TAGUCHI METHOD TO OPTIMIZE MACHINING CONDITIONS AFFECTING CEMENTED CARBIDE TOOL'S WEAR LIFE IN TURNING AISI 1020 STEEL

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ABSTRACT:

The present work studied the performance of a carbide tool with a chemical composition of (65% W, 14 % Ti, 9 % Co and 12 % C). Turning tests were conducted on a workpiece of mild steel (AISI 1020) using four spindle speeds (80, 315, 500 and 800 rpm), two feed rates (0.2 and 0.5 mm/rev) and two depth of cut (0.5 and 0.7 mm). Taguchi method is a statistical approach to optimize the process parameters and improve the quality of components that are manufactured. The objective of this study is using Taguchi method to optimize the machining conditions of a turning operation such as spindle speed; feed rate and depth of cut. Orthogonal array, signal-to-noise ratio, and analysis of variance were employed using Mtb14 software to study the performance characteristics on turning operation represented by the tool life. Accordingly, a suitable mixed orthogonal array L16 (3×4) was selected. The tool life was measured basing on a maximum flank wear width of 0.3 mm.Optimum parameter values were obtained and confirmation experiments were carried out. The analysis results showed that the parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for optimizing the process parameters. Only 6.4 % error was recorded. The regression analysis was applied using Datafit ver.9 software. The results of the analysis showed that the non-linear quadratic polynomial appears to be more suitable to represent the relation of the spindle speed, feed rate and depth of cut with the tool's wear life. .

Key words: Tool life, Machining parameters, Taguchi method, Flank wear, Optimization, Modeling.

طريقة تاكوجي لأمثلية طرق التشغيل المؤثرة على عمر البلى للعدد الكاربيدية المسمنتة في خراطة الفولاذ(AISI 1020)

الخلاصة:

العمل الحالي يدرس أداء العدة الكاربيدية ذو تركيب كيميائي يتضمن (65% W, 14 %Ti, 9 % Co and 12 % C) . اختبارات الخراطة قد اجريت على مشغولة من فولاذ مطيلي (AISI 1020) باستعمال اربعة سرع دورانية (80, 315, 500, 800) دورة/دقيقة , قيميتين لمعدل التغذية (0.2 and 0.5) ملم/دورة , وقيمتين

لعمق القطع (0.5 and 0.7) ملم .طريقة تاكوجي هي منهج إحصائي لتحسين محددات العملية وتحسين نوعية المركبات المصنعة. هدف هذه الدراسة هو توضيح الأجراء المستعمل في استخدام طريقة تاكوجي لتحسين ظروف التشغيل في عملية الخراطة مثل السرعة الدورانية, معدل التغذية وعمق القطع. المصفوفة المتعامدة , نسبة الأشارة الى الضوضاء وتحليل التباين قد تم استخدامها بأستعمال Mtb 14 لدراسة مميزات الاداة في عملية الخراطة متمثلة بعمر الاداة وفقاً لذلك , مصفوفة متعامدة مختلطة ومناسبة (4×3) L16 قد تم اختيارها. عمر العدة قد تم قياسه اعتمادا على عرض البلى الخلوصي الاقصى (0.3 mm) . الظروف المثلى قد تم الحصول عليها واختبارات التحقق قد تم تنفيذها . تحليل النتائج التجريبية اظهرت أن تصميم المعلمة بطريقة تاكوجي زودت طريقة بسيطة, منهجية وفعالة لجعل ظروف العملية مثالية. فقط % 6.4 نسبة خطأ قد سجلت. تحليل التراجع قد تم اضافته باستعمال برنامج داتافت النسخة التاسعة . نتائج هذا التحليل اظهرت ان المتعدد الحدود من الدرجة الثانية غير الخطي هو اكثر ملائمة لتمثيل العلاقة بين السرعة الدورانية , معدل التغذية وعمق القطع مع عمر الأداة. .

