A Study of the Effect of (Cutting Speed, Feed Rate and depth of cut) on Surface Roughness in the Milling Machining

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Abstract

The purpose of this research is to investigate the effect of the main factor of the surface roughness in aluminum alloy (Al-2024) as a workpiece and face milling machining by using computer numerical controlled milling machine with 50 millimeter diameters of the tool with triple cutting edges of carbides. The controlled factors were the speed, feed rate and the depth of cut and this factors effect on the surface roughness. The result of the tests showed that the surface roughness was likely to reduce when the cutting speed increase. It is found the surface roughness is increase with increasing both of feed rate and depth of cut. then drawing a charts illustrate the relationship between variables (cutting speed, feed rate and depth of cut) with surface roughness and analysis resulting data by utilizing the SPSS software to predicted surface roughness by using milling machining parameters and graphical analysis of the obtained data, The percentage of accuracy was 96%.

Keywords: surface roughness, milling machining, cutting speed, feed rate and depth of cut

دراسة تأثير (سرعة القطع، معدل التغذية وعمق القطع) على خشونة السطح في عملية التفريز

الخلاصة

الغرض من هذا البحث دراسة تأثير العامل الرئيسي لخشونة السطح عند تشغيل سبيكة المنيوم (المنيوم-2024) كمشغولة وعملية تفريز وجهية بأستخدام ماكنة تفريز ذات التحكم الرقمية بواسطة الحاسوب مع استخدام عدة قطع بقطر 50 ملميتر بحافات قطع ثلاثية من الكاربيد. عوامل السيطرة كانت السرعة، معدل التغذية وعمق القطع وهذه العوامل تؤثر على خشونة السطح. اظهرت نتائج الأختبارات ان خشونة السطح من المحتمل ان تقل مع زيادة سرعة القطع. ووجد ان خشونة السطح تزداد مع زيادة كل من معدل التغذية وعمق القطع. وتم رسم مخططات توضح العلاقة بين المتغيرات (سرعة القطع، معدل التغذية وعمق القطع) مع خشونة السطح وتم تحليل وتخمين النتائج بأستخدام برنامج SPSS لتقدير خشونة السطح بواسطة متغيرات عملية التفريز وتحليل البيانات التي تم الحصول عليها وقد كانت النسبة المئوية للدقة 96%.

INTRODUCTION

Milling is a fundamental machining process and the most encounter metal removal operation in manufacturing industry. The quality of a milled surface is a key role for improving fatigue strength, corrosion resistance, and creep life [1]. The process of generating a milled surface is affected by several factors, some of them, namely the cutting conditions and tool geometry, are of primary importance in determining the quality of a milled surface [2]. Suitable setting of cutting parameters is important before the process takes place [3]. Generally, is characterized by change in material properties, cut edge deformation,

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cut surface properties and cut channel geometry. Common use of many cutting processes introduces questions like "which cutting method is more efficient for a given material?" Within this context, main aim is to find the fastest, cheapest, top quality method yielding in the least deformation on the cut edge and its vicinity. In many cases, one or more of these criteria may be neglected. Despite the ongoing evolution of cutting methods since more than a century, some application limitations and weaknesses makes it inevitable to search for new methods [4]. Milling is a process of producing flat and complex shapes with the use of multi-tooth cutting tool, which is called a milling cutter and the cutting edges are called teeth. The axis of rotation of the cutting tool is perpendicular to the direction of feed, either parallel or perpendicular to the machined surface. The machine tool that traditionally performs this operation is a milling machine [5]. In this research study face milling; cutter is perpendicular to the machined surface. The cutter axis is vertical, but in the newer CNC machines it often is horizontal. In face milling, machining is performed by teeth on both the end and periphery of the face-milling cutter.

Nitin Agarwal [6] studied analyze the effect of machining parameters on the surface quality of aluminum alloy in CNC milling operation with HSS tool. A multiple regression model is developed with spindle speed, feed rate and depth of cut as the independent variables and surface roughness parameter 'Ra' as the dependant variable. The prediction ability of the model has been tested and analyzed using 't-test' and it has been observed that there is no significant different between the mean of Ra values of theoretical and experimental data at 5% level of significance.

Kasim M.S. et al [7] investigated the effect of cutting speed, feed rate and depth of cut on the surface roughness of Inconel 718 when milled under minimum quantity lubrication, the results showed that the interaction between the feed rate, fz and the radial depth of cut, ae, was the primary factor controlling surface roughness.

Manop Vorasri et al [8] this research was to study factors, which were affected on surface roughness in high speed milling of hardened tool steel. Factors were consisted of cutting speed, feed rate, and depth of cut. The results showed that influenced factor affected to surface roughness was cutting speed, feed rate and depth of cut which showed statistical significant. Higher cutting speed would cause on better surface quality. On the other hand, higher feed rate would cause on poorer surface quality.

Mohammed T. Hayajneh et al [9] this study is to develop a better understanding of the effects of spindle speed, cutting feed rate and depth of cut on the surface roughness and to build a multiple regression model. Such an understanding can provide insight into the problems of controlling the finish of machined surfaces when the process parameters are adjusted to obtain a certain surface finish.

Dražen Bajić et al [10] the roughness of technical surfaces presents one of the most important criterions relating to the choice of machining process and cutting parameters in project processing. The following article will therefore focus on researching results of the roughness of treated surface depending on the cutting parameters characterized to the up milling process. In order to find the most suitable empiric model to describe the depending character of the roughness of treated surface the following elements have been taken into consideration: cutting speed, the depth of cut and a feed rate. The experiment with the material 2011(AlCuPbBi) has been conducted and the central composite design of the second degree has been applied. Given results determined by regression analysis led to the empiric equation that is used for the purpose of the calculation of the average arithmetic roughness.

Avinash A. Thakre [11] this study includes understanding the effects of various milling parameters such as spindle speed, feed rate, depth of cut and coolant flow on the surface roughness (Ra) of finished products. The results indicated that coolant flow with the contribution of 60.69% is the most important parameter in controlling the surface roughness, followed by spindle speed. The optimal parameters for surface roughness is obtained as spindle speed of 2500 rpm, feed rate of 800 mm/min, 0.8 mm depth of cut, 30 lit/min coolant flow.

Shather S. K. [12] this study is to predict surface roughness of workpiece which machined by ceramic cutting tool using SPSS program and compare the results with the experimental values which performed under different cutting conditions. Cutting speed (60,80, 90,100,110 m/min) and feed rate (0.1, 0.08, 0.3mm/rev) and depth of cut (0.25, 0.5 ,0.7mm), the conclusions were the prediction accuracy of the surface roughness in this research with SPSS calculations are 90% ,experiments prove that increasing cutting speed from 60 m/min to 110 m/min lead to improve the quality of surface roughness.

Ibrahim A. F, [13] this research propose multiple regression model (MRM) by using response surface method (RSM) in Minitab program, to predict surface roughness and study the effect of the spindle speed, feed rate and depth of cut on the surface roughness. The result indicated that the depth of cut is the most significant machining parameter and influence surface roughness (Ra), then the feed rate and spindle speed.

The goal of this study is to investigate the machining parameters of cutting speed, feed rate and depth of cut and its effect on surface roughness in CNC milling machining operation with comparison and prediction the results by using SPSS software to analyze the data and determine the convergence in the results between measured and predicted values of the experiments.

Selecting the Variables

In this study the dependant variable is the surface roughness (Ra) and the independent variables are the cutting speed, feed rate and depth of cut. Because these variables are controllable machining parameters, they can be used to calculate the surface roughness in vertical milling which will then improve the product quality. The variables are defined as follows:

Surface Roughness (Ra)

Surface roughness is one of the most important parameters to determine the quality of product. The mechanism behind the formation of surface roughness is very dynamic, complicated, and process dependent. Several factors will influence the final surface roughness in a CNC milling operations such as controllable factors (spindle speed, feed rate and depth of cut) and uncontrollable factors (tool geometry and material properties of both tool and workiepce) [6]. The surface roughness plays a great part in fatigue strength and corrosion resistance, surface friction, light reflection, ability of holding a lubricant, electrical and thermal contact resistance, appearance, cost, etc [14, 15]. High quality of the surface after end milling makes further machining of the surface not necessary, which brings about decreased power consumption and environment load. However, optimization of surface roughness is consistently challenged by its uncertainty of prediction model as well as various influencing parameters, which can be divided into controlled and non-controlled parameters [16].

Cutting Speed

Metal cutting is one of the most significant manufacturing processes in the area of material removal. Defined metal cutting is as the removal of metal chips from a workpiece in order to obtain a finished product with desired attributes of size, shape, and surface roughness [9]. Cutting speed of a milling cutter is its peripheral linear speed resulting from the operation. It is expressed in meters per minute. The cutting speed can be derived from the formula as following:

$V = \pi\, d\, n / 1000$

where

d= Diameter of milling cutter in mm,

V= Cutting speed (linear) in meter per minute, and

n= Cutter speed in revolution per minute (r.p.m).

Spindle speed of a milling machine is selected to give the desired peripheral speed of cutter.

Feed Rate

It is the relative velocity at which the cutter is advanced along the workpiece. Feed rate is measured in mm/min [6]. The rate with which the workpiece under process advance under the revolving milling cutter. It is known that revolving cutter remains stationary and feed is given to the workpiece through worktable. Generally feed is expressed in three ways [17].

Feed per Tooth

It is the distance traveled by the workpiece (its advance) between engagements by the two successive teeth. It is expressed as mm/tooth (ft).

Feed per Revolution

Travel of workpiece during one revolution of milling cutter. It is expressed as mm/rev. and denoted by F(rev)

Feed per Unit of Time

Feed can also be expressed as feed/minute or feed/sec. It is the distance advances by the workpiece in unit time (Fm).

Above described three feed rates are mutually convertible.

$Fm = n \times F(rev)$

where n= rpm of cutter.

It can be extended further as

$Fm = n \times F(rev) = z \times n \times Ft$

where z = Number of teeth in milling cutter.

Depth of Cut

Depth of cut in milling operation is the measure of penetration of cutter into the workpiece. It is thickness of the material removed in one pairs of cutter under process. One pairs of cutter means when cutter completes the milling operation from one end of the workpiece to another end. In other words, it is the perpendicular distance measured between the original and final surface of workpiece. It is measured in mm [17].

Experimental Part

Experiments have been performed in order to investigate the effects of machining parameters (cutting speed, feed rate and depth of cut) on the surface roughness of the machined surface. First stage of experiments were conducted by selection cutting speed as a variable value with constant values of feed rate and depth of cut, second stage of experiments were performed by chosen variables values of depth of cut with constant values of cutting speed and feed rate, at last with third stage we choose feed rate as a variable value with constant values of cutting speed and depth of cut, we took the cutting speed depending on the spindle speed of CNC milling machine, as shown in table (1) and five readings had been taken for each stage. Then we examined the surface roughness for all experiments and listed the values of surface roughness with draw a charts illustrate the relationship between variables (cutting speed, feed rate and depth of cut) with surface roughness. The place of performed of the experiments in the turning unit in the University of Technology / Baghdad, also been inspect the samples in the State Company for Inspection and Engineering Rehabilitation for the period of 10/9/2014 to 7/1/2015.

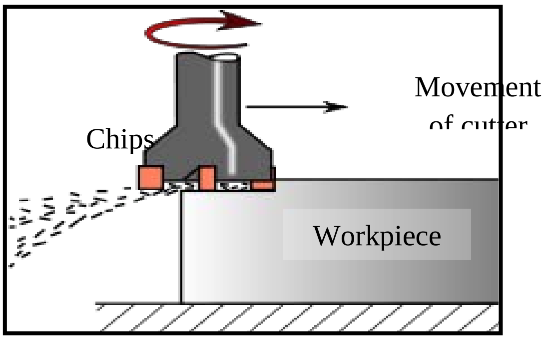
Machine

In this work, machine used is computer numeric control (CNC) Milling Machine (C-TEK Technology Corporation), with model KM-80D, specifications of the machine shows in table (2), this machine shows in figure (1)

Figure (1) shows CNC Milling machine (model KM-80D).

In this work used face milling tool has carbide cutters, the external diameter of the face tool is (50 mm) and contains three cutters, face milling tool and it's process as shows in figure (2) A and B.

A



B

Figure (2) show: (A) face milling tool and, (B) face milling process.

Workpiece

Fifteen specimens made of Aluminum alloy (Al-2024) have been chosen with 40 mm diameter and 10 mm thickness. Material properties and chemical composition of alloy are listed in table (3) and (4) respectively, workpiece as show figure (3).

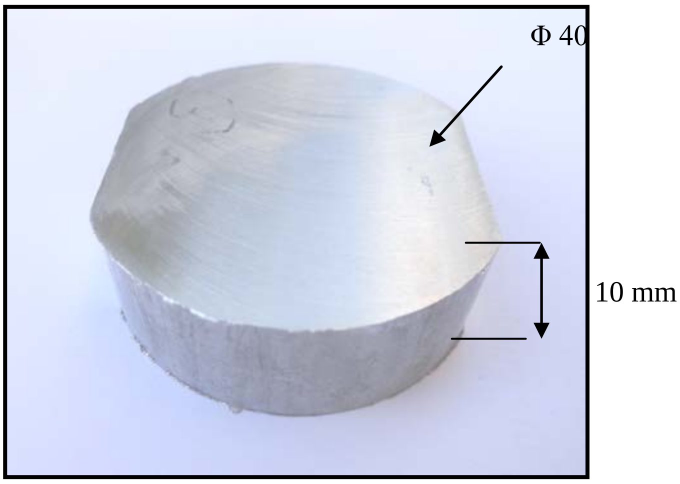


Figure (3) workpiece of Al-Cu-Mg alloy.

Roughness Measurement

Using the Portable Surface Roughness Gauge (Pocket Surf) for surface roughness measurement and take examination with three values for each machined surface then extract the average of surface roughness, the gauge as shows in figure (5), with specification in table (4).

Figure (4) shows Portable Surface Roughness Gauge

Data Analysis

In this work, analysis based on the linear regression is performed by utilizing the SPSS software to estimate the significant factors of the milling machining process parameters and graphical analysis of the obtained data. Linear regression is the next step up after correlation. It is used when we want to predict the value of a variable based on the value of another variable. The variable we want to predict is called the dependent variable, by dependence on the following equation in this software to predict the value of surface roughness:

$$Ra = 0.397 - 0.009\ Vc + 0.002\ F + 3.423\ T + 2.248E\text{-}5\ Vc^2 - 1.351E\text{-}6\ F^2 - 1.822\ T^2$$

Where:
Vc is cutting speed
F is feed rate
T is depth of cut

Result and Discussion

The experiment results showed that face milling carbide cutters can achieve good surface finish. According to the table (1), achieved surface roughness ranged from 0.2200 μm to 1.4533 μm, as shown in figure (5) illustrate surface roughness is decrease with increase of cutting speed, the range of surface roughness is decreased from (0.4166 to 0.2566) μm and the range of cutting speed (94.24 to 235.61) mm/min as show in stage (1) for table (1), that's agree with references [6] and [9] , with referring to figure (6) show the surface roughness is increase with increase in depth of cut, the surface roughness increased from (0.2200 to 1.4533) μm and depth of cut increases from (0.25 to 1.00) mm as show in stage (2) and that's compatible with reference [1], figure (7) shows the relationship between surface roughness and feed rate, and indicates surface roughness increase from (0.3166 to 0.6933) μm with increasing of feed rate from (50 to 500) mm/min and this agree with reference [8], other figures (8,9 and 10) show the relationship between the real and predicted values of surface roughness for three stages when change cutting speed, depth of cut and feed rate, and proved convergence in the results, as shows in table (8).

Conclusion

In the present study, 15 specimens of Aluminum alloy have been machined in a CNC milling machine with tool has carbide cutters and then inspect surface roughness tester has been used to determine Ra values of all the specimens. A multiple regression model has been developed and evaluated by means of significant difference between the predicted Ra values and the actual Ra values with the help of SPSS software. The significant conclusions drawn from the present research are recapitulated as follows:

1. The surface roughness could be efficiently calculated by using cutting speed, feed rate, and depth of cut as the input variables.
2. Higher cutting speed would be cause of better surface quality.
3. Lower feed rate would be increase the better surface roughness.
4. Lower depth of cut would be getting the better surface roughness.
5. At high cutting speed with low depth of cut and low feed rate would be better surface quality more than low cutting speed.

Table (1) Experimental results.

No.	Spindle speed (rpm)	Cutting speed (mm/min)	Feed rate (mm/min)	Depth of cut (mm)	Surface roughness (Ra) (μm)			
					Trail 1	Trail 2	Trail 3	Average
Stage 1								
1	600	94.24	200	0.150	0.43	0.42	0.40	0.4166
2	800	125.66	200	0.150	0.36	0.37	0.34	0.3566
3	1000	157.07	200	0.150	0.36	0.32	0.34	0.3400
4	1200	188.49	200	0.150	0.31	0.29	0.30	0.3000
5	1500	235.61	200	0.150	0.26	0.24	0.27	0.2566
Stage 2								
6	1700	267.03	200	0.25	0.22	0.24	0.20	0.2200
7	1700	267.03	200	0.45	1.19	1.15	1.13	1.1566
8	1700	267.03	200	0.60	1.30	1.25	1.35	1.3000
9	1700	267.03	200	0.85	1.35	1.40	1.43	1.3933
10	1700	267.03	200	1.00	1.41	1.47	1.48	1.4533
Stage 3								
11	2000	314.15	50	0.150	0.30	0.33	0.32	0.3166
12	2000	314.15	150	0.150	0.52	0.54	0.52	0.5266
13	2000	314.15	250	0.150	0.59	0.62	0.61	0.6066
14	2000	314.15	350	0.150	0.62	0.63	0.65	0.6333
15	2000	314.15	500	0.150	0.68	0.69	0.71	0.6933

Table (2) specifications of CNC Milling Machine

Model	KM-80D
Table surface	305*1270mm
T-slot(WxN)	18/3T
Table load capacity	400kg
TRAVELS	
X travel	800mm
Y travel	500mm
Z travel	500mm
Spindle center to column	530mm
Spindle nose to table	620mm
SPINDLE	
Taper of spindle nose	BT40 or CAT40
Spindle speed	6000rpm
FEED	
Rapid on X,Y&Z axis	10000mm/min
MOTOR	
Spindle motor	7.5HP
AC servo motor	1KW
GENERAL	
power required	12KVA
Net weight	2600kg
Gross weight	3000kg
Measurement(LxWxH)	2100*2260*2520mm

Table (3) Material properties of Aluminum alloy

Tensile Strength, Yield (MPa)	68.9 - 520
Modulus of Elasticity (GPa)	70.0 - 115
Shear Modulus (GPa)	26.0 - 28.0
Melting Point (°C)	502 - 670
Poisson Ratio	0.300 - 0.340
Density (g/cc)	2.58 - 2.88
Machinability (%)	30.0 - 90.0

Table (4) Chemical composition (wt. %) of Aluminum alloy

Element	Si%	Fe%	Cu %	Mn %	Mg %	Cr%	Ni%	Zn %	Ti%	Pb %	Sn %	Al %
Wt %	0.308	0.413	4.54	0.606	1.24	0.0098	0.046	0.070	0.040	0.008	0.004	92.7

Table (5) Portable Surface Roughness Gauge (Pocket Surf)

Pocket Surf	Specification
Dimensions	140 mm x 76 mm x 25 mm
Weight	435 g
Measuring Ranges	0.03 µm to 6.35 µm
Display Resolution	0.01 µm
Measurement Accuracy	Meets ASME-B46.1, ISO, DIN standards and MIL specifications
Digital Readout	LCD with, "Battery low" signal; "H" and "L' (measured values out-of-range)
Traverse Speed	5.08mm per second
Cutoff	0.8mm ASME 2 RC-filter
Probe Type	Piezoelectric
Maximum Stylus Force	15.0 mN
Power	Consumer-type alkaline battery, 9 Volt
Battery Capacity	Approx. 2500 measurements, depending on frequency of use and output option
Operating Temperature	10° to 45°C
Storage Temperature	-20° to 65°C

Table (6) Model Summary of analysis by SPSS

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.966a	.932	.881	.15136	.932	18.332	6	8	.000

a. Predictors: (Constant), T2, Vc2, F2, T, F, Vc

b. Dependent Variable: Ra

Table (7) Coefficient of analysis

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.397	.467		.851	.419
Vc	-.009	.005	-1.497	-1.868	.099
F	.002	.002	.348	.888	.400
T	3.423	.839	2.214	4.079	.004
A	2.248E-5	.000	1.619	2.008	.080
B	-1.351E-6	.000	-.181	-.439	.673
C	-1.822	.766	-1.244	-2.379	.045

Table (8) Casewise Diagnostics

Case Number	Std. Residual	Ra (μm)	Predicted Value (μm)	Residual
1	-.398	.42	.4769	-.06028
2	.054	.36	.3484	.00820
3	.500	.34	.2643	.07568
4	.498	.30	.2246	.07540
5	.055	.26	.2482	.00837
6	-2.438	.22	.5889	-.36894
7	.912	1.16	1.0186	.13802
8	.362	1.30	1.2452	.05483
9	-.313	1.39	1.4407	-.04735
10	.031	1.45	1.4486	.00466
11	-.060	.32	.3257	-.00913
12	.473	.53	.4550	.07161
13	.326	.61	.5572	.04937
14	.006	.63	.6324	.00086
15	-.009	.69	.6946	-.00129

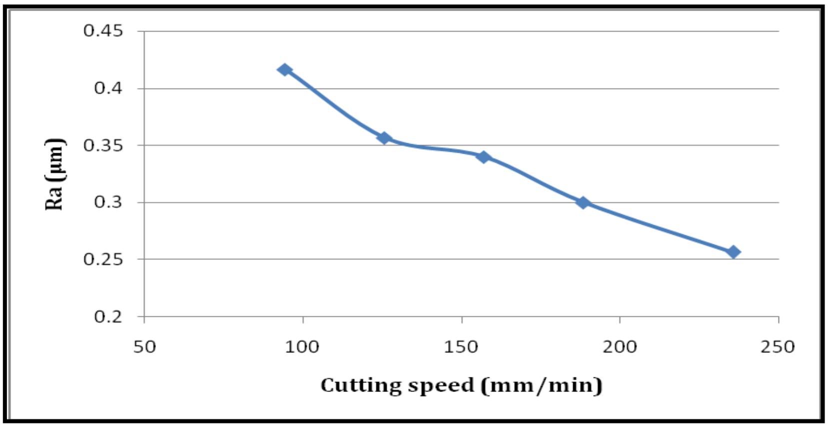


Figure (5) Effect of cutting speed on surface roughness.

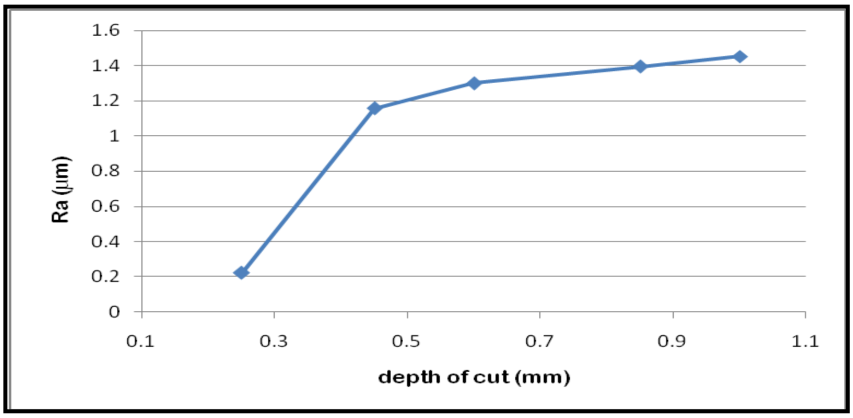


Figure (6) Effect of depth of cut on surface roughness.

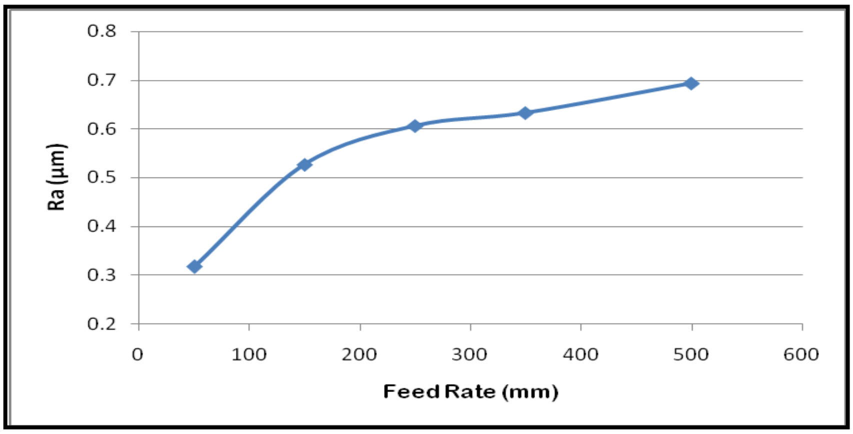


Figure (7) Effect of feed rate on surface roughness

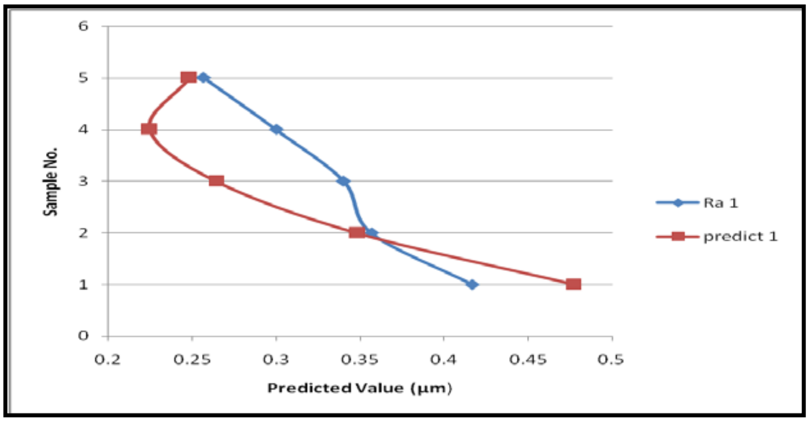


Figure (8) Relationship between real and predicted values at first stage of experiments.

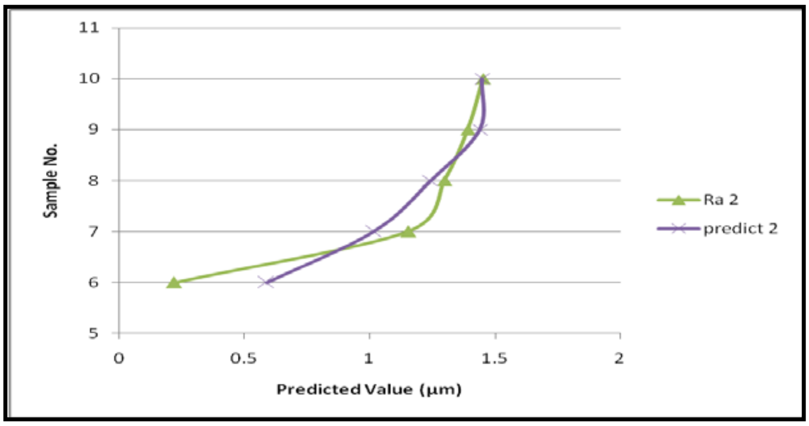


Figure (9) Relationship between real and predicted values at second stage of experiment.

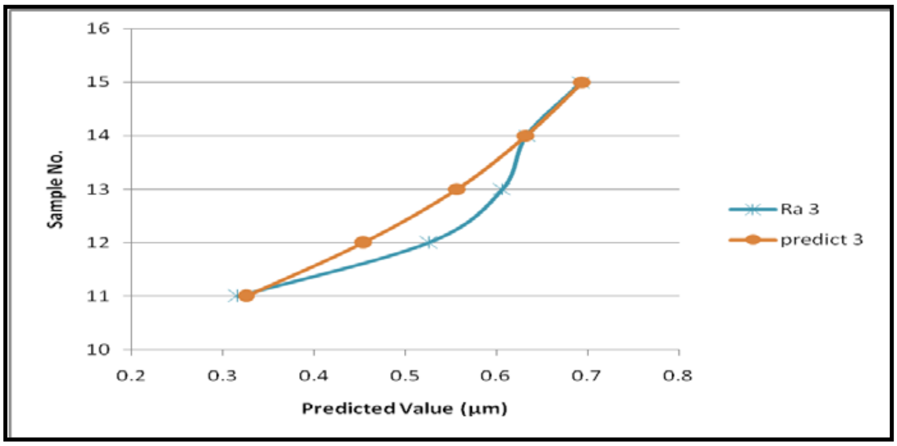


Figure (10) Relationship between real and predicted values at third stage of experiments.

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