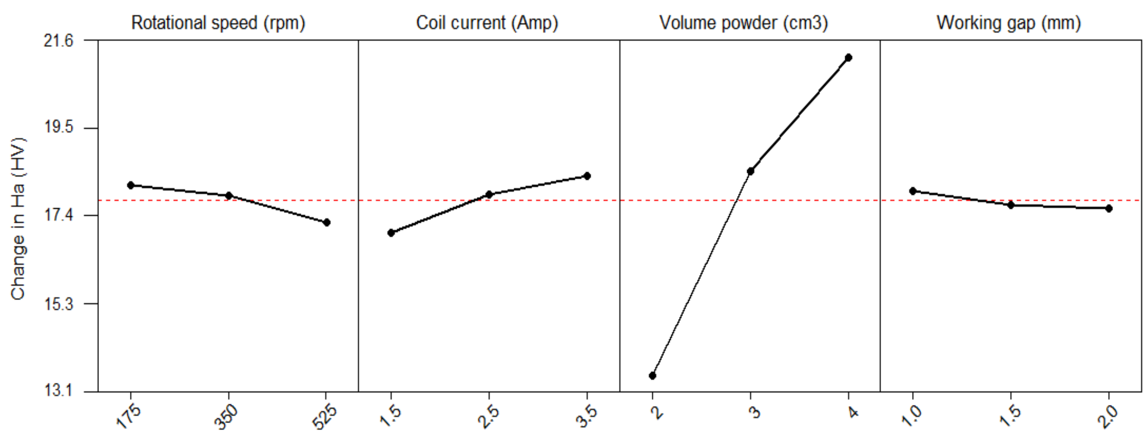


Fig (13): Influence of parameters on the experimental ΔRa values of brass plate.

Table 6 presents calculated ANOVA for the change insurface roughness (ΔRa) and Micro-Vickers hardness (ΔHa)of the experiment. The rotational speedhad significant impact on (ΔRa), whilethe volume of powderhad the highesteffect on(ΔHa).Also reveal the same results areshown by main effects in**Fig.12** and**Fig.13**.

Table 6: Percentage contribution of parameter influencing ΔRaand ΔHa

Parameter	ΔRa	ΔHa
Rotational speed (P_1)	99.01%	1.30%
Coil current (P_2)	0.31%	3.15%
Volume of powder (P_3)	0.61%	95.25%
Working gap (P_4)	0.07%	0.30%
Total	100%	100%

Fig.14 shows the good agreementbetween the experimental and regression resultsof the two parameters which have the largest impact on the finishing quality for brass (therotational speed the volume of powder).

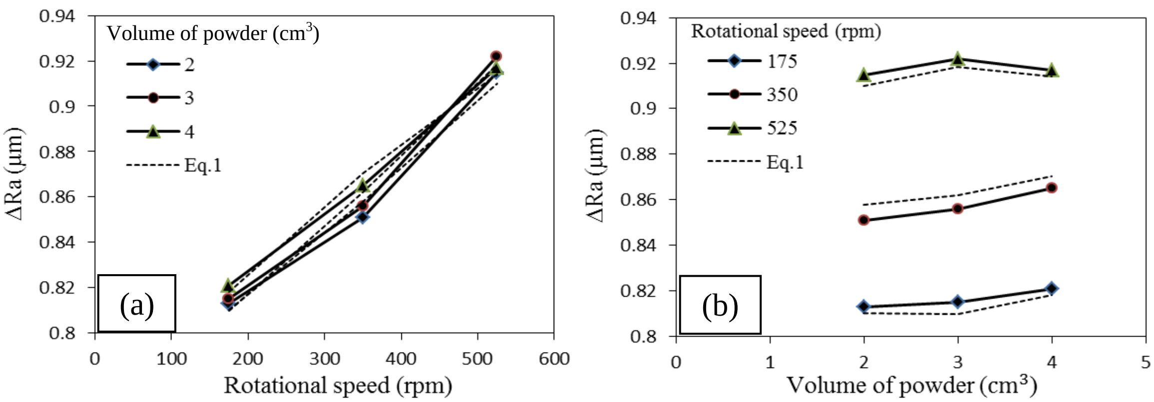


Fig (14): comparison between the experimental and regression results for change in roughness.

