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Improving the Micro-Hardness of Brass-Plate Alloy CuZn28 According to Optimum Geometry of Magnetic- Inductor and Pole by MAF Method

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Article Info
Volume 83
Page Number: 5836 - 5846
Publication Issue:
March - April 2020

Article History
***Article Received**: 24 July 2019*
***Revised**: 12 September 2019*
***Accepted**: 15 February 2020*
***Publication**: 30 March 2020*

Abstract: Magnetic abrasive finishing (MAF) a non-conventional finishing process, is suitable for all types of materials Preventing the problem of micro-cracks and fundamental normal stresses, that produced by the traditional finishing method. MAF process improves the quality and properties of the surface layer. The main objective of this research is to study the effect of geometry shape for inductor and pole on the micro-hardness, then finding the optimal shape that improves the value of (ΔHv) in the surface layer and improves the MAF process. Nine different geometry shapes (inductor and pole) are considered. Taguchi matrix L9 is used for designing experiments to find the influence of parameters (radius of hole, angle of the core, angle of the pole, the radius of the pole) with 3levels on (ΔHv). The experiments are Analyzed and improved using Minitab 18 software. It is concluded that the optimum parameters that reach to optimum (ΔHv) are (radius of holeR_3 (9mm),angle of core α_1(82°), angle of poleβ_1 (60°), the radius of poler_3 (18mm). The most significant factor that influences (ΔHv) is an angle of the pole β (43.21%) followed by radius of pole r (39.76%) in the MAF process. In addition, the maximum improvement in (ΔHv) by 13% of the overall experiments test.

Keywords: *Magnetic abrasive finishing process, Micro-hardness, Regression model, Taguchi matrix.*

I. Introduction

To obtain a better-quality surface and geometrical precision in the modern industries, various finishing technologies are applied to obtain the target of high surface accuracy and reduce the defects on the surface like microcracks. Those technologies include chemical mechanical polishing (CMP), electrical polishing (EP), and another finishing process, that sometimes gets difficult to control the high pressure and high force on the workpiece. For this purpose, the researchers in academic and industries try to develop a new finishing technique that get over those challenges. Magnetic abrasive finishing was recently appeared as a new process that reaches a higher surface accuracy (surface like a mirror) with controlled pressure and forces, in minimum cost and lower environment pollution (1,2). A recent review on MAF process that compares between a various method for polishing surfaces (3). MAF is applied to a workpiece under a magnetic field, the cutting force is primarily controlled by magnetic flux (4), so that leads to the possibility of decreasing microcracks on the workpiece surface. MAF process applied on external, internal surfaces, edge corners and various complicated shapes. MAF

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process is very economical, easy for controllability, low energy consuming and other important advantages over conventional finishing processes.
In general, the workpiece fixed between two holders at the fixing table. The space between the workpiece and the pole is called a working gap, the working gap is filled with magnetic abrasive particle (MAP). MAF process is shown in Figure 1. When the direct current is applied the magnetic field generated, the (MAP) that fills the working gap will be magnetized and arranged to form a magnetic abrasive particle brush (MAPB) which acts as a cutting tool. When the magnetic pole starts rotating, relative motion between MAP and workpiece is beginning (5). Under the effect of the magnetic force that acts on MAPB, the finishing process done on the workpiece. The MAP is flexible so, it can perform finishing on a variable shaped surface, moreover, it removes a very small amount of microchip that guarantees a higher quality (6,7).The MAF process can be used with the unbonded and bonded type of magnetic abrasives particle. MAF with unbounded magnetic abrasives yields higher material removal rate (MRR), while bonded magnetic abrasives produce a good surface finish (8).
Taguchi techniques contributes to products development processes and parameters optimization process by saving time and costs. Recently, Taguchi techniques are being adopted to describe the products development in MAF process. Taguchi process runs through three steps: system design, parameter design, and tolerance design (9). It recommends two routes for analyzing and optimizing results: signal-to-noise-ratio (SNR) and analysis of the variance (ANOVA).
The design and manufacture of magnetic inductor is a crucial issue. An attempt to go through this issue using a milling machine (vertical) for finishing on a brass material plate with the use of magnetic abrasive powder (40%iron and 60%quartiz). In this work, Taguchi experimental design method was used for finding the effect of