1. INTRODUCTION:

The tool is an important part required in material removal process in order to produce the components. It not only provides product but also maintains the geometricaltolerances, dimensional accuracies and surface finish of the outcome. The manufacturing industry is striving to improve the productivity, quality and longer tool life. Achievement of longer tool life depends on different factors such as cutting parameters, tool wear, hardness of the work piece and machine tool materials [1,2]. Many improvements can be done to obtain longer tool life duration like changing the tool material, tool geometry, tool edge honing, optimizing machining conditions, using coolants and applying thin layer coating. Tool wear influences cutting power, machining quality, tool life and machining cost. Whentool wear reaches a certain value, variation in cutting force and cutting temperature will causesurface integrity deteriorated and dimension error greater than tolerance. When machining steel with uncoated carbide tools, different tool wear mechanisms occur, such as: abrasion, adhesion, oxidation and even some diffusion, which act simultaneously and mainly depending on the temperature [3,4]. Bala Murugan Gopalsamy et al. in 2009 [5] applied Taguchi method and analysis of variance ANOVA for machining parameters optimization during machining hardened steel. ANOVA, signal-to-noise ratio, and L18 array had been used to study the performance characteristics of the machining conditions (feed rate, cutting speed and depth of cut) with consideration of tool life and surface roughness. S.R. Das et al. in 2014 [6] experimentally investigated the effects of the machining conditions on the behaviour characteristics (surface roughness, cutting force and flank wear) by using multi layer coated carbide insert in hard turning of AISI 4340 steel. Taguchi standard has been used to develop the regression models for machining response. Results showed that, the most significant factor on flank wear is the cutting speed and that the feed rate has statistical significance on the surface roughness.

The objective of the present work is studying the optimization process of the machining conditions that affecting the tool wear. Basing on the analyses of multiple regression method, mathematical predictive model was designed and validated to select an optimum combination of the studied parameters.Taguchi design is successfully used for optimizing the cutting conditions that affecting tool life. To achieve the analysis of the present work, Datafit ver9 and Mtb14 softwares had been employed.

2. EXPERIMENTAL PROCEDURE :

2.1. MATERIALS USED :

2.1.1. CARBIDE TOOL (TIP):

Carbide tips type P10 with a chemical composition of (65% W, 14 % Ti, 9 % Co and 12 % C) were used in this investigation. The tip has a tool angle of 60^o and a nose radius of 1.6 mm.

2..1.2. WORKPIECE MATERIAL :

The machining experiments were performed using cylindrical work-piece of AISI 1020 steel with a chemical composition demonstrated in **Table (1)**. The tests were carried out for a length of (210 mm) and (40 mm) diameter. This kind of steel is the most common form of steel because it's price is somewhat low while it offers material characteristic that are tolerable for many applications.

2.2. DESCRIPTION OF TURNING PROCESS:

In this work, external longitudinal turning operation was used for machining experiments. The 210 mm length and 40 mm diameter low carbon steel bar was divided into working regions of 50mm length as shown in **Fig.(1)**. For all machining experiments, dry cutting condition was used. Four spindle speed (80, 315, 500, and 800 rpm) for each of which two feed rates 0.2 and 0.5 mm/rev and two values for the depth of cut (0.5 and 0.7 mm) were used. The inserts used were rigidly mounted on a tool holder type (**TAK Holder**).

2.3. TESTS (MATERIAL TESTING) OR FLANK WEAR :

A maximum width of 300 µm for the flank wear was considered as a criterion for the tool life. The width of the flank wear was measured every one minute of machining. Optical microscope type (Electron Eyepiece, model YJEYE01, resolution of 1280(H)*1024(V), China) integrated with CCD camera was used to capture the image of worn tools and to measure the flank wear width.

3. RESULTS AND DISCUSSION:

Table (2) demonstrate the results of the machining experiments according to the used machining program. **Figure (2)** represent examples for the method used in estimating the tool life. These figures shows the typical behavior of the flank wear width (**VB**) with the machining time. An accelerated increase of **VB** can be noticed with the machining process at the first stage of cutting, then a constant rate of this increase at the second stage, after which a very rapid increase at the third stage that will continue till premature failure of the tool. The figures also indicate that a higher cutting speed causes a higher value of **VB**. This is due to the increase in cutting temperature accompanying with the increase in cutting speed and this causes increase in adhesion wear on tool cutting edge, also the increase in temperature may soften a very thin surface layer of the tool cutting edge. In addition to that a higher cutting speed means a higher repeated contact between the machined surface and the flank surface which increases the scratching action of machined material (i.e. the abrasive wear). **Figure (3)** shows examples of the wear occurred at the flank surface of the tool during.

Both fundamental and empirical approaches can be used to establish models or equations for quantitatively predicting the cutting performance such as tool life and surface roughness. In the case of the empirical approach, the machining characteristic values which experimentally measured (tool life) are related to the cutting conditions by regression analysis. Several forms of mathematical models, as linear, exponential, power function, and non- linear quadratic polynomial were used to exam the approach. .