The volume of powderand the coil currentparameters which havethe largest impact on the micro hardness for brass are shown in **Fig.15,**good agreementbetween the experimental and regression resultsof the two parameters are shown.

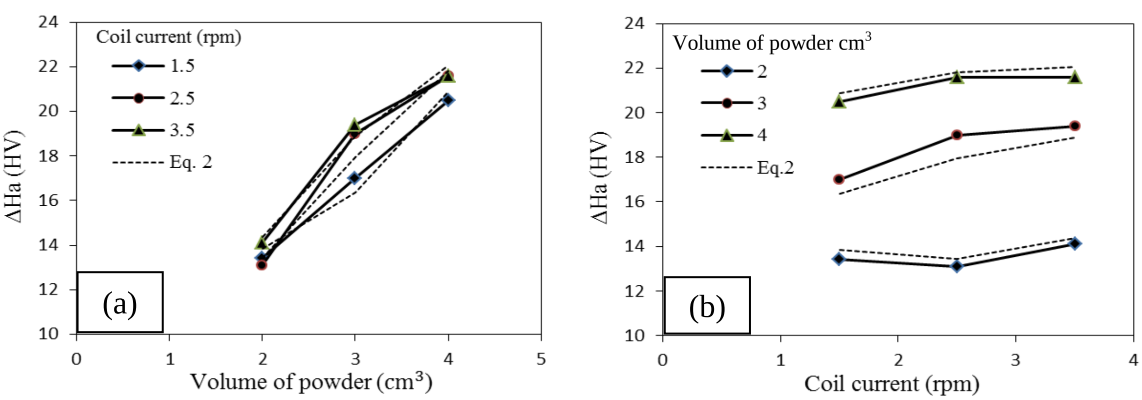


Fig (15): comparison between the experimental and regression results for change in micro surface hardness.

The MAP regression modelcan be used to analyze the effects of the selected process parameters on the surface roughness using**Eq.(1)**. A relationship (**Fig.16a**) between the changes in *R*a (ΔRa) with rotational speed for different coil current values has been obtained. The magnitude of ΔRais slightly more for lower coil current. The ΔRa increases with increase in rotational speed because by increasing the speed, the cutting velocity also increases. Hence, larger numbers of cutting edges take part in machining that material removal by abrasives in unit time increases, which results in more improvement in surface finish.

The insignificant factor, working gap, has least impact on the surface roughness(**Fig.16b**) at the same rotational speed andΔRa slightly increase with working gap.

Fig.16cshows a relationship between coil current and change in surface finish (ΔRa) at different values of volume of powder. The trend of the curves is the same for different volume of powder values but the magnitude of ΔRais higher at a higher volume of powder.It is observedfrom this Figure that improvement in surfacefinish decreases with increase in current.The brass is soft material and need flexible ferro magnetic abrasive brush (FMAB), therefore when current increases for a specified powder volume, FMAB strength and particle density in the FMAB both increase, and hence forces increaseleading to an increase in cutting force due to increased rigidity of the FMAB whichscratch the surface and then decreasing its smoothness.