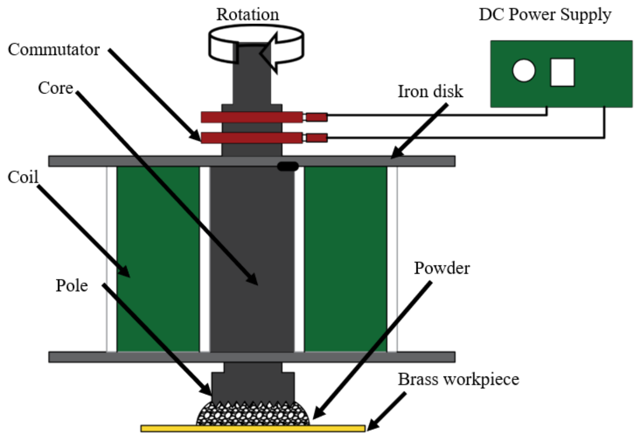

Fig 1. Electromagnetic inductor acting on workpiece.

the process parameters (working gap, rotational speed and powders volume) on surface roughness and micro-hardness. It was shown that the rotational speed and volume of powder are the most signeficant parameters on change in the surface roughness and micro-hardness, respectively. And the process can impove the surface hardness in rang of (99Hv-120.6Hv) (10).
An extend to the previous study considered a similar system parameter with the similar condition but with different powder (70% silicon carbide and 30% iron). This study conducted on ferromagnetic material (Aluminum alloy 7020) and non-ferromagnetic material (Stainless Steel 410), for finding the relationship between the parameters of MAF and the surface roughness. The regression model for the two materials can be obtained by using SPSS software. From the experimental results, it was shown that the surface roughness for non-ferromagnetic was reduced by 30 – 40%, while ferromagnetic material was reduced by 40 - 60% (11).
Modifying the geometry design of the magnetic inductor and pole in MAF is shown as a promising way to the researchers that achieves a higher finishing level. To study the effect of pole geometry design, two different pole shapes considered conical magnetic pole without groves

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and conical magnetic pole with six groves. This study is also conducted on stainless steel using the same powder used in (11).The parameters used in this process are (Number of grooves, finishing time (min), Cutting speed (rpm), Voltage (volt), Volume of powder(cm3)). The aim of this paper is to improve the micro hardness (Hv) by using MINITAB software program. The results show that the magnetic pole with six grooves can create a good surface quality with improved in micro hardness in rang of 149.1Hv-170.8Hv (12). The most influential parameters on change in hardness are volume of powder (42.34%) and pitches number that exist between grooves (25.30%). To improve the surface quality and accuracy with scratch and micro-chip reduced. A finishing experiment was produced on Ti-6Al-4V workpieces to investigate and found the optimum condition of (spindle rotational feed, the rotary table speed, and the working gap) that improve the surface roughness by 0.073µm (13).

Finishing process is also applied on external surfaces such as AISI ST ball bearing. There are many important parameter effects on performance of surface finish are (electromagnetic speed, current and the direct voltage induced, magnetic flux density, the quantity of abrasive particles size, working environment, and workpieces materials). The optimum finishing condition can be obtained by using analysis of variance ANOVA by taking a large number of the signal to noise ratio S/N ratio (14). MAF process is also applied to the Aluminum pipe for finishing internal surfaces. Used Different process parameters (diameter Work specimen material Machining Time, frequency, Lubricant, and pole gap) using response surface methodology (RSM) for analyzing surface roughness and material removal rate. Finding at optimum process condition maximum material removal rate of 81.49% with a minimum surface roughness of 0.09µm (15).

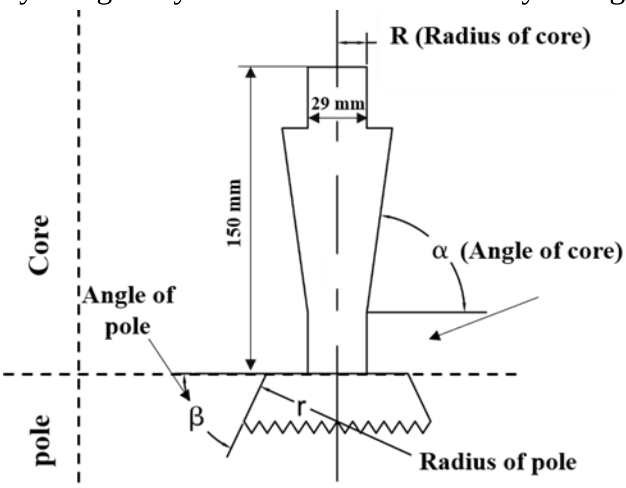

Fig 2. The geometry parameters of magnetic inductor and pole.

