



Contents lists available at <http://qu.edu.iq>

Al-Qadisiyah Journal for Engineering Sciences

Journal homepage: <http://qu.edu.iq/journaleng/index.php/IQES>



# Experimental investigation of metal removal and micro-hardness during MAF process

Waqass S. Khudhir

Production Engineering and Metallurgy, University of Technology/ Baghdad – Iraq

## ARTICLE INFO

### Article history:

Received 08 February 2022

Received in revised form 06 March 2022

Accepted 15 May 2022

### Keywords:

Magnetic Abrasive Finishing

Metal Removal Rate

Feed rate

Micro-hardness

## ABSTRACT

This work aims to provide an experimental investigation into metal removal and micro-hardness through the Magnetic Abrasive Finishing process (MAF) and study the impact of some process parameters (feed rate, coil current, and spindle speed) on these responses with (1008-AISI) workpieces and spherical electromagnetic tool based on Taguchi design of the experiment using Minitab 17 software. The results show that metal removal was strongly affected by the feed rate, while the strongly influential variable on micro-hardness was the coil current. The highest value of metal removal rate is achievable at conditions 10 mm/min, 2.5 A, and 700 RPM for feed rate, coil current, and spindle speed respectively.

© 2022 University of Al-Qadisiyah. All rights reserved.

## 1. Introduction

Magnetic abrasive finishing (MAF) is an electro-magnetic field-assisted process. The forces in this process are controlled by the magnetic field. The movement made by the pole brush and fixed plate work surface will cause a little amount to be removed from the workpiece and produce a mirror finishing surface [1,2]. The machining gap between the magnetic pole and workpiece is filled by abrasive powder which is consist of abrasive and iron powder plus a binder material because of the relative motion that occurs the abrasive friction force will cause the work surface machining [3]. Due to the flexibility of the magnetic brush, the machined surface will be free of the micro-cracks that appeared by traditional finishing processes such as grinding which uses a rigid tool [4]. Joshi et al. (2014) investigated the cylindrical MAF process of brass and cast iron workpieces using an

electromagnetic pole. The results prove that the increase of coil turns to increase the metal removal due to the increase that occurs in magnetic flux. The initial surface roughness and hardness were taken into account to make a comparison between the initial and final values of both hardness and roughness [5]. Yuewu et al. (2020) studied the finishing process of (SS304) plate by MAF process utilizing three types of abrasive powder (diamond particles embedded in a spherical iron matrix, CBN, and alumina). The study included four machining parameters which are the size of magnetic abrasive powder, rotational speed, gap, and feed rate on the responses to metal removal and surface roughness. Finite element analysis was used to estimate the normal pressure of magnetic abrasive powder. The results illustrated that the diamond powder was the best one when compared with

\* Corresponding author.

E-mail address: [waqass.s.khudhir@uotechnology.edu.iq](mailto:waqass.s.khudhir@uotechnology.edu.iq) (Waqass Khudhir)

<https://doi.org/10.30772/qjes.v15i2.817>

2411-7773/© 2022 University of Al-Qadisiyah. All rights reserved.

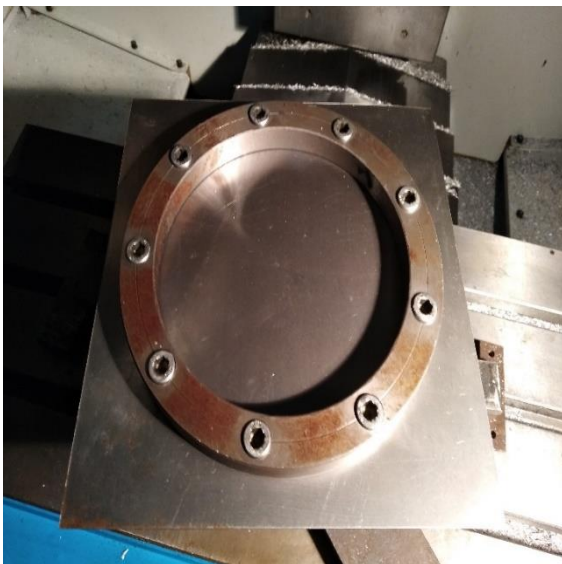


This work is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/).

