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Optimization of Material Removal Rate and Temperature in Magnetic Abrasive Finishing Process for Stainless Steel 304

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Abstract

The effect of the magnetic abrasive finishing (MAF) method on the temperature rise (TR), and material removal rate (MRR) has been investigated in this paper. Sixteen runs were to determine the optimum temperature in the contact area (between the abrasive powder and surface of workpiece) and the MRR according to Taguchi orthogonal array (OA). Four variable technological parameters (cutting speed, finishing time, working gap, and the current in the inductor) with four levels for each parameter were used, the matrix is known as a L16 (4^4) OA. The signal to noise ratio (S/N) ratio and analysis of the variance (ANOVA) were utilized to analyze the results using (MINITAB17) to find the optimum condition and identify the significant parameters affecting on the TR., and MRR of the steel 304. IR camera was used to measure the experimental temperature. The results showed that the optimum temperature in contact area of workpiece is 70.7 °C.

Keyword: *IR camera ,Magnetic abrasive finshing , Temprature rise.*

1. Introduction

Magnetic Abrasive Finishing (MAF) process is the one in which material is removed in such a way that the surface is finished. The most uses of MAF are manufacturing semiconductors, medical instruments, atomic energy parts and aerospace components that have a very precise surface roughness [1]. One of the main advantages of MAF operation as compared with traditional finishing operations is the minimizing of the possibility of micro cracks on the surface of the workpiece, because the cutting force is primarily controlled by the magnetic field [2]. The principle work of magnetic abrasive finishing involves filling the working gap between the workpiece and the pole with the magnetic abrasive powder, the current or the magnetic flux density is passed through the coil to produce the magnetic field, and the pole is rotating with the powder along the work piece. The magnetic field provides the abrasive powder with the energy, this energy makes the magnetic abrasive powder as a cutting tool for treating the surface, and the rotation of the pole makes the friction between the workpiece and the magnetic abrasive powder which the material can be removed from the workpiece [3-4]. MAF was inventoried by Harry P. Coat in 1938's in U.S.A, the first patent was given in1940's, the research began in the universities of Germany, and Soviet union in 1960's and particularly appeared during 1980's, 1990's [5]. Many of the parameters, like number of the turns, and magnetic flux density affect on the materials removal rate [6]. Girma B. et al. [7] explored the MAF process by analyzing the materials removal rate and the surface roughness using response surface method in plane surfaces. It was concluded that the current, ratio size and the magnetic abrasive powder grain size are more effective on the material removal rate. The MAF process, the thermal effect of electromagnetic flux in the coil produced from current and from the friction between the magnetic abrasive powders with workpiece. Vivek Mishra et al. [8] used the finite element method in the magnetic abrasive finishing process. The friction between the magnetic abrasive particles and the surface of the workpiece leads to frictional heating in the working zone of the surface, based on the ANSYS software to simulate the temperature and the magnetic field. The factors used were the magnetic flux density (0.233T) at (0.91A), it was found that the temperature was between (34–51◦C). Chandan Gaur [9] applied the voltage and the working gap as parameters, and is used MINITAB17 to obtain regression model to analyze the data, the result showed that the temperature increased with increasing the voltage and decreasing the machining gap. The maximum temperature during this process was 94.7 ◦C**.** It was concluded that the effect of the temperature during the MAF process is very small on the quality of the surface roughness, and there is no any conclusion on the various parameters. Singh et al. [10] according to the Taguchi's design of experiments planned, used four parameters (working gap, voltage, and mesh number size of the abrasive and rotational speed). The result showed that the working gap and the voltage are more effective on the change in the surface roughness (ΔR_a).

The objective of this work is:

1-Optimization the MAF parameters through the materials removal rate, and determining the optimum temperature according to optimum MRR of stainless steel 304
2- Studying the influence of MAF parameters (cutting speed, finishing time, working gap, and current in the coil) on the MRR.

2. Experimental Work

2.1. Selection of MAF Process Parameters and Their Levels

In this research, four parameters were considered to be effective on the temperature in the MAF process, these chosen parameters are (rotational speed, working time, current, and working gap) with four levels for each parameter. The selected parameters and their levels are listed in the Table 1; these parameters were selected based on the initial experiments.

Table 1,
The selected parameters and their levels.