Yet, the researches that considered the geometry design of the magnetic system (inductor and core) especially, that study the impact of changing the design of the magnetic system on the quality of surface micro-hardness is limited and do not cover this important aspect. And the optimal design of the magnetic parts is not assigned. Therefore, it was a great motivation for us to conduct this study.

In this study, the core and pole geometry shape were considered. The main objective is to measure the effect of geometry parameters (Radius of a hole(mm), angle of core(degree), angle of a pole(degree)) on the surface micro-hardness of the workpiece. This is considered as a novel study. Furthermore, according to variable parameters, the study comes up with the optimal geometry parameters of the magnetic inductor and pole that improves the surface micro-hardness. To simplify and implement the design of experiments and find the prediction model for each criterion, the Taguchi matrix L9 was adapted for designing the nine experiments. These experiments are analyzed using Minitab 18 software.

II. Design of experiment for MAF machine

1. Selection Input parameter and their levels

According to the classification of the magnetic abrasive finishing machine, four input geometry parameters with 3 levels were selected, as shown in Figure 2. The four variable parameters are (radius

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of the hole (R mm), angle of core (α deg), the radius of the pole (β mm) and angle of the pole (r deg)). The values and levels of input parameter are listed in Table 1.

Table 1. The value and levels of input parameters.

MAF parameters				
Variable parameters				
Input parameters	code	Level1	Level2	Level3
Radius of hole (mm)	R	0	4.5	9
Angle of core (degree)	α	82°	90°	98°
Angle of pole (degree)	β	60°	90°	120°
Radius of pole(mm)	r	-18	0	18

2. Selection of orthogonal array (OA) for nine experiment.

Orthogonal array (OA) is a technique of minimizing the number of experiments by taking the most effective experiments. In this work, the total number of experiments L9 is (3^4 = 81) independent experiments. The utilization of OA leads to reduce the total number of experiments (81) independent experiments to only (9) experiments. [6], [10]– [12], as shown in Table 2.

Table 2. The experimental design of magnetic inductor based on L9.

Experiment	(R)	(α)	(β)	(r)
1	0	82	60	-18
2	0	90	90	0
3	0	98	120	18
4	4.5	82	90	18
5	4.5	90	120	-18
6	4.5	98	60	0
7	9	82	120	0
8	9	90	60	18
9	9	98	90	-18

III. Experimental work

1. Geometry shape for magnetic inductor and pole.

Magnetic system geometry has been designed and manufactured using a lathe and milling machines in a manufacturing laboratory of Baghdad university. According to the Taguchi technique matrix, nine are proposed shapes for inductor and pole geometry as shown in Figure 3.

Fig 3. Shape of magnetic inductors and poles.

Insulated the core and disks by using x-ray paper, which prevents any attaching between the pole and coil wire. The coil wire made from copper with a diameter of (0.5mm), the wire turned around a core with 5000 turns. Finally, the actuator was having been fixed for each inductor. The gap is set to (1.5mm), filled with ferromagnetic abrasive

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powder ($10cm^3$). The uesd magnetic abrasive powder is amixed from 100gm of iron with 50gm of the tungsten carbide, (ratio:2 Iron to 1 Tungsten carbide) with grain size diameter (320µm).The used workpiece is brass CuZn28 with dimensions [length 100mm, width 50 mm, and thickness 3mm]. The MAF machine is turned by cutting speed (550 rpm), and the supply current to the coil is (0.85Amps). The timer is set to ten minutes for each experiment. After turning on the power supply, MAP forms a brush shape due to the magnetization created from the coil, thus, the finishing operation is started. The MAF machine is illustrated in Figure 4.