4. DEVELOPMENT OF MATHEMATICAL PREDICTIVE MODEL:

Mathematical predictive models for the tool life had been developed in forms shown in **Table (3)**. Such models were constructed basing on the statistical data of the carried out machining experiments. Data fit ver.9 software was used for constructing these models basing on multiple regression analyses. The value of the coefficient of multiple determination (R^2) for the non-linear quadratic polynomial is highest rank among all forms of other models. Hence, this model is selected to predict value of tool life. So the final mathematical predictive model developed will be:

$$T=2.3931+5.5524X_1+13.4310X_2+13.3856X_3+8.6831X_1^2+10.9889X_2^2+6.6217X_3^2+7.2496X_1X_2$$

$$+10.3714X_2X_3 \; +4.0852X_1X_3+8.7428X_1X_2X_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (1)$$

Where: T = Tool life (min.); X_1= Spindle speed (rpm); X_2= Feed rate (mm/rev.), and X_3= depth of cut (mm).

Fig.(4) shows the matching between the experimental values of the tool life and their predicted values due to the designed models. The figure indicates their close matching.

5.TAGUCHI APPROACH :

5.1. Selection of control factors and noise factors:

Cutting speed, feed rate, and depth of cut have a significant influence on tool life in the turning operations, so they were considered as the controllable factors in this study, while tool life as response factor as shown in **Table (4)**. Design of experiments via Taguchi method and L16 (3×4) mixed orthogonal array is utilized for the parametric design [7,8,9]. To obtain optimal cutting conditions, the larger-the-better is used as S/N ratio of quality characteristic. This expressed as [10]:

$$\eta = S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \qquad \mathbf{i= 1, 2, \ldots n} \quad \ldots\ldots\ldots\ldots\ldots \; \mathbf{(2)}$$

Where: η = signal to noise ratio (S/N), y_i = observed value of the response, n = number of observation in a trial.

Table (5) shows the experimental results and the corresponding S/N for tool life. **Table (6)** shows the response values for signal- to-noise ratios and the response values formeans for tool life. **Figure (5)** shows the results of Taguchi design analysis (main effect plot for Means and main effect plots for S/N ratio) for tool life. Also, Taguchi orthogonal array is demonstrated in **Table (5)**. **Figure (5)** indicate that the optimal machining conditions representing the conditions at which the tool life will be maximum are: spindle speed, Vc =315 rpm, feed rate, f= 0.4 mm/rev, and depth of cut, t= 0.6 mm.

5.2. Analysis of Variance ANOVA:

Determining which machining parameter significantly affect the quality characteristic (tool life) is the main purpose of ANOVA. This can be done by separating the total mean S/N ratio from the total variability of the S/N ratios which is determined by sum of square deviations. First, the total mean S/N ratio η_m from the total sum of squared deviations SS_T can be calculated as :

$$SS_T = \sum_{i=1}^{n}(\eta_i - \eta_m)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where η_i is the mean S/N ratio for the i^{th} experiment and n is the number of experiment in the orthogonal array. **Table (7)** shows the ANOVA (with 95% confidence level) and F-test values with the P- value which reflects effectiveness of the individual studied parameters on the tool life. The table indicates that the feed rate is the most significant parameter for maximum tool life.

5.3. Predicting optimum performance :

The optimum tool life can be predicted by using the designed model (eq. 2) based on the determined optimum cutting conditions (*i*.e. at V_c = 315 rpm, f = 0.4 mm/rev., and t = 0.6 mm) at which the tool life equals to 7.8 min.

5.4. Confirmation of The Optimum Results:

The purpose of the confirmation experiment in this study was to validate the optimum cutting conditions. The predicted tool life was calculated basing on the optimum machining conditions resulted by Taguchi analysis. Also basing on these machining conditions, experimental values for tool life were measured. **Table (8)** shows the comparison of the actual tool life with the predicted tool life using optimal cutting parameters for the used inserts with an error percentage of 6.4 % for tool life.

6. CONCLUSIONS:

In this study, the Taguchi method was used to predict the most turning conditions of the AISI 1020 steel affecting the cemented carbide tool life, according to the results obtained, the following points can be concluded:

1-The Taguchi method is a robust orthogonal array design method, suitable for analysis of the tool machining parameters have an effect on the tool life. Among these parameters feed rate has the largest effect on the tool life.

2- Multiple regression analysis can be applied to develop a mathematical model for tool life prediction. The models developed are found to be reliable. An assessment of turning of AISI 1020 steel can be achieved by the designed empirical model for selecting the appropriate machining conditions for a required carbide tool life.

