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Optimization of Machining Parameters for MRR and Surface Roughness for 7024 AL-alloy in Pocket Milling Process

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Abstract— The objective of this work is to investigate the affecting variables of milling process to optimize surface roughness and material removal rate during machining of 7024 Al-alloy. The machining operation is implemented on C-TEK CNC milling machine. The effects of the selected parameters on the chosen characteristics have been accomplished using Taguchi's parameter design approach; also ANOVA is used to evaluate the contribution of each parameter on the process outputs. Different feed rates are studied ranging from (60, 80 and 100) mm/min. It is found that high feed rates give a high material removal rates and good surface roughness. On the other hand, it is found that a higher spindle speeds gives better surface roughness with a little effect on material removal rate MRR. The process results showed that maximum MRR achieved (2.40) mm3/min when machining feed rate (100) mm/min, spindle speed (1000) r.p.m, and depth of cut (0.6) mm. While good surface roughness (0.41 µm) is obtained when machining feed rate was (100) mm/min, spindle speed (1000) r.p.m, and depth of cut (0.2) mm. The level of importance of the machining parameters for material removal rate and surface roughness is determined by using Taguchi designing experiments and the variance analysis (ANOVA).

Keywords— Taguchi method, MRR, Surface roughness, ANOVA, Pocket mill.

1. Introduction

Pocket milling operation is one of the most widely used processes in machining. It is vastly used in shipyard industries and aerospace. In pocket milling the material inside of a closed bounded area on a plane surface of a workpiece is machined to a constant deepness. In general flat- end mills utilized in pocket milling. Roughing is the first operation done for removing bulk of material and after it a finishing process is done to the pocket by finishing end-mills. Most of these operations in pocket milling can be machined by three axis CNC milling machines. That kind of paths control could machine up to 80% of whole mechanical parts. The efficiency of this milling type is so relevant, therefore the pocket milling approach can reduce machining cost and time [1]. NC pocket milling could be preceded by two types of tool path strategies, linear and non-linear paths. In the linear tool paths strategy, the cutter motion is unidirectional. The linear tool path includes zig and zig-zag tool path strategies, where in zig-zag paths, material is machined back and forth, removing materials done in the two directions with and against spindle rotation, which minimize the time of machining but raises the tools wear. On the other hand the zig tool path is in one direction, the cutter must be lifted and withdrawn after each cutting round, that increases machining time, but using the zig strategy gives better surface quality [2]. Many variables affecting surface roughness and quality of machined parts through CNC pocket milling, namely feed rate, spindle speeds, depth of cutting and the fixed cycle structure. The surface roughness plays an effective role on the desired tolerance and fit for assembling the manufacturing parts [3].

Noor et al (2008) [4] investigated the optimization of the surface roughness when milling mold aluminum alloys (A6061-T6) with carbide coated inserts. The approach is based on Response Surface Method (RSM) and Radian Basis Function Network (RBFN). Their objectives are to find the optimized parameters, and to find out the most dominant variables (cutting speed, feed rate, axial depth and radial depth). The optimized value has been used to develop a blow mold. The first order model and RBFN indicates that the feed rate is the most significant factors affecting surface roughness.

Abdullah and Karagoz (2012) [5] investigated the effect of milling variables that relevant to surface roughness of the pocket milling MDF illustrated on CNC machines. They investigated the effect of the feed rate, spindle speed, depth of cut and step-over on the surface roughness on MDF panel. The evaluated result shows that surface roughness decreases with increases of the spindle speeds values. While increases in the feed rates, depth of cuts and step-over coincide with an increase in the surface roughness.

Jatin and Sharma (2013) [6] investigated the effect of a various cutting variables (feed rate, cutting speeds depth of cuts) in end mills on the surface roughness. The calculations are done by utilizing Taguchi designing method. L-9 standard orthogonal array utilized for the calculations of factors number and the levels number. In addition to the S/N Ratio, also ANOVA have illustrated to clarify the Impact of variables through the result studied milling process for hardened die steel H-13, using flat-end cutter with four flue of solid carbide for finishing process. The results show that surface roughness decreases at the increasing of cutting speeds.

The objective of the proposed work is the investigation of milling process variables which check the optimal values of the surface roughness and material removal rate during machining of Al-alloy to improve the manufactured products.