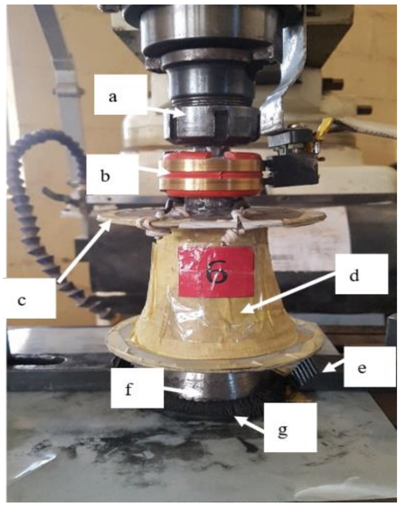


Fig 4. MAF machine. Where: a) Spindle b) Actuator c) Disks d) core e) Fixer f) Pole g) Brush.

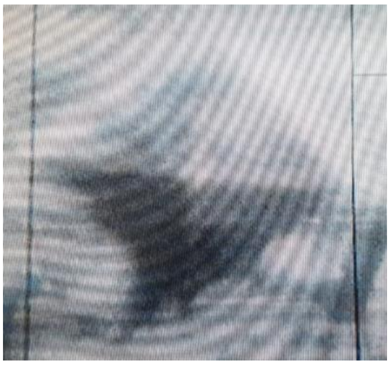
2. Measuring micro-hardness of brass plate.

The microhardness test is measured for the nine experiments by taking three values at a different location and average them out before and after the MAF machine. (MICRONET) are used as microhardness tester. The Vickers Hardness Test is done before and after the MAF operation. When the force applied to the workpiece surface, it forms a rhombus shape as shown in Figure 5.a and b, that depicts the penetration on the pyramid before and after MAF. The penetration before MAF is larger than that after MAF, in other word, the measuring of the diagonal of pyramid before MAF is larger than after. The practical result of Hv before and after the machining process for the nine experiments, is found according to equation (Eq.1) and its average, as shown in Table 3.

$$\Delta Hv = \text{before MAF}(Hv) - \text{after MAF}(Hv). \quad \textbf{Eq.(1)}$$

Table 3. The practical result of Hv before and after machining and its average.

NO.	(Hv) before machining	(Hv) after machining	ΔHv
1	109.27	115.35	6.0800
2	107.93	115.84	7.9133
3	101.07	104.25	3.1767
4	114.03	126.54	12.5133
5	102.35	103.16	0.8067
6	101.85	109.20	7.3533
7	99.91	105.39	5.4833
8	115.67	130.33	14.6600
9	103.71	109.30	5.5933



(a) Before MAF

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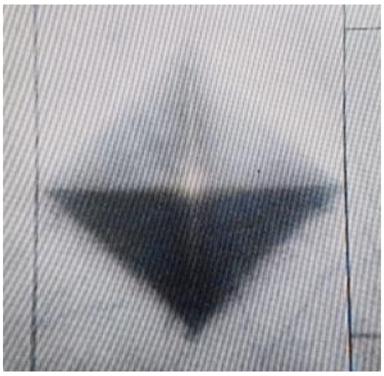

(b) After MAF

Figure 5.a and b. Vickers Hardness Test before and after MAF process.

IV. Result and Discussion

1. Signal to noise S/N ratio

The criteria of selecting the optimal level for each experiment is simply is the standard (large is better) the value of the S/N ratio that has a maximum reaction affected the brass workpiece to reach an improvement in (ΔHv). The terms of mean square diversion (MSD) and S/N ration are calculated using MINITAB 18 software (16,17).

$$S/N = -\log 10\left(\frac{1}{n}\sum\nolimits_{i=1}^{n}\left(\frac{1}{y_i^2}\right)\right) \qquad \textbf{Eq.(2)}$$

$$MSD = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{y_i^2}\right) \qquad \textbf{Eq.(3)}$$

Where: n number of experiment (input), y_i number of measurement (output).

A) Analysis of the results of the parameters in the change in micro-hardness (ΔHv).

MAF is the process that is used for finishing surfaces with higher quality and lower efforts. Larger S/N ratio (large is better) value is the criteria that point out to the optimum level for each experiment. The mean and S/N ratio results and the response for ΔHv are illustrated below in Table 4 and Table5.a and b, respectively.