the other powder which gives higher material removal and better finish at the same machining conditions [6]. Nazar Kais M. Naif (2012) investigated the effect of some machining parameters during the MAF process. The abrasive powder is made from quartz and iron powder with percentages of 60%, and 40 % respectively. The experiments were performed on the brass plate (CuZn33) and the output responses are surface roughness and micro-hardness [7]. O. Kadhum (2018) predicted the value of the working time which obtains the required value for metal removal and surface roughness through designing and implementing an automated machine. The values were predicated by controlling the machining factors (velocity of the magnetic pole, electromagnetic voltage, machining gap, and machining time) during the MAF process. As a result of this work, about 97% for metal removal and 95% for surface roughness were the matchings between predicted values and experimental results [8]. S. Shather and M. Abd (2019) studied the metal removal and surface roughness during the MAF process utilizing different concentrations and mesh sizes of silicon carbide as the abrasive powder. As a result of this study, the higher metal removal was 0.004 g gained using 25% Si and 75% Fe with 1.5 mm gap and 100 μm mesh size. The optimum change in surface roughness was 0.007 μm utilizing 33% Si and 67% Fe, gap 2 mm and, 200 μm mesh size. [9]. The main aim of this work is to study the impact of machining parameters on the metal removal and microhardness of machined surfaces during the MAF process.

**2. Experimental procedure**

MAF is performed on an NC milling machine, which is used to control the tool movement. In this work, the tool is a spherical electromagnetic tool with a (20 mm) diameter which is shown in Fig.1, whereas Fig.2 illustrated the machined sample it Consists of an iron core covered with copper wire. The specimens of (1008-AISI) plate with dimensions (100 X 50 X 0.9) mm, were used to implement the 9 experiments. The workpiece’s chemical composition is shown in Table1. The experiments were carried out at rotation speed 700 RPM and the density of magnetic field 1113.5, 3047.6, 4415.9 μ Tesla for 1.5, 2, 2.5 A respectively.



**Figure 1. Experimental setup**



**Figure 2. Machined sample**

**Table 1. Workpiece (AISI-1008) chemical composition**

COMPOSITION WEIGHT (%)	C	Si	Mn	S	P	CR
	0.08	0.02	0.32	0.024	0.014	0.035
COMPOSITION WEIGHT (%)	Ni	Mo	V	Cu	Al	FE
	0.032	0.002	0.001	0.072	0.044	Remain

A50 percent is mixed from tungsten carbide and pure iron powders were performed to get the magnetic abrasive powder with 350°C sintering temperature after the sintering process the high ball mill and sieving machines were utilized to have a 300 μm mesh size of the magnetic abrasive powder. The process parameter levels are shown in Table 2. Table 3 illustrates the Taguchi L9 Orthogonal array of the parameters. The hardness was measured, before and after the MAF process, the differences in HV values at three different locations, and then the value was averaged by utilizing a Micro-hardness tester device.

**Table 2. The Proposed control parameters and their levels**

Symbol	Input parameters	Level 1	Level 2	Level 3	Unit
A	Feed rate	10	20	30	mm / min
B	Coil current	1.5	02	2.5	Ampere
C	Spindle speed	500	600	700	RPM

**Table 3. Taguchi L9 orthogonal array**

No. of experiment	Machining parameters levels		
	A	B	C
1	10	1.5	500
2	10	2	600
3	10	2.5	700
4	20	1.5	600
5	20	2	700
6	20	2.5	500
7	30	1.5	700
8	30	2	500
9	30	2.5	600

### 3. Results and discussion

Table 4 and Table 5 illustrate the experimental results of metal removal and hardness respectively.

**Table 4. Experimental metal removal and S/N results**

No. of experiment	Machining parameters levels			MRR (g)	S/N (dB)
	F	CC	SS		
1	10	1.5	500	0.009	-40.9151
2	10	2	600	0.029	-30.7520
3	10	2.5	700	0.044	-27.1309
4	20	1.5	600	0.003	-50.4576
5	20	2	700	0.018	-34.8945
6	20	2.5	500	0.003	-50.4576
7	30	1.5	700	0.007	-43.0980
8	30	2	500	0.001	-60.0000
9	30	2.5	600	0.010	-40.0000

FR: Feed rate (mm / min)

CC: Coil current (ampere)

SS: Spindle speed (RPM)

From Fig. 3, it is clear to see lower metal removal when higher feed rate, because more magnetic abrasive passes into the machining gap with lower feed rate values, which causes an enhancement of metal removal. On the other side, the abrasive particle passes quickly with increasing the feed rate and produces a small amount of metal to be removed from the machining

zone. Increasing the magnetic flux density means more material removal. The increase in tool rotational speed will cause an increase in the value of metal removal. The reason behind this action is belonging to a higher