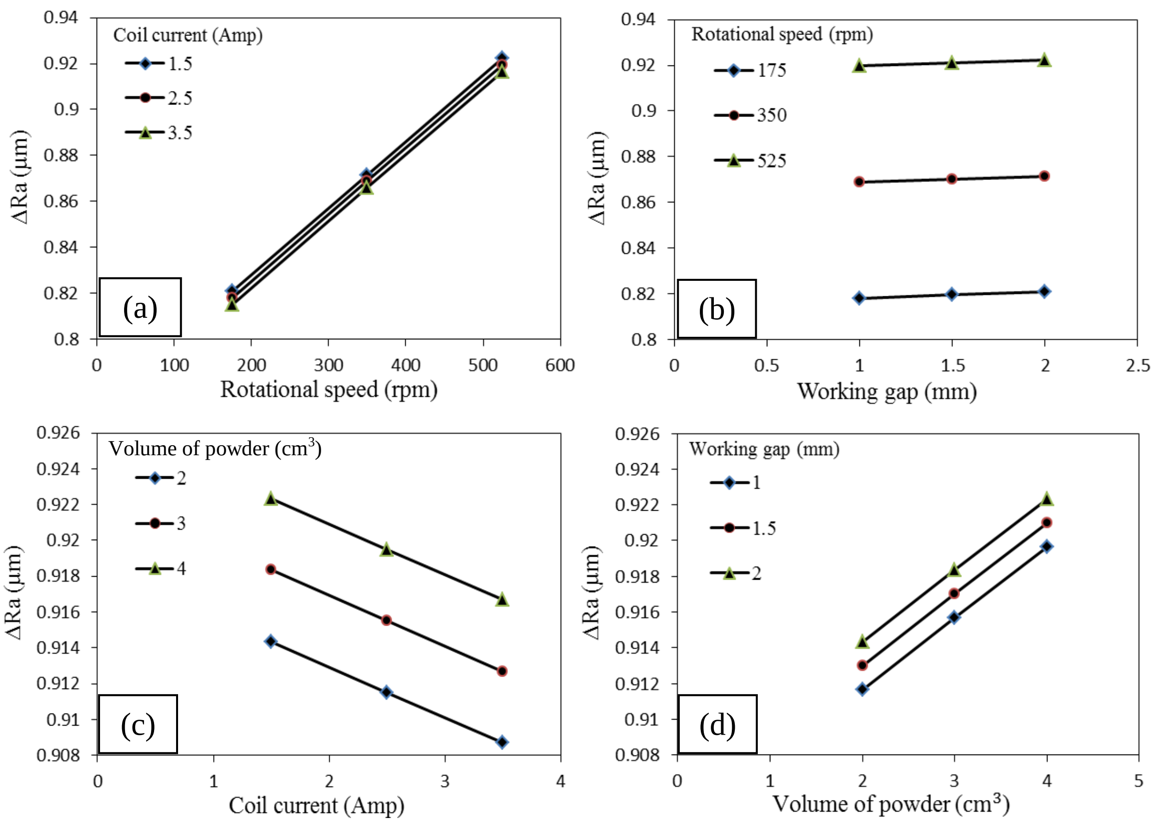


Fig (16): Effects of process variables on change in surface roughness (ΔRa). (a) Effect of rotational speed on ΔRa for different coil current values, volume= 4cm^3; gap= 2mm. (b) Effect of working gap on ΔRa for different speeds,coil current= 1.5Amp;volume= 4cm^3. (c) Effect of coil current onΔRa for different volumeof powder values, speed= 525rpm; working gap = 2mm. (d) Effect of volumeof powder onΔRafor different working gap, speed= 525rpm; coil current= 1.5Amp.

It is also observed from figure 16a and 16c that thecoil current had very low impact on the surface roughness.The reason is that brass is non-magnetic material,the change of magnetic flux density, which mainly occurredby current change, did not have obvious impact on themagnetic force on the brass workpiece.

The effect of volume of powder on change in surface roughness is evident in**Fig.16d**.

For the three working gap values (1, 1.5, and 2), ΔRa seems to increase with the increase of volume of powder.This is so because in the same machiningarea there will be many more cutting edges if higher powder are used. Hence, microcutting increasesresulting in reduced surface roughness value (increasedΔRa).

The MAP regression model(**Eq. (2)**) can be used to analyze the effects of the selected process parameters on theMicro-Vickers hardness. A relationship (**Fig.17a**) between the changes in hardness (ΔHa) with volume of powder for different working gap values has been obtained.