No.	Parameters	Unit	Code	Levels			
1	Rotational speed	rpm	A	250	500	750	1000
2	Working time	min	B	5	10	15	20
3	current	Amp	C	1.5	2	2.5	3
4	Working gap	mm	D	1	1.25	1.5	1.75

2.2. Selection of the Orthogonal Array

The experiments were designed based on the orthogonal array (OA) technique to reduce the number of the experiments. From the MINITAB17 software and by total degree of the freedom (DOF) needed to be computed, in order the select the appropriate OA for the experiments, each variable with four levels has two degrees of freedom. Based on Taguchi method, the total DOF of selecting OA must be greater than or equal to the total DOF required for the experiment; therefore, an orthogonal array L16 (4^4) for the four factors with the four levels was used in the present investigation to perform the most effective experiments (16 experiments) from the overall experiments (256 experiments).

2.3. Experimental Procedure of MAF Process

In this work, sixteen different tests are designed based on the Taguchi OA L16. Stainless steel 304 is used as flat workpiece with dimensions (100×50×3) mm. the chemical composition of stainless steel 304 is explained in the Table 2

Table2,
The chemical composition of the stainless steel 304.

Chemical analysis of stainless steel 304						
C	Si	Mn	Cr	Ni	Mo	Cu
0.07	0.9	1.4	20.3	9.2	0.12	0.17
P	S					
-	-					
Chemical composition standard						
C	Si	Mn	Cr	Ni	Mo	Cu
0.08 max	1 max	2 max	18-20	8-10.5	-	-
P	S					
0.045 max	0.03 max					

The physical properties of stainless steel 304 are listed as in the Table 3.

Table 3,
The physical properties of stainless steel 304.

Density (kg/m^3)	**Elastic Modulus (GPa)**	**Coefficient of Thermal Expansion (µm/m/°C) 0- 100°C**	**Thermal Conductivity (W/m.K) at 100°C**
8000	193	17.2	16.2
Specific Heat (J/kg.K) 0-100°C		Electrical Resistivity (nΩ.m)	
500		720	

In the MAF process, an electromagnetic inductor was manufactured because it plays an important role in the finishing the surface layer. The inductor consists of the following:
The core is from low carbon steel, the diameter of core is 22 mm, and the length of the core is 280 mm, while the diameter of the wire of coil is 0.9 mm, number of turns is 2400 for the primary coil and 1600 for the secondary coil, as shown in the Fig.1. A conventional "Turret vertical milling machine Model: MDM 4VS/4HS/4S'' with its spindle was used to fix the magnetic inductor. This work is implemented on the workshop in the college.

Fig. 1. The coil in the MAF process.

Before MAF process, the weight of the stainless steel 304, was measured the work- piece was fixed by a special fixture to clamp the flat surface on the table, as shown in the Fig .2.

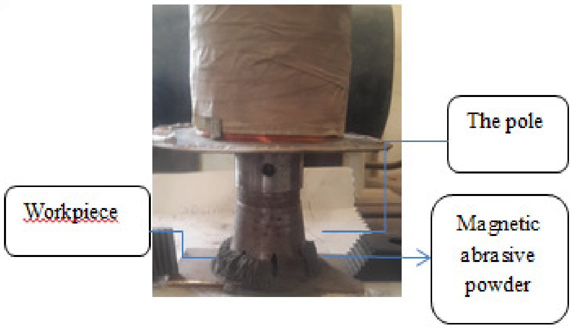

Fig. 2. Fixing the workpiece in the MAF process.

In the MAF process, the parameters for all 16 experimental tests were adjusted, the gap between the workpiece and the pole was first measured by the Verne instrument, and then filled with the MA powder, then the coil was provided with the current through the DC power supply. After that adjustment, the cutting speed was measured by the tachometer, and then the time was adjusted by using a timer. A properly calibrated Infrared camera was used measure the temperature in the contact region during finishing of workpiece at the last two second by. The fringe pattern readily changes with the change in any technological parameters, affecting the cutting temperature. The equation for measuring the MRR (g/min) is:

$$MRR = \frac{\text{W befor MAF} - \text{W after MAF}}{\text{Density of w.p.} \times \text{time}} \quad \dots (1)$$

W: is the weight of the workpiece (g).