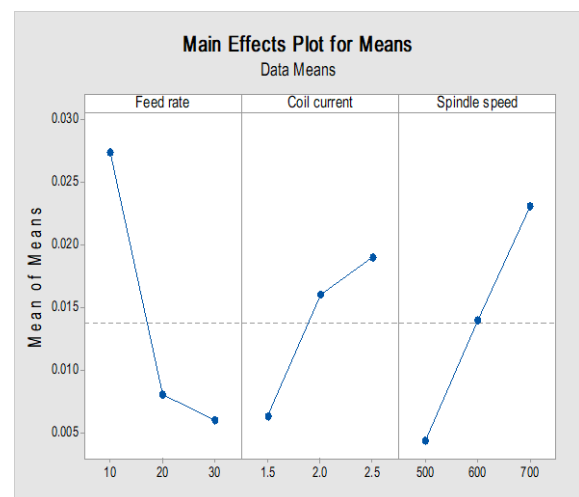
**Table 5. Experimental microhardness and S/N results**

No. of experiment	Machining parameters levels			$\Delta$ HV	S/N (dB)
	FR	CC	SS		
1	10	1.5	500	8.21	18.2869
2	10	2	600	14.21	23.0519
3	10	2.5	700	20.75	26.3404
4	20	1.5	600	11.65	21.3265
5	20	2	700	6.20	15.8478
6	20	2.5	500	29.50	29.3964
7	30	1.5	700	10.30	20.2567
8	30	2	500	19.00	25.5751
9	30	2.5	600	21.38	26.6002

FR: Feed rate (mm / min)

CC: Coil current (ampere)

SS: Spindle speed (RPM)

**Figure 3. Main effect plot of metal removal**

The main effect plot of metal removal and microhardness are illustrated in Fig. 2 and Fig. 3 respectively. Frictional force occurs at a higher rotational speed because of the irregular jumbling of the abrasive that happened under these conditions, which produces over-removal of the material by the aggressive strikes of the jumbling abrasives.

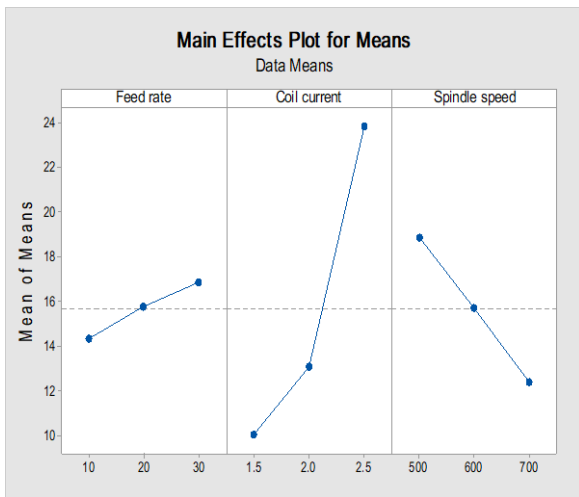


Figure 4. Main effect plot of microhardness

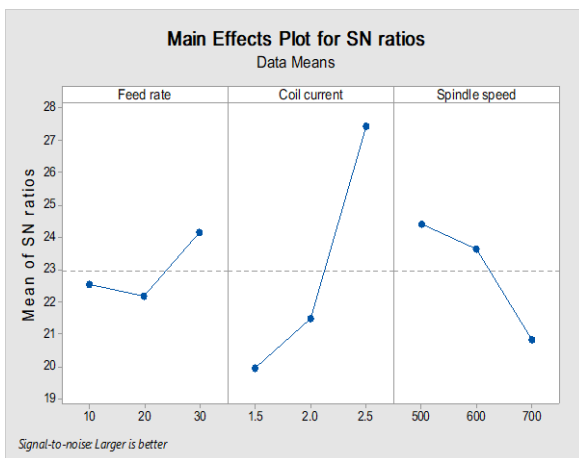


Figure 5. Signal-to-noise plot of metal removal

Fig.4 demonstrated when increasing the rotational speed, the normal magnetic force will decrease that meaning a decrease in the improvement of surface hardness. At high speed the magnetic abrasives will splash from the machining gap when normal magnetic force decreases, Fig.4 also illustrated it seen that the increase in coil current causes the change in Micro-Vickers hardness to increase. A higher number of indentations in the workpiece surface occur when increasing the coil current because of an increase in the strength of the magnetic brush [9]. Some influence of feed rate on change in micro-hardness is illustrated in Figure 4, the increases in feed rate values from (10 to 30) mm/min an improvement occurs in the change in micro-hardness. Fig 5. and Fig.6 illustrated the signal-to-noise ratio for metal removal and microhardness respectively, from Fig.5 can be noticed that the maximum values of the S/N ratio were obtained at the lower level of feed rate and the higher level of coil current and spindle speed. Fig.6 demonstrated that the maximum value of the S/N ratio at higher levels of feed rate and coil current whereas the lower level of spindle speed results in the maximum value of the S/N ratio.