3- An optimum machining combination of AISI 1020 steel for maximum tool life is spindle speed of 315 rpm, feed rate of 0.4 mm/rev., and depth of cut of 0.6 mm.

Table (1): Chemical composition of the workpiece material (wt %).

C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu	Fe
0.156	0.0048	0.386	0.0181	0.0200	0.0248	0.0051	0.0176	0.0077	0.0157	0.0139	99.3 (Balance)

Table (2) : Results of machining experiment for the used tool.

Spindle speed (rpm)	Feed rate (mm/rev)	DOC (mm)	Width of flank wear VB (micron)				Predicted tool life (min)	Measured tool life (min)
			1 min	2min	3min	4min		
80	0.2	0.5	123.789	157.041	210.523	295.786	3.9	3.6
	0.2	0.7	143.514	165.021	220.545	295.814	5.1	4
	0.5	0.5	159.389	198.015	247.525	318.442	4.3	3.8
	0.5	0.7	165.439	197.010	250.621	325.436	4.9	3.8
315	0.2	0.5	148.111	180.314	255.349	300.026	3.4	3
	0.2	0.7	151.810	190.658	264.985	303.850	4.6	3.9
	0.5	0.5	161.697	253.870	307.143	330.651	3.5	2.7
	0.5	0.7	171.580	264.331	315.954	325.521	3.2	2.9
500	0.2	0.5	180.507	258.751	265.842	315.698	3.8	2.4
	0.2	0.7	192.000	255.670	321.821	323.010	3.3	2.8
	0.5	0.5	191.001	274.718	320.432	397.102	2.9	2.2
	0.5	0.7	188.451	280.745	330.002	390.565	2.7	2.2
800	0.2	0.5	202.809	276.222	316.152	401.230	2.5	1.9
	0.2	0.7	214.274	285.450	380.360	411.529	3.7	2.1
	0.5	0.5	260.112	308.804	397.669	440.054	2.1	1.4
	0.5	0.7	257.640	320.111	395.325	461.767	1.9	1.5

Table (3) : Predictive models for the tool life.

No.	Form of the Model	Model Definition	R^2
1	Three Parameter Polynomial	$Y = a.X_1+b.X_2+c.X_3$	0.41
2	Four Parameter Polynomial	$Y = a.X_1+b.X_2+c.X_3+d$	0.53
3	Four Parameter Exp. Polynomial	$Y = \exp(a.X_1+b.X_2+c.X_3+d)$	0.55
4	Power Function	$Y = a.X_1^b.X_2^c.X_3^d$	0.41
5	Non-linear Quadratic Polynomial	$Y = a+b.X_1+c.X_2+d.X_3+e.X_1^2+f.X_2^2+g.X_3^2+h.X_1.X_2+i.X_1.X_3+j.X_2.X_3+k.X_1.X_2.X_3$	0.96

*Y = Tool life; a, b, c, d, e, f, g, h, i, j, and k are constants.

Table (4) :Parameters and Levels for Experimental Design.

Parameter	Symbol	Unit	Level 1	Level 2	Level 3	Level 4
Spindle speed	X_1	rpm	80	315	500	800
Feed rate	X_2	mm/rev	0.2	0.3	0.4	0.5
Depth of cut	X_3	mm	0.5	0.6	0.7	0.8

Table (5): Experimental results and the corresponding S/N for tool life.

.No.	Vc (rpm)	f (mm/rev)	t (mm)	T (min)	S/N ratio
1	1	1	1	3.6	11.1261
2	1	2	2	4	12.0412
3	1	3	3	3.8	17.9525
4	1	4	4	3.8	11.5957
5	2	1	2	3	9.5424
6	2	2	1	3.9	11.8213
7	2	3	4	2.7	8.6273
8	2	4	3	2.9	11.1261
9	3	1	3	2.4	12.0412
10	3	2	4	2.8	15.563
11	3	3	1	2.2	19.0849
12	3	4	2	2.2	13.9794
13	4	1	4	1.9	13.0643
14	4	2	3	2.1	13.9794
15	4	3	2	1.4	13.2552
16	4	4	1	1.5	18.0618

Table (6) : Response values for signal- to-noise ratios and the response values for means.