2. Taguchi Experimental Design Method

The method is depending on that the machined parts quality must be computed by the deviation amount from the required value [7]. This technique is depending on two groups; a unique kind of matrix called "orthogonal array (OA)", the columns include a number of tests depending on the no. of levels of controlling parameters, and (S/N) the signals to noise ratio [8]. The expression 'signal' indicating to the required value (mean) of the output characteristics, and the expression 'noise' indicating to the unrequired value. The calculation of S/N ratios is varying according to objectives functions, i.e., a characteristics amount. [9].

Designing the method using MINITAB16 program as follow:

STAT ⟶ DOE ⟶ Taguchi

3. Variance Analysis

The experimental results could be investigated by (ANOVA) variance analysis to discover the effecting of machining variables on surface roughness material removal rate that dependent on machining variables feed rates, spindle speeds and depth of cut, while others is independent variables. In the analysis, the ratio between mean square errors and residual called F- ratio and it is utilized for determining the importance of each parameter. F ratio correspondent to 95% reliable levels in calculations of the operation variables exactly is F 0.05, 2, 26=3.369. P values report the importance levels (appropriate and inappropriate) [10].

4. Experimental Work:

The experiments have been conducted on 3-axis CNC milling machine which is available in training and workshop Center University of technology in Iraq. This operation needs some accessories and experimental setup, the main elements that must be used in the milling machine can be divided into the following elements :

4.1 *CNC Milling Machine:*

Figure 1 shows the C-TEK CNC milling machine model KM80D, which was used in the machining process of the samples which machined in the present work.

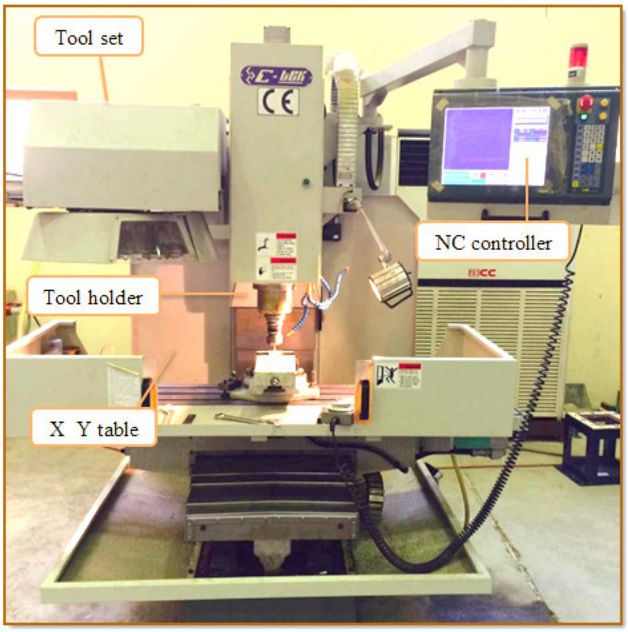

Figure 1: CNC C-TEK milling machine.

4.2 *Cutting Tool:*

Flat-end milling tools (Ø 10 mm) dia., with four flutes and flute length equal to (40 mm) of High-Speed Steel (HSS) utilized for each milling phases, roughing and finishing as shown in Fig (2).

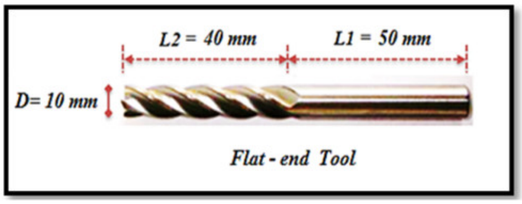

Figure 2: Cutting tool dimensions.

4.3 *Work Piece*

Al-7024 alloy work piece is chosen to be milled. Table (1) shows the chemical composing of the work piece shown in, which is tested in the "Central Organization for Standardization and Quality Controls". In addition to the standard composition of Al-7024 alloy.

Table 1: Chemical compositions of Al -7024.