Fig7. and Fig.8 represent the effect of input parameters on metal removal, from these figures can be observed that the highest value of metal removal achievable at the lower right corner of the contour plot where the maximum value of coil current and spindle speed while the feed rate at the minimum level. This is because the abrasive particle passes quickly with increasing the feed rate and produces minimizes the metal removal to be removed from the machining zone. From Fig.9 can be observed that the highest value of metal removal was obtained at the upper right corner at the maximum levels of both coil current and spindle speed. This attribute can be explained due to higher frictional force occurring at a higher rotational speed.

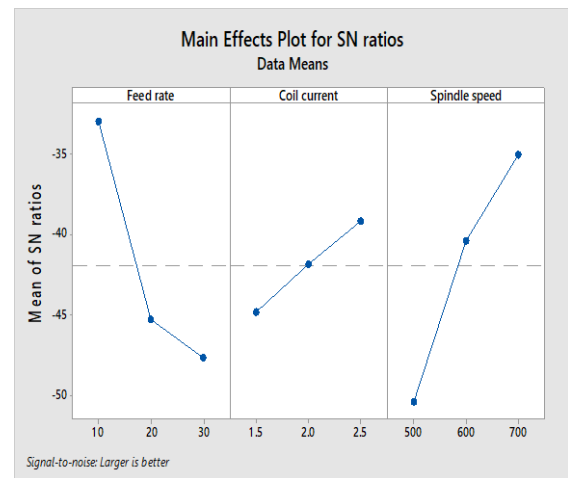


Figure 6. Signal-to-noise plot of microhardness

Fig 5. and Fig.6 illustrated the signal-to-noise ratio for metal removal and microhardness respectively, from Fig.5 can be noticed that the maximum values of the S/N ratio were obtained at the lower level of feed rate and the higher level of coil current and spindle speed. Fig.6 demonstrated that the maximum value of the S/N ratio at higher levels of feed rate and coil current whereas the lower level of spindle speed results in the maximum value of the S/N ratio. Fig7. and Fig.8 represent the effect of input parameters on metal removal, from these figures can be observed that the highest value of metal removal achievable at the lower right corner of the contour plot where the maximum value of coil current and spindle speed while the feed rate at the minimum level. This is because the abrasive particle passes quickly with increasing the feed rate and produces minimizes the metal removal to be removed from the machining zone. From Fig.9 can be observed that the highest value of metal removal was obtained at the upper right corner at the maximum levels of both coil current and spindle speed. This attribute can be explained due to higher frictional force occurring at a higher rotational speed. Fig.10 demonstrated the impact of the feed rate and coil current on the microhardness of the machined surface, from this figure can be noticed that the highest value of microhardness was obtained at the upper right corner at the maximum levels of both coil current and spindle speed. Fig. 11, and Fig. 12 illustrated the highest value of microhardness was obtained at the upper left corner at the minimum level of spindle speed and maximum levels of coil current and feed rate.