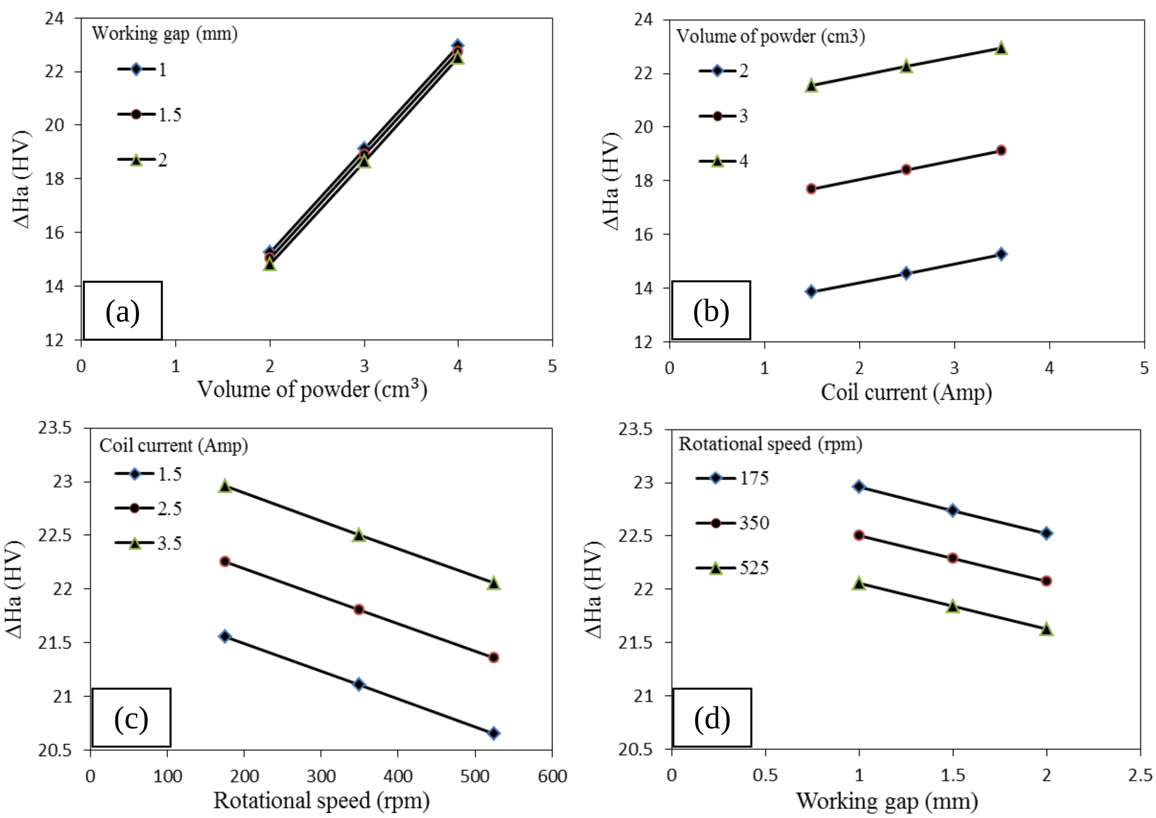


Fig (17): Effects of process variables on change in micro surface hardness (ΔHa). (a)Effect of volumeof powder onΔHafor different working gap, speed= 175rpm; coil current= 3.5Amp. (b)Effect of coil current onΔHa for different volumeof powder values, speed= 175rpm; working gap = 1mm. (c) Effect of rotational speed on ΔHa for different coil current values, volume= 4cm^3; gap= 1mm. (d) Effect of working gap on ΔHa for different speeds,coil current= 3.5Amp;volume= 4cm^3

There is least effect of working gap on ΔHa. The ΔHa increasessignificantly with increase in volume of powder, because the specific permeability of the magnetic brush increases with abrasive mass or volume and thus the pressure is also increased[14].
The magnetic force lines generated power to apply pressure from the magnetic abrasives to the workpiece [10]. If P is the magnetic pressure acting on a spherical abrasive grain of diameter d; the normal force $F_n$acting on it is given byJain et al. [16].