Tested composition						
Si%	**Fe%**	**Cu%**	**Mn%**	**Mg%**	**Cr%**	**Ni%**
0.16	0.42	2.14	0.21	1.55	0.090	0.012
Zn %	**Ti%**	**Ga%**	**V%**	**Pb%**	**Other%**	**AL %**
4.93	0.038	0.010	0.007	0.071	0.132	90.21
Standard composition						
Si%	**Fe%**	**Cu%**	**Mn%**	**Mg%**	**Cr%**	**Ni%**
0.30	0.4	0.10	0.1-0.6	0.5-0.1	0.05-0.35	--
Zn %	**Ti%**	**Ga%**	**V%**	**Pb%**	**Other%**	**AL %**
3 - 5	0.10	--	--	--	0.15	Rem

The work piece dimension (50 x 50) mm and thick (40) mm. Figure (3) clarify the modeling of the required part.

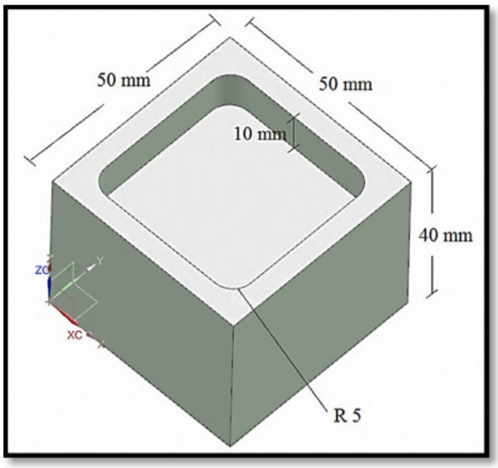

Figure 3: Pocket part.

4.4 *Implementation the machining process*

The milling process is done in two processes; rough machining and finishing, removing materials take place on a rapid way as much as possible in rough machining. In this process, a higher material removal rate is used for minimizing the process time. Rough machining in most cases is illustrated in parallel levels of layers accessing to the exact depths. The quality of the final surfaces is not reliable, where that layers are removed by subsequent process (finishing process), the value of step over (side step) of tool paths in roughing will be higher than its value in finishing, which is approximately equal to five times of finishing step over value. Figure (4) shows the samples during machining.

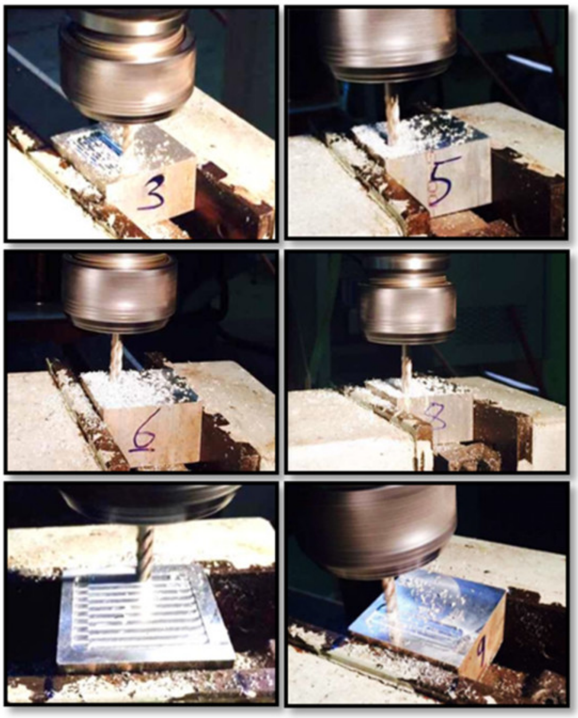

Figure 4: Samples during machining.

4.5 *Design of Experiments*

The designing of experimental tests using Taguchi approach had a great influence on the required experimental tests numbers. Accordingly, the experiments of machining required an appropriate design. The overall number of machining experimental tests is (9) experiments, on the basis of (3) levels and (3) variables. The material removal rate MRR and surface roughness value were obtained by full factorial design. The variables were spindle speed, feed rate, and depth of cut. The levels of cutting parameters are listed in Table (2).

Table 2: Cutting variables

No	**Parameter**	**Level 1**	**Level 2**	**Level 3**	**Units**
1	Spindle speed	800	1000	1200	*rpm*
2	Feed rate	60	80	100	*mm/min*
3	Depth of cut	0.2	0.4	0.6	*mm*

The final distributional division of the experimental tests and the level of each experiment are clarified in table (3) depending on the Taguchi experimental design method.

Table 3: Experimental design of work .