Table 5.a Response table for signal to noise ratio for ΔHv

Larger is better

Level	R	A	β	r
1	14.562	17.469	18.777	9.588
2	12.470	13.141	18.289	16.693
3	17.686	14.108	7.651	18.437
Delta	5.215	4.328	11.125	8.848
Rank	3	4	1	2

Table 5.b Response table for mean for ΔHv.

Level	R	α	β	r
1	5.723	8.026	9.364	4.160
2	6.891	7.793	8.673	6.917
3	8.579	5.374	3.156	10.117
Delta	2.856	2.651	6.209	5.957
Rank	3	4	1	2

From Table 5.a and b the value of S/N ratio and mean for all parameters is compatible by taking the large number, so that we do not need to make a prediction. The main effect plot for mean and S/N ratio as shown in Figure 6.a and b.

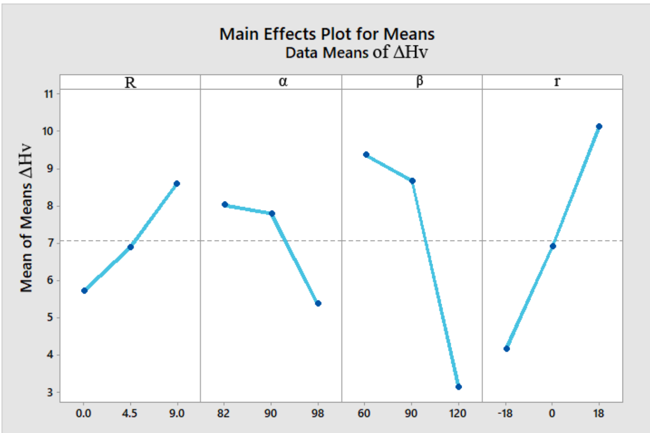

Fig 6.a main effect plot for mean for micro hardness(ΔHv).

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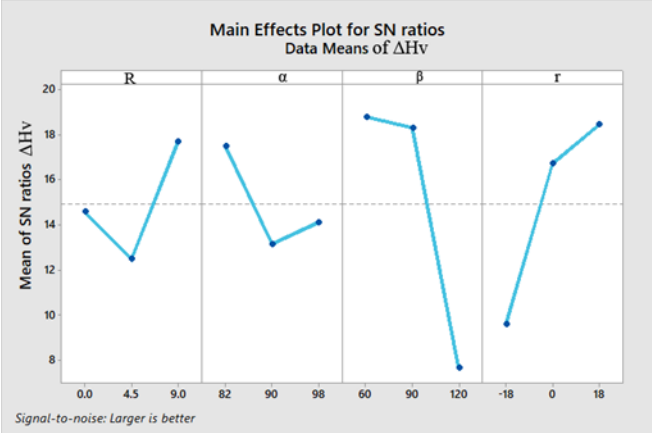

Fig 6.b main effect plot S/N ratio for micro hardness(ΔHv).

Table 4. The Results of the mean and S/N ratio of ΔHv.

Experi-ment	Radius of hole R(mm)	Angle of core α (degree)	Angle of pole β (degree)	Radius of pole r (mm)	ΔHv	S/N ratio	Mean
NUM.	*R*	α	B	r	ΔHv	SNRA1	MEAN1
1	0.0	82	60	-18	6.0800	15.6781	6.0800
2	0.0	90	90	0	7.9133	17.9672	7.9133
3	0.0	98	120	18	3.1767	10.0394	3.1767
4	4.5	82	90	18	12.5133	21.9475	12.5133

The optimum value of parameters that based on the highest number of S/N ratio are (radius of hole R_3(9mm), angle of core $\propto_1$ (82°), angle of pole β_1(60°), the radius of pole r_3(18mm) .

But these optimum levels do not exist among those nine experiments. Taguchi orthogonal array only represent nine experiments from all the possibilities of experiment [$3^4 =$ 81 experiments].

The regression model equation for (ΔHv) (Eq.4) is obtained from Minitab software program. This equation finds the theoretical result for the nine experiments. The practical and theoretical result as illustrated in Table 6. and the competition between them is shown in Figure 7.

$$\Delta Hv = 29.86 + 0.317\,R - 0.1657\,\alpha - 0.1035\,\beta + 0.1655\,r \qquad \textbf{Eq.(4)}$$

R-sq=90.36%, where R-sq is the Coefficient of Determination

Table 6. The practical and theoretical results of hardness ΔHv.