Response values for Signal to Noise Ratios (Larger is better)				**Response Values for Means**			
Level	Vc	F	t	Level	Vc	F	t
1	13.90	11.57	11.72	1	5.325	4.038	4.506
2	14.65	15.49	15.63	2	5.831	6.300	6.288
3	14.01	16.39	12.98	3	5.613	6.900	5.138
4	12.58	11.69	14.81	4	4.919	4.450	5.756
Delta	2.07	4.82	3.92	Delta	0.912	2.863	1.781
Rank	3	1	2	Rank	3	1	2

Table (7) : One way ANOVA results.

T versus V_c						T versus f						T versus t					
Source	**DF**	**SS**	**MS**	**F**	**P**	**Source**	**DF**	**SS**	**MS**	**F**	**P**	**Source**	**DF**	**SS**	**MS**	**F**	**P**
V_c	3	7.46	2.49	0.46	0.709	**f**	3	93.07	31.02	7.88	0.00	**t**	3	28.49	9.50	1.89	0.140
Error	12	321.89	5.36			**Error**	12	236.28	3.94			**Error**	12	300.86	5.01		
Total	15	329.35				**Total**	15	329.35				**Total**	15	329.35			

*DF – Degree of freedom, SS : Sum of Squares, Ms : Mean Square, P: probability.

Table (8) : Confirmation test results for the used insert.

Performance	Predicted	Experimental	Error%
Tool life (min)	7.8	7.3	6.4

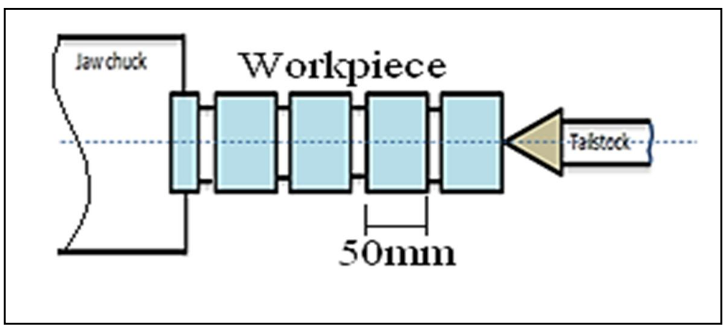
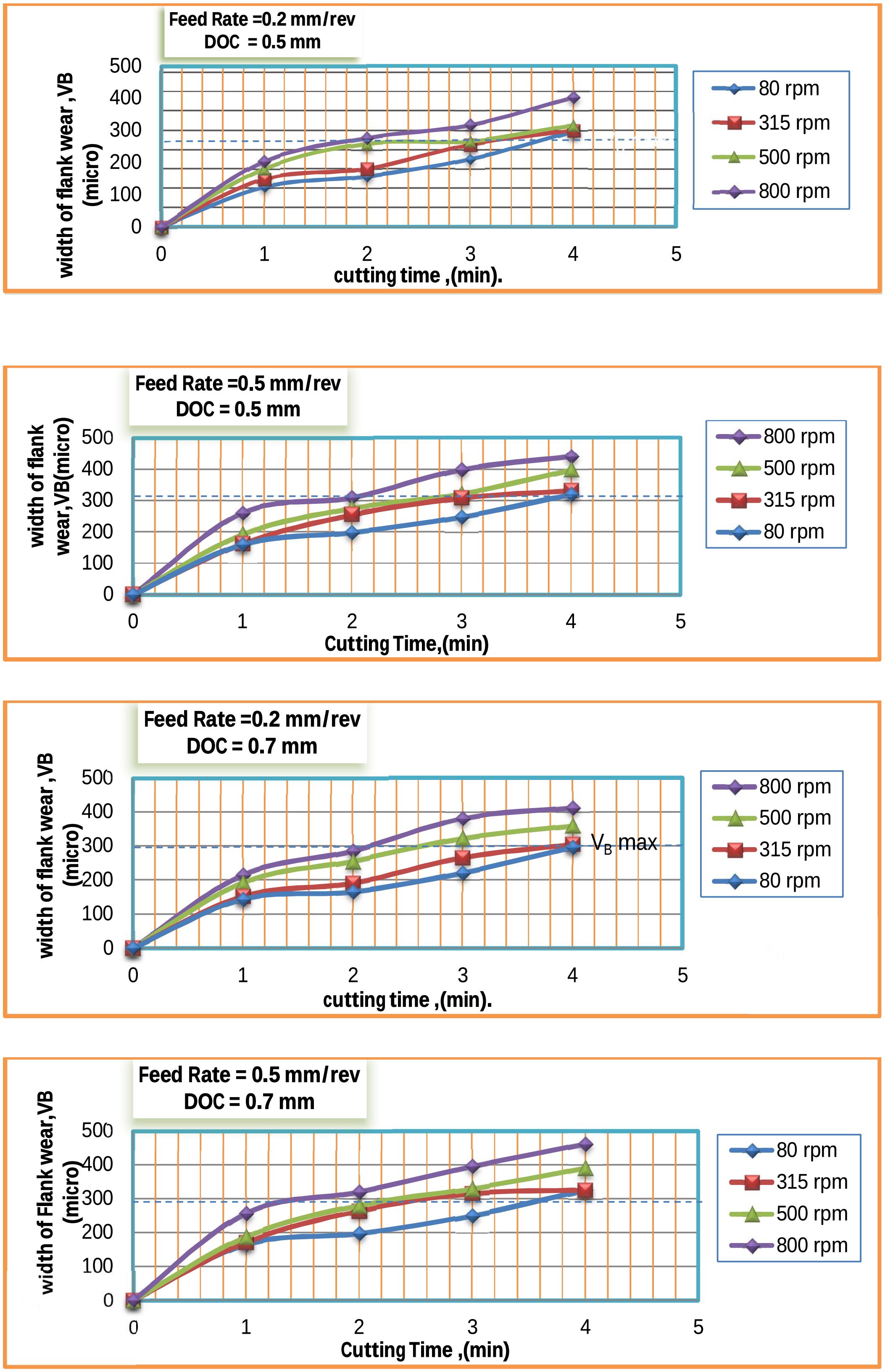
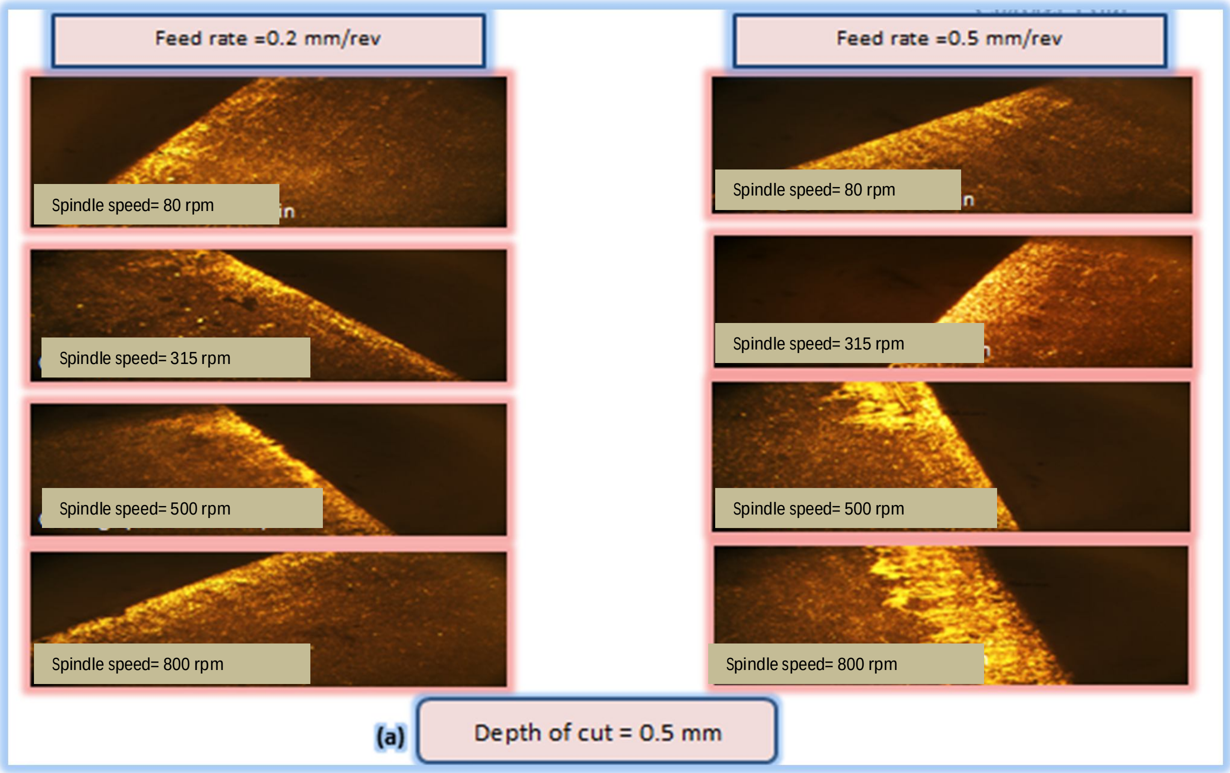


Figure (1) : Workpiece regions.



Figure(2): Estimation of the tool life.



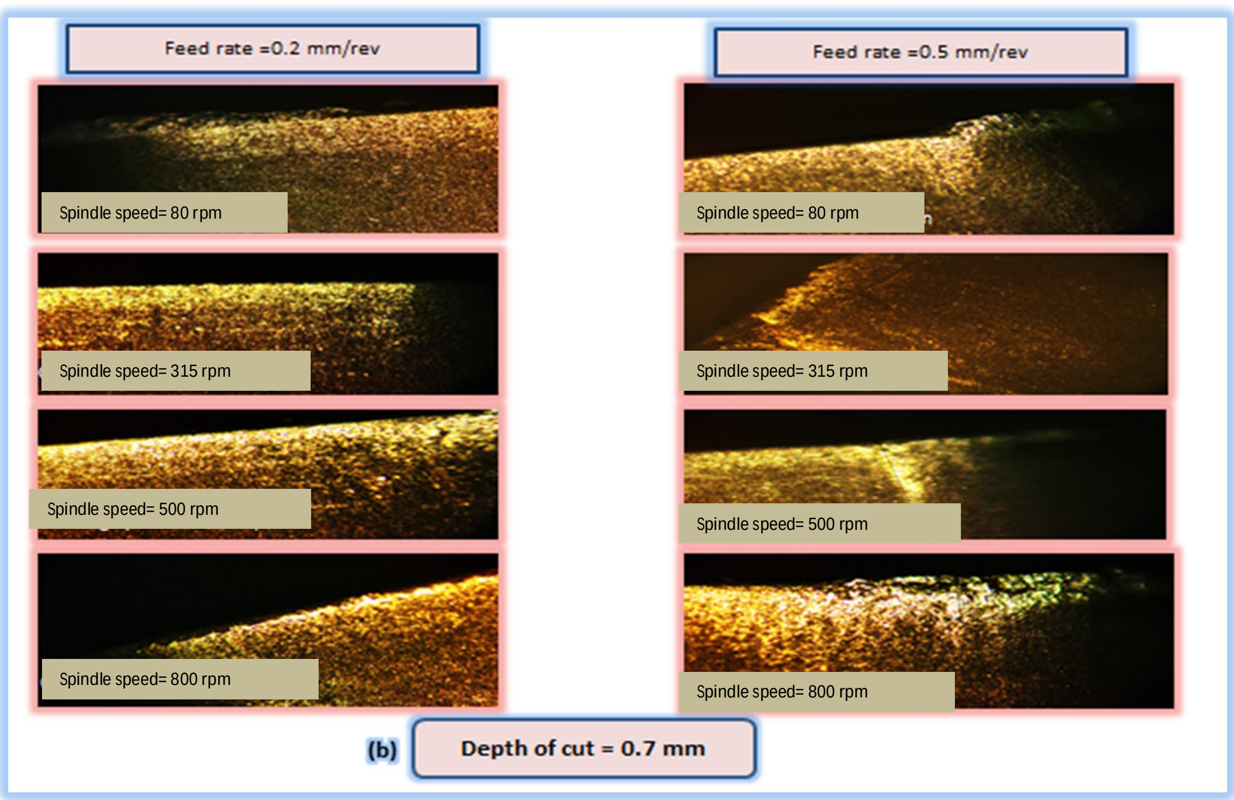


Figure (3) : The flank wear of the tools during the machining process.

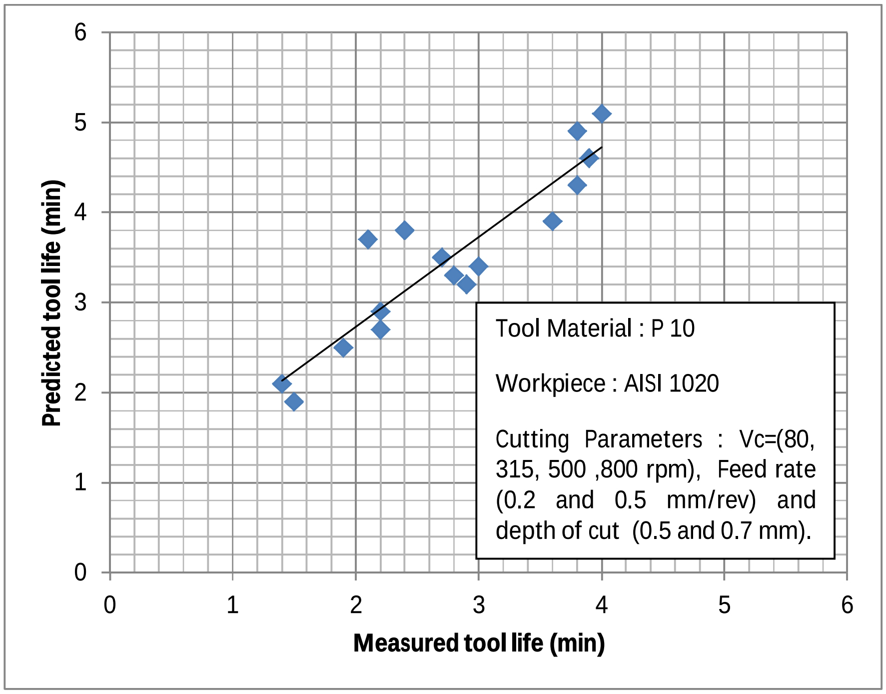


Fig.(4): Scatter plot of the experimental and predicted values of tool life.

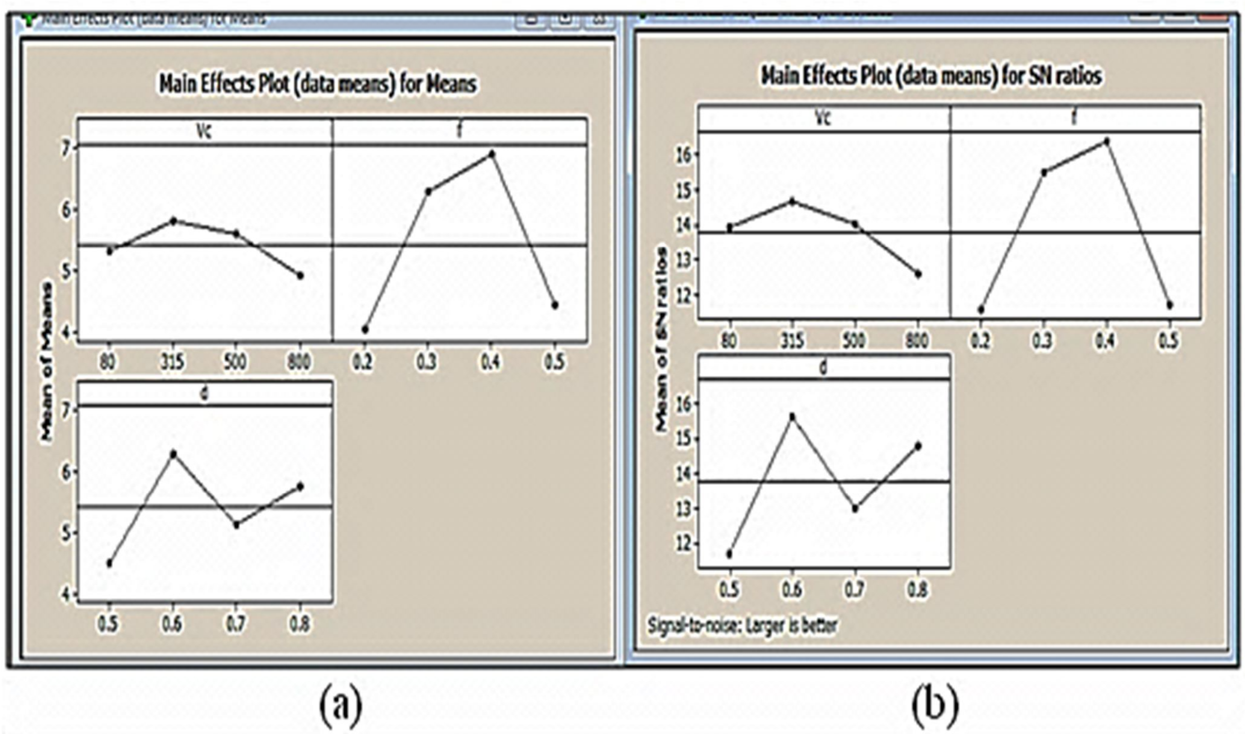


Fig.(5): Results of Taguchi design analysis: (a) main effect plot for Means; (b)main effect plots for S/N ratio for tool life.

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