No.	Spindle speed (r.p.m)	Feed rate (mm/min)	Depth of cut (mm)
1	800	60	0.2
2	800	80	0.4
3	800	100	0.6
4	1000	60	0.4
5	1000	80	0.6
6	1000	100	0.2
7	1200	60	0.6
8	1200	80	0.2
9	1200	100	0.4

4.6 *Roughness Inspection*

Pocket-Surf device, the portable gauge of surface finish (Mahr Federals patented). The gauge is a pocket sized, which has a suitable economical price, integral portable device, provides a tracing for surface roughness measurement through widely surface types. This inspection device demonstrated in Fig.(5) is a solid structured, with a durable cast-aluminum harborage, to obtaine a long time accurately dependable surface roughness inspection.

Figure 5: Pocket-surf gauging instrument.

4.7 *MRR Calculations*

Metal removal rate could be determined as following [9]:

$$MRR = a_p * a_e * V_f / 1000 \quad (1)$$

where: (ap) depth of cut (mm), (ae) width of cut (mm), and (Vf) the feed rate velocity (mm/min).

5. Results and Discussions

5.1 *The influence of Feed rate and Spindle speeds on MRR:*

Fig.(6) clarifies the influence of feed rate and depth of cut on the MRR. Increasing the feed rates increases MRR, because high energy generated from the cutting process, increases the separation chipping rate from the materials. Also, the increasing in depth of cut increased the MRR, which gives a shorter time of machining by reducing the number of levels for the cuttings.

Table 4: Experimental work readings material removal rate

No.	Spindle speed (r.p.m)	Feed rate (mm/min)	Depth of cut (mm)	MRR mm^3/min
1	800	60	0.2	0.48
2	800	80	0.4	1.28
3	800	100	0.6	2.40
4	1000	60	0.4	0.96
5	1000	80	0.6	1.92
6	1000	100	0.2	0.80
7	1200	60	0.6	1.44
8	1200	80	0.2	0.64
9	1200	100	0.4	1.60

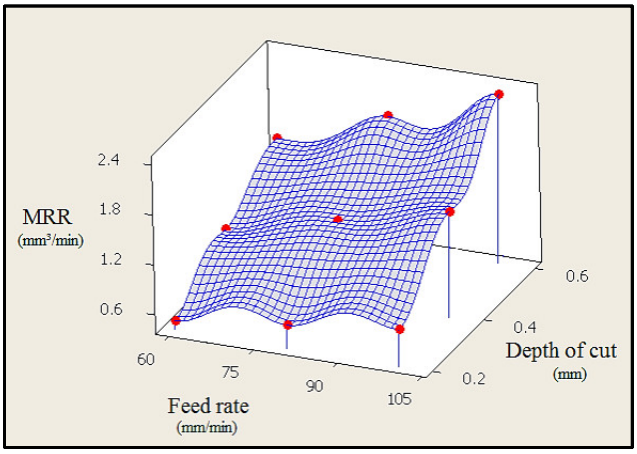

Figure 6: Surface plot of MRR vs. depth of cut and feed rate.

5.2 *Variance Analysis*

The experimental results are analyzed using analysis of variance (ANOVA) to determine the effect of machining parameters on MRR. MRR as the dependent variable, spindle speed, feed rate and depth of cut as independent variables .

The F ratio value of 48.19 the depth of cut is greater among the parameters (see Table 5). Therefore, the most influential parameter is depth of cut (77.42%) which is about four times of the feed rate (19.35%). The spindle speed has a small influence with 1.61%. In the analysis, F-ratio is a ratio of mean square error to residual, and is traditionally used to determine the significance of a factor.

5.3 *Optimal Design Conditions for MRR*

The main effects plot is used to determine the optimal design conditions to obtain the optimum MRR and hence select the better machining parameters using SPSS software package. Fig (7) shows the main effect plot for

MRR with the process inputs .This plot shows the variation of individual response with three parameters, i.e. spindle speed, feed rate and depth of cut separately. The results show the optimal conditions for maximum MRR were: spindle speed at level-1 (800 rpm), feed rate at level-3 (100 mm/min), and depth of cut at level-3 (0.6 mm).

Table 5: ANOVA for MRR

Source of variance	DOF	Sum of squares	