Experiment Num.	Practical ΔHV	Theoretical ΔHV	Accuracy
1	6.0800	7.0102	-0.1529
2	7.9133	5.5590	0.297
3	3.1767	4.1078	-0.293
4	12.5133	11.5423	0.0775
5	0.8067	0.9057	-0.1227
6	7.3533	8.2655	0.1240
7	5.4833	6.8890	-0.256
8	14.6600	14.2488	0.0280
9	5.5933	3.6122	0.3541

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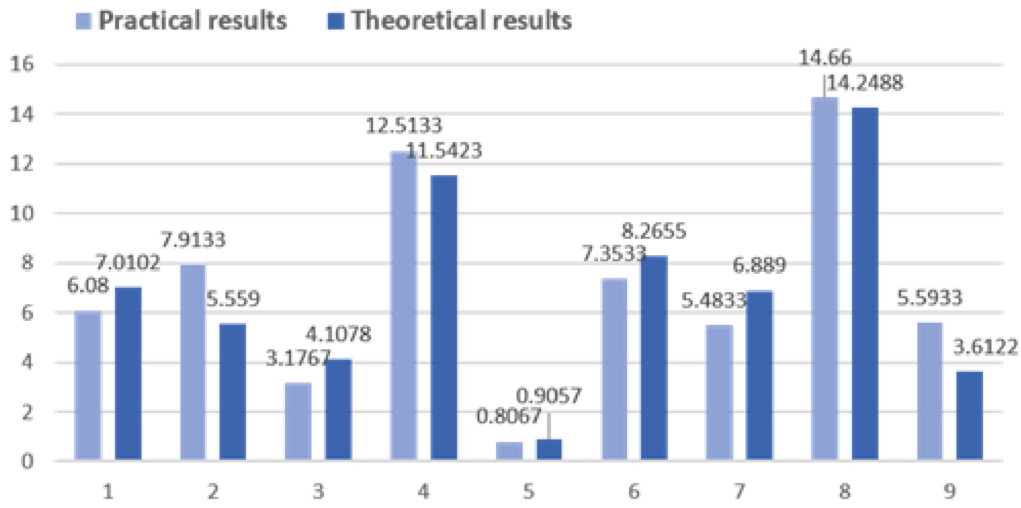

Fig 7. competition between the theoretical and practical.

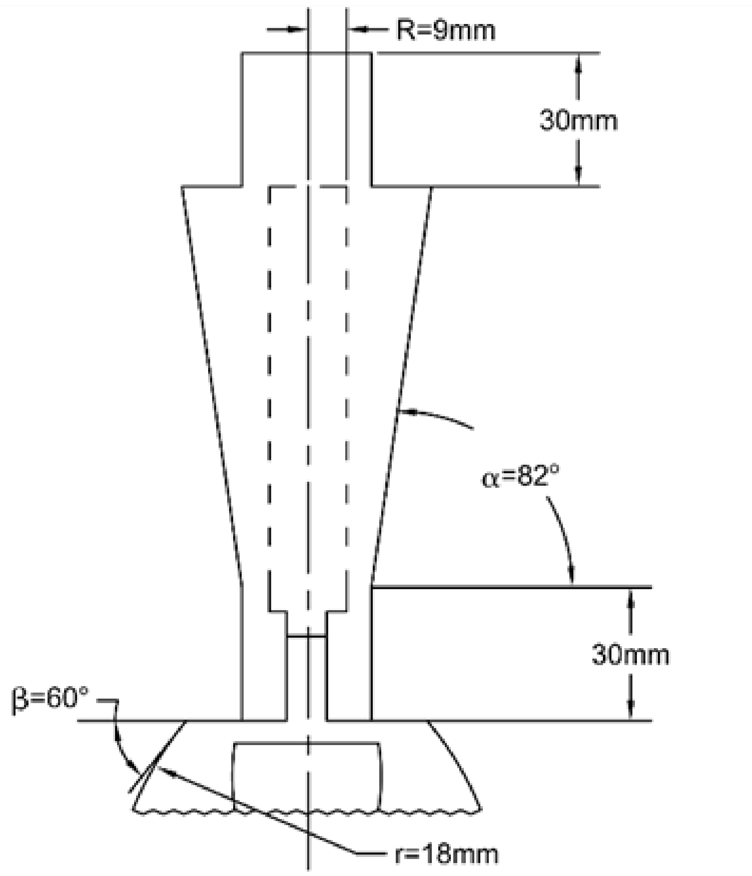

Fig 8. The dimensions of optimum geometry inductor and pole for ($\mathbf{\Delta Hv_{op}}$).