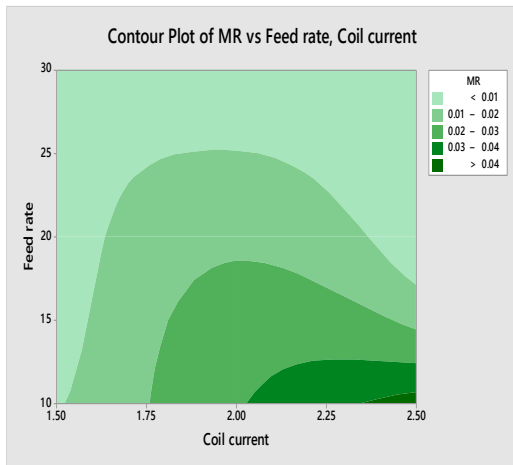


Figure 7. Effect of feed rate and coil current on metal removal

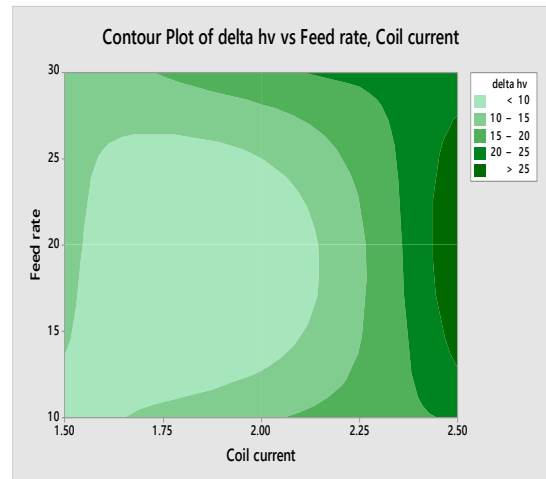


Figure 10. Effect of feed rate and coil current on microhardness

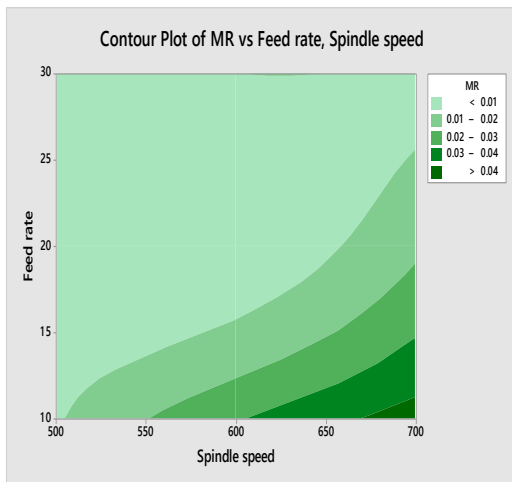


Figure 8. Effect of feed rate and spindle speed on metal removal

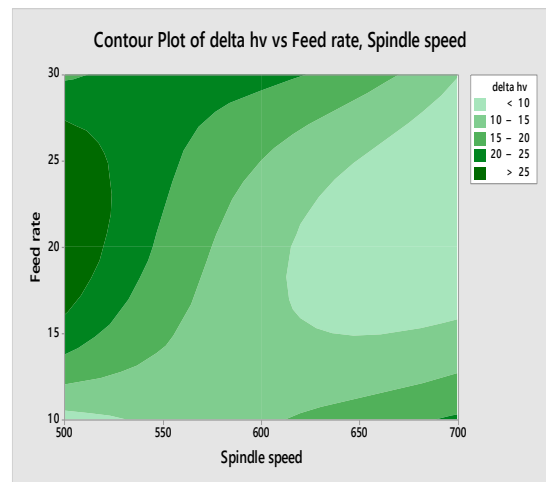


Figure 11. Effect of feed rate and spindle speed on microhardness

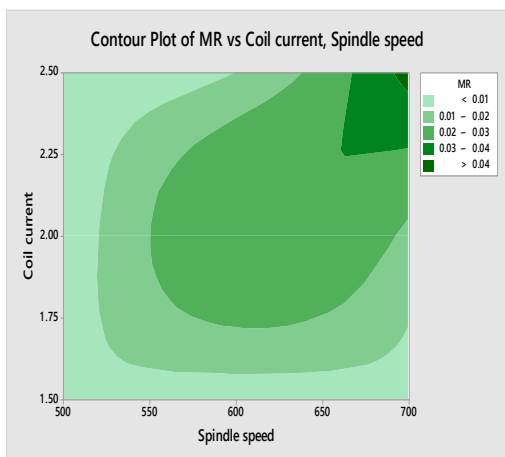


Figure 9. Effect of feed rate and coil current on metal removal

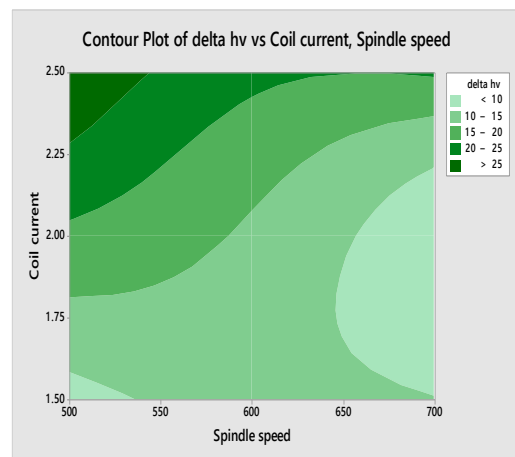
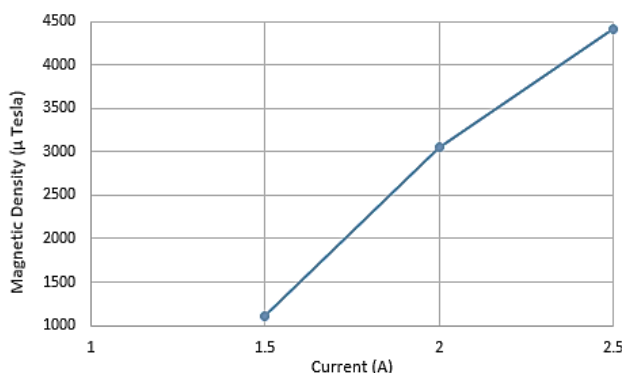


Figure 12. Effect of coil current and spindle speed on microhardness



**Figure 13. Magnetic density ( $\mu$ Tesla)**

Fig. 13 illustrated the magnetic density utilized in this work for the individual value of coil current. From this figure can be noticed that the highest value of magnetic density is 4415.9  $\mu$  Tesla, whereas the lowest value is 1113.5  $\mu$  Tesla.

#### 4. Conclusions

In this work, metal removal and microhardness have been investigated experimentally using three machining factors on (1008-AISI) workpieces based on the Taguchi design of the experiment.

The following conclusions are listed:

- 1- The investigation was conducted by considering the varying parameter of (feed rate, coil current, and spindle speed) with the Taguchi method.
- 2- The (feed rate) is the most influential variable for the metal removal flowed by speed and then coil current.
- 3- The (Coil current) is the most influential variable for the microhardness flowed by speed then feed rate.

#### Authors' contribution

All authors contributed equally to the preparation of this article.

#### Declaration of competing interest

The authors declare no conflicts of interest.

#### Funding source

This study didn't receive any specific funds.

#### REFERENCES

- [1] Tudor, Andrea "Magneto-abrasive finishing of complex surface" Romanian Association of Nonconventional Technologies, December (2013).