$$F_n = \frac{P\pi d^2}{4} \quad (3)$$

This is the normal magnetic force responsible for packing or concentrating magnetic abrasive particles (MAPs) in the working gap and causes micro indentations into the workpiece [7].
The depth of indentation of abrasive into workpiece$h_d$in terms of H_w, the hardness of workpiece material is given by [16].

$$h_d = d/2 - \sqrt{d^2/4 - (F_n/H_w \pi)} \quad (4)$$

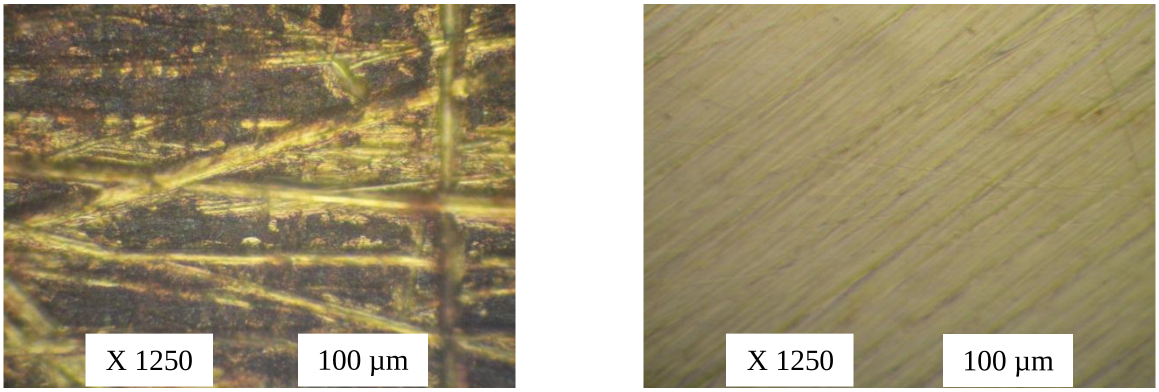
Where, d is the diameter of abrasive grain**Fig.4.**

It is clear from **Eq. (3)** and **Eq. (4)** that increasing the magnetic pressure leading to increase innormal magnetic forcethat resulting in increase in hardness of workpiece due to the work surface hardening action.
The effect of coil current on change in Micro-Vickers hardness is evident in**Fig.17b**.For the three volume of powder values (2, 3, and 4), ΔHa seems to increase with the increase of coil current.This is so becausestrength as well as area of contact ofthe magnetic brush with workpiece increases with increasein current, leading to a greater number of indentations intothe workpiece [7]. Therefore, normal magnetic force increasesleading to an increase in hardness(**Eq. (4)**).

Fig.17cshows a relationship between rotational speed and ΔHa at different values of coil current. It is observed that improvement in surfacehardnessdecreases with increase in rotational speed, becausethe normal magnetic force marginally decreaseswith increase in speed [7], leading to decrease inhardness. The decrease in normalmagnetic force can be partially attributed to splashing ofthe few abrasives from the working gap at higher RPM.

The gap between the magnetic pole and workpiece is another factor that influences the change in hardness, since the pressure decreases as the gap is increased[13]. Therefore, the hardnessdecreases because of decreasing inthe normal magnetic force, as shown in**Eq. (4).**

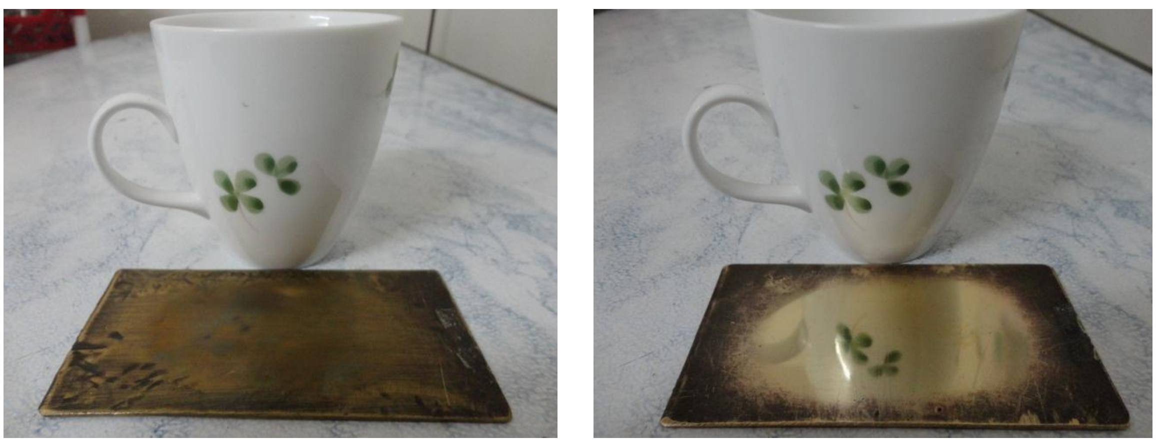
Fig.18 shows SEM photographs of a workpiecesurface before and after MAP, respectively. It revealedthat the polished surface was quite smoother than before,indicating that the MAP process is very useful to improvethe surface roughness of brass material.



Before After

Fig (18): SEM photos of brass surface before and after finishing.

Fig.19 Show the photographs of the workpiece surface beforeand after MAP experiment at the optimum parameters which show clearly the smoothness of the surface (*Ra* = 0.035µm).



Before After

Fig (19): Photographs of workpiece finishing, speed= 525rpm; coil current= 1.5Amp;volume= 4cm^3; gap= 2mm.

9. Conclusions

In this study, MAP was performed on the brass (CuZn33) material and design of experimental method was applied to evaluate parameter's effect on the surface roughness and Micro-Vickers hardness with the use of new magnetic abrasive powder (40wt% iron and 60wt% quartz). The results can be summarized as follows:

1. The improvement of the surface roughness from 1.046µm to 0.131µm shows the effectiveness and validity of a MAP method to refine rough surface of brass.
2. The process is capable of producing surface hardness improvement in range of 99HV-120.6HV.
3. Among the four tested parameters, the inductor rotational speed had the largest impact on the process while the coil current, volume of powder, and working gap had low effect on surface roughness.
4. The volume of powder is found to be themost significant parameter on the surface hardness followed by coil current. However,the effect of rotational speed and working gap seems to be small.
5. The optimized control factors determined by experiments for surface roughness improvement were rotational speed 525rpm, coil current 1.5Amp, volume of powder 4 cm^3, and working gap 1.5mm.
6. The optimal operation condition for better surface hardness was a rotational speed of 175 rpm, acoil current of 3.5Amp, a volume of powder of $4cm^3$, and a working gap of 1.0 mm.
7. Regression models for Ra indicate that ΔRa increase with increase in rotational speed, volume of powder, and working gapwhile it decreaseswith increase in coil current working gap.
8. The obtained data from Ha regression show that the values of ΔHa increase with increaseinvolume of powder and coil current it decreases with increase in rotational speedand working gap.

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Nomenclature

D Diameter of magnetic abrasive particle (μm)
dDiameter of abrasive particle (μm)
F_nNormal magnetic force for concentrating magnetic abrasive particles (N)
H_wMicro Hardness of workpiece material (HV)

Ha_1Micro-Vickers hardness value before MAP(HV)
Ha_2Micro-Vickers hardness value after MAP(HV)
h_d Depth of indentation of abrasive into workpiece (μm)
PMagnetic pressure acting on a spherical abrasive grain (N/mm^2)
P_1Rotational speed (rpm)
P_2Coil current (Amp)
P_3Volume of powder (cm^3)
P_4Working gap (mm)
Ra_1Surface roughness value before MAP(μm)
Ra_2 Surface roughness value after MAP(μm)
ΔRa The difference between Ra_1 and Ra_2(μm)
ΔHa The difference between Ha_1 and Ha_2(HV)