3. Results and Discussion

3.1. Signal to Noise Ratio (S/N)

The S/N ratio is defined as a standard approach used for the average of the result in run with the main parameter. The optimum with S/N ratio is studying the main effect of the parameters and giving the best result which effect on the process [11].

In the MAF process, the S/N ratio is used to measure the MRR with the parameters, there are three categories of the quality characteristics: smaller is better, normal is better and bigger is better, in this case selecting the bigger is better which means the maximum response of the MRR.

The mean squared deviation (MSD) and (S/N) ratio are determined by the equations:

$$MSD = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{y_{ij}^2}\right) \quad ...(2)$$

$$S/N = -10log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_{ij}^2}\right] \quad ...(3)$$

Where:
n: number of trails
y_{ij}^2: the total result of the trails

Table 4,
Design of the experiments and result of the mean, S/N ratio for MRR the stainless steel 304.

No. of EXP.	A (rpm)	B (min)	C (amp)	D (mm)	MRR steel (g/min)	S/N ratio	Mean (g/min)	TR. (°C)
1	250	5	1.5	1	0.0155	-36.1934	0.0155	28
2	250	10	2	1.25	0.0090	-40.9151	0.0090	24.1
3	250	15	2.5	1.5	0.0400	-27.9588	0.0400	49.6
4	250	20	3	1.75	0.0350	-29.1186	0.0350	68.5
5	500	5	2	1.5	0.0278	-31.1191	0.0278	35.9
6	500	10	1.5	1.75	0.0263	-31.6009	0.0263	32.8
7	500	15	3	1	0.0399	-27.9805	0.0399	54.9
8	500	20	2.5	1.25	0.0465	-26.6509	0.0465	70.3
9	750	5	2.5	1.75	0.0178	-34.9916	0.0178	22.3
10	750	10	3	1.5	0.0330	-29.6297	0.0330	41.5
11	750	15	1.5	1.25	0.0300	-30.4576	0.0300	34.1
12	750	20	2	1	0.0349	-29.1435	0.0349	39.9
13	1000	5	3	1.25	0.0480	-26.3752	0.0480	41.9
14	1000	10	2.5	1	0.0298	-30.5157	0.0298	40.3
15	1000	15	2	1.75	0.0350	-29.1186	0.0350	35.0
16	1000	20	1.5	1.5	0.0200	-33.9794	0.0200	29.2

3.1.1. Optimization of the MAF Process Parameters with MRR of Stainless Steel 304

In this study, the results of the MRR of the stainless steel 304 with factors are analyzed by S/N ratio, to obtain the influence of the levels of the parameters on the quality of the surface; the mean and the S/N ratio are given in Table 4. The main effect of each parameter with four levels on the mean and S/N ratio for MRR stainless steel 304 are calculated and listed in the Table 5.

Table 5,
The effect of the (S/N) ratio and mean of MRR stainless steel 304.

The S/N ratio effect

level	A	B	C	D
1	-33.55	-32.17	-33.06	-30.96
2	-29.34	-33.17	-32.57	-31.10
3	-31.06	-28.88	-30.03	-30.67
4	-30.00	-29.72	-28.28	-31.21
Delta	4.21	4.29	4.78	0.54
Rank	3	2	1	4

The means effect

level	**A**	**B**	**C**	**D**
1	0.02488	0.02728	0.02295	0.03002
2	0.03513	0.02452	0.02668	0.03338
3	0.02892	0.03623	0.03352	0.03020
4	0.03320	0.03410	0.03897	0.02853
Delta	0.01025	0.01170	0.01602	0.00485
Rank	3	2	1	4

S/N ratio optimization
Mean optimization

From the Table 5, the optimum parameters of the S/N ratio when (A_2, B3, C4, and D_3) (A= 500rpm, B= 15min, C= 3A, and D= 1.5mm) as shown in Fig. 3. and for mean effect in the (A_2,B_3,C_4,andD_2)(A=500rpm,B=15min,C=3A,and D=1.25mm) as shown in Fig. 4. The values of the S/N ratio and mean in table (5) are calculated from Minitab software. The delta is a difference between maximum value and minimum value, for example (-29.34 +-33.55) = 4.21. Although the Rank of the S/N ratio and the means is the same, but this state need to make prediction, because the working gap value is different for two plots in Fig (3, 4). The prediction is used to determine the optimum value by choosing the large value of the S/N ratio in the prediction, as shown in the Table 6.

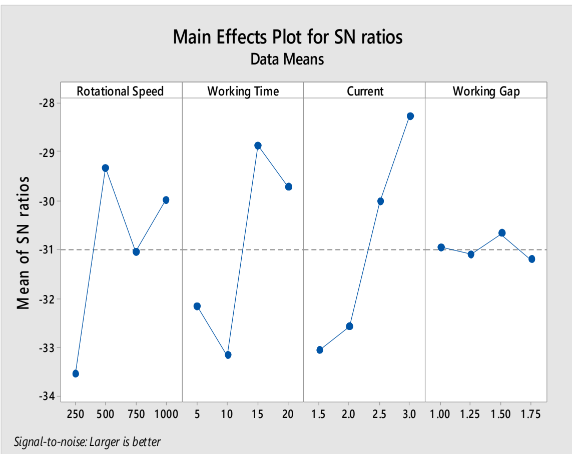

Fig. 3. The S/N ratio effect on the parameters of stainless steel 304 on the MRR.

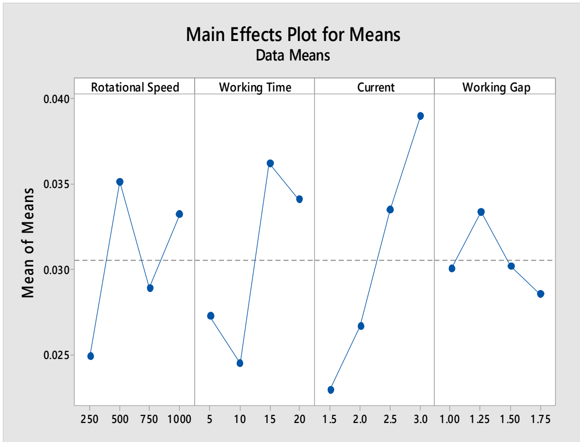

Fig. 4. The mean effect on the parameters of stainless steel 304 on the MRR.

$$\{\Delta MRR_{\text{Predicted}} = \bar{A}_{Nop} + \bar{B}_{Nop} + \bar{C}_{Nop} + \bar{D}_{Nop} - 3\bar{T}\} \quad \ldots(4)$$

Where:
$\bar{T}$ = The overall mean of response MRR.
$\bar{A}_{Nop}, \bar{B}_{Nop}, \bar{C}_{Nop}, and\ \bar{D}_{Nop}$ = the average of response at the optimum level.
From the Table 6, the optimum conditions of the MRR stainless steel 304 when (A= 500rpm, B=15min,C=3A, and D=1.5mm),
and the temperature in the optimum experiment is 70.7°C

Table 6,
The prediction of the mean and S/N ratio.

S/N ratio			
A	**B**	**C**	**D**
2	3	4	3
mean		S/N ratio	
0.0489312		-24.2117	
Mean			
A	B	C	D
2	3	4	2
mean		S/N ratio	
0.0521062		-24.6396	

3.2. The Analysis of Variance ANOVA of the MRR Stainless Steel 304

Anova was used to determine the effect of parameters with MRR and Ra, the results showed that the pole geometry and time are more effected on the MRR [12].

In order to obtain percentage of the effect of all parameters (A,B,C,D) on the materials removal rate of the stainless steel 304 surface, ANOVA was used to predict which parameter has a significant effect on the MRR, the contribution P% of each factors is explained in the Table 7.

Table 7,
ANOVA for MRR stainless steel 304.

Source	DOF	Adj ss	F	P (%)
A	3	0.0002512	0.49	14.022
B	3	0.0003673	0.72	20.503
C	3	0.0006104	1.19	34.073
D	3	0.0000499	0.10	2.785
Error	3	0.0005126		28.614
Total	15	0.0017914		

Where:
DOF: degree of freedom
Adj ss: adjusted sum of squares
F: F value or fisher factor, measurement of the significance of the factor
P%: percentage contributed of each factor.
The contribution of all factors is also manifested in Fig. 5. From this figure, it is noticed that the current (C) is more influence on the MRR, following by the working time (B), rotational speed (A) and then working gap (D), because the current and the working time lead to increase the heating in the MAF process, the heating effected on the surface layer of the workpiece and on the MRR.

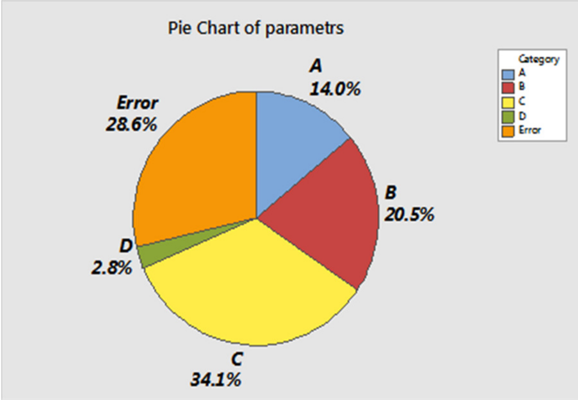

Fig. 5. Contribution of the parameters in the MRR stainless steel 304.

3.3. The Regression of the MRR of the Stainless Steel 304 with Temperature

The regression is used to define the relationship between the temperatures with the MRR of the stainless steel 304, see Fig .6. The results of the MRR stainless steel 304 with temperature are listed in the Table 4; the temperature was measured during the experimental work for 16 experiments by infrared camera.

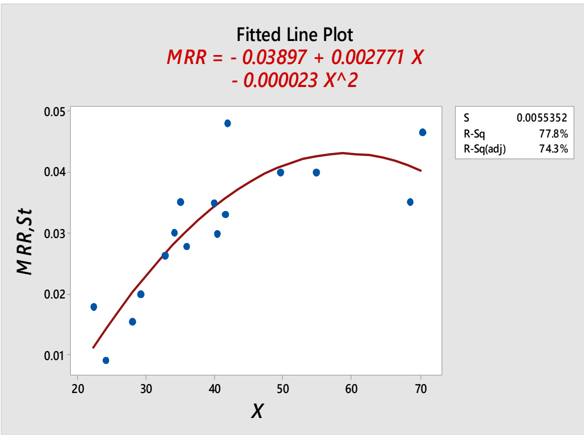

Fig.6. The relationship between the temperature and MRR of steel.

Where:
x: temperature of the stainless steel 304.

Fig.6. We shows the relationship between the temperature and the MRR of stainless steel 304. Is noticed that increasing the stainless steel 304 temperatures caused to increase MRR when the temperature is about (60°C) then after that decreases because the value of the temperature degree is obtained from the effect of the four

parameters at each experiment. The optimum temperature is mean temperature which measured by the optimum conditions when (A= 500 rpm, B=15 min, C= 3A, and D=1.5 mm), Fig. 7. is explains the infrared camera at optimum conditions.

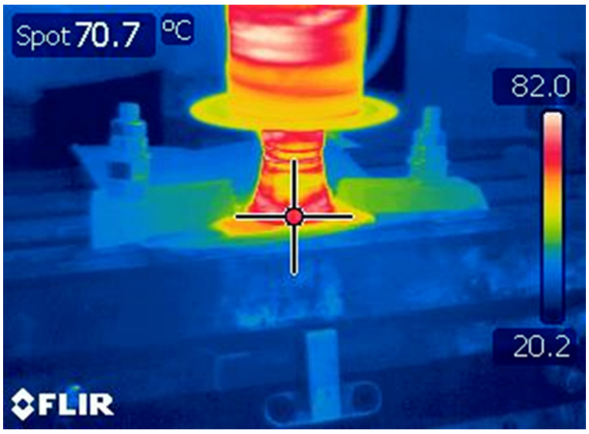

Fig. 7. Infrared photography for optimum conditions.

4. Conclusions

From the previous results, the followings can be concluded:

1- The optimum temperature rise is obtained according to optimum MRR (maximum) ,for the steel 304 the optimum levels are (A_2, B_3, C_4, and D_3) when rotational speed is (500 rpm), working time is (15 min),current is (3A) and working gap is (1.5mm) ,and then the optimum temperature at these levels is TR=70.7°C.

2- The analysis of the variance for the materials removal rate, it is noticed that the current (C) is more influential on the MRR, followed by the working time (B), rotational speed (A) and then working gap (D).

3- MRR of the steel 304 is increasing when the temperature increase up to 60 °C.

5. References

[1] Mithlesh Sharma,and Devinder Pal Singh" ,To Study the Effect of Various Parameters on Magnetic Abrasive Finishing", international Journal of Research In Mechanical Engineering & Technology Vol. 3, Issue 2, May - Oct 2013.

[2] S. Jayswal, V. Jain, and P. Dixit, "Modeling and simulation of magnetic abrasive finishing process", International Journal of Advanced Manufacturing Technology, Vol.26, pp. 477–490, 2005.

[3] Tae-Wan Kim" Application of Magnetic Abrasive Polishing to Composite Materials", Journal of Mechanical Science and Technology, Vol 5, PP 1029-1034, 2010.

[4] Japman singh, and radhey sham "Experimental Investigation of Process Parameter of MAF on Surface Roughness, "International Journal of the Science, Technology and Management,'SGI Reflection ' may 2013.

[5] Yamaguchi H, and Sato T, "Polishing and Magnetic Field-Assisted Finishing", intelligent energy Field Manufacturing Interdisciplinary Process Innovations, 2012.

[6] Rishi Devi Joshi,.Gursewak Singh Brar, and Mithlesh Sharma."Effect on Magnetic Abrasive Machining with Different Range of the Electrical Parameters ",International Journal of Emerging Technology and Advanced Engineering , Vol.4,Issue 9,Sep 2014.

[7] Girma B., Joshi S.S., Raghuram M. V. G. S., and Balasubramaniam R., "An Experimental Analysis of Magnetic Abrasive Finishing of Plane Surfaces", Machining Science and Technology, Vol. 10, Issue 3, pp 323–340, 2006.

[8] Vivek Mishra, Harsha Goel, Rahul S. Mulik, and P.M.Pandey, "Determining work-brush interface temperature in magnetic abrasive finishing process' Journal of Manufacturing process,Vol.16,Issue 2,PP.248-256,2014.

[9] Chandan Gaur "The analysis of the temperature during magnetic abrasive finishing of the plane plate "International Journal for Scientific Research & Development" Vol. 3, issue 4, PP. 1835-1841, 2015.

[10] Dhirendra K. Singh, V.K. Jain, and V. Raghuram, "Parametric study of magnetic abrasive finishing process", Journal of Materials Processing Technology, Vol.149, Issue 1-3, pp.22-29, 2003.

[11] Ranjit K. Roy,"Aprimer on the Taguchi method,1ST Edition ,New York: Van Nostrand Reinhold ,1990.

[12] M. K. Qate'a , A. .H. Kadhum, F. F. Mustafa ,"The influence of the magnetic abrasive finishing system for cylinder surface on the surface roughness and MRR" AL-Khwarizmi engineering journal ,Vol. 11,No.3, pp. 1-10,2015.

ايجاد القيم المثلى للمعدن المزال وللحرارة خلال عملية التشغيل بالحك المغناطيسي لمعدن الفولاذ ٣٠٤

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الخلاصة

في هذا البحث سوف يدرس تأثير التشغيل بالجلغ المغناطيسي على عملية ازالة المواد من المعدن وكذلك على ارتفاع درجات الحرارة. اجريت ست عشرة تجربة لايجاد القيمة المثلى للحرارة في منطقه الاتصال بين مسحوق المعدن والقطعة المشغولة وكذلك لايجاد القيمة المثلى للمعدن المزال هذه التجارب تتم وفقا لمصفوفة العالم الياباني تاجوشي وذلك باستخدام اربعة مدخلات هي (سرعة القطب المغناطيسي وزمن التشغيل والتياروارتفاع القطب المغناطيسي عن سطح المشغولة) مع وجود أربعة مستويات لكل مدخل. في هذا العمل سوف يطبق (نسبة الأشارة الى الضوضاء) (S/N ratio) وتقنية تحليل التباين (ANOVA) وذلك باستخام البرنامج الاحصائي (MINITAB17) لأيجاد الشروط المثلى مع تعريف المدخلات المهمة التي تؤثر على أرتفاع درجات الحرارة ومعدل أزالة المادة للمعدن المذكور.
الكاميرا الحرارية سوف تستخدم لقياس درجة الحرارة خلال التجارب العملية ان النتائج اظهرت ان درجة الحرارة المثلى *70.7 °C* لمعدن الفولاذ.