- [2] Sumit1, Yogesh2, Gaurav Chhikara3 "Modern magnetic abrasive finishing process". International Journal of Enhanced Research in Science Technology & Engineering. Vol. 3 Issue 6, June 2014, pp: (460-462).
- [3] Japman Singh1, Radhey Sham2 "Experimental Investigation of Process Parameter of MAF on Surface Roughness" International Journal of Science, Technology, and

Management, 'SGI Reflections', May (2013).

- [4] Dhirendra K. Singh, V. K. Jain, V. Raghuram, "Superfinishing of Alloy Steels Using Magnetic Abrasive Finishing Process", aspe.net/ publications/Annual\_Kanpur- 208016 (India) Corresponding author(2003).
- [5] Rishi Dev Joshi, Dr. Gursewak Singh Brar, Mithlesh Sharma., "effect on magnetic abrasive machining with different range of electrical parameters", International Journal of Emerging Technology and Advanced Engineering, Vol. 4, Issue 9, sep.(2014).
- [6] Yuewu Gao Yugang Zhao Guixiang Zhang Fengshi Yin Haiyun Zhang "Modeling of material removal in magnetic abrasive finishing process with spherical magnetic abrasive powder", International Journal of Mechanical Sciences, volume 177, 1 July 2020, 10560.
- [7] Nazar kais M. naif, "study on the parameter optimization in magnetic abrasive polishing for brass CUZN33 plate using Taguchi method, "The Iraqi journal for mechanical and material engineering, Vol. 12, No.3, (2012).
- [8] O. Chasib Kadhum, " Design and Fabrication of Automated Predictive Magnetic Abrasive Finishing Machine" A MSc Thesis University of Baghdad, 2018.
- [9] S. K. Shather and M. Abdal-khadim Abd Alaqeeli "Influence of Silicon Carbide (Sic) Abrasive on Surface Roughness And Metal Removal Rate During Magnetic Abrasive Finishing", Global Journal of Engineering Science and Research Management, ISSN 2349-4506, 2019.
- [10] A. Kumar, Johan Verbert, Bert Lauwers, and Joost R. Duflou, "Tool path compensation strategies for single-point incremental sheet forming using multivariate adaptive regression splines", Computer Aided design – Elsevier, Vol. 45, pp. 575-590, 2013