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Table 7. Analysis of variance (ANOVA) for micro hardness(ΔHv).

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Effect	Parameter contribution P %		
Regression	4	133.82	33.456	9.38	0.026				
R	1	12.23	12.231	3.43	0.138	Not Significant	9.139142		(3)
α	1	10.54	10.543	2.95	0.161	Not Significant	7.876252		(4)
β	1	57.83	57.825	16.21	0.016	Significant	43.21477		(1)
r	1	53.22	53.223	14.92	0.018	Significant	39.76984		(2)
Error	4	14.27	3.568						
Total	8	148.09							

Table 8. The result of improving of ΔHv.

No.	R	α	B	R	Response		
					(Hv) before machining	(Hv) after machining	ΔHv%
1	0.0	82	60	-18	109.27	115.35	5.6
2	0.0	90	90	0	107.93	115.84	7.3
3	0.0	98	120	18	101.07	104.25	3.1
4	4.5	82	90	18	114.03	126.54	11
5	4.5	90	120	-18	102.35	103.16	1
6	4.5	98	60	0	101.85	109.20	7.2
7	9.0	82	120	0	99.91	105.39	5.4
8	9.0	90	60	18	115.67	130.33	13
9	9.0	98	90	-18	103.71	109.30	5.3

The dimension and fabrication of the inductor and pole to reach the optimum of Micro hardness (ΔHv_{op}) as shown in Figure 8.

B) ANOVA Technique for Micro-Hardness(ΔHv).

analysis of variance (ANOVA) test is a statistical processing, it is used for determining the P% (percentage of contribution) for each parameter (radius of hole, angle of core, angle of pole, radius of pole). We make ANOVA for the criteria of ΔHv. As shown in Table 7.

It has shown that the angle of the pole is the parameter with a higher impact on ΔHv that followed by the radius of the pole while the radius of the core is the parameter with a lower impact on ΔHv that followed by the angle of the core. The optimum levels of parameters contribution are shown in Figure 9.

2. Improvement of micro-hardness at various geometry parameters

The percentage improvement of the change in micro-hardness (ΔHV) of the brass plate CuZn28 at various geometry of magnetic inductor and pole, can be found by using equation (4). The results of

(ΔHv) improvement with the value of (Hv) before and after machining are listed in Table 8.

$$\Delta HV=\left|\frac{\text{Initial micro hardness}-\text{Final micro hardness}}{\text{Initial micro hardness}}\right|*100\% \quad \textbf{(Eq.4)}$$

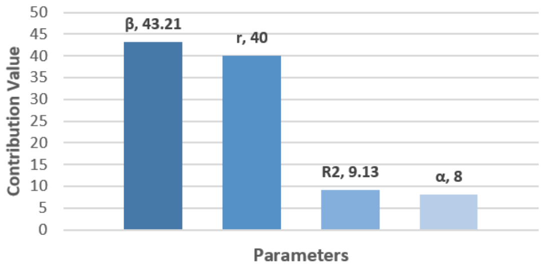

Fig 9. The optimal level of parameter contribution for ΔHv.

V. Conclution

1.The optimum parameters that create highest result in microhardness change(ΔHv) are (radius of hole R_3(9mm), Angle of core $\propto_1$ (82°), Angle of pole β_1(60°), the radius of pole r_3(18mm) .So the optimum level ($R_{3,}$ $\propto_{1,}$ β_1, r_3) for optimum ΔHv.

2.The most significant factor that has an effect on ΔHv in MAF process are angle of pole (β) followed by, radius of pole (r) followed by, radius of core (R) and by angle of core (α).

3.The process can improve the change in micro-hardness(ΔHv) by 13% of the overall experiments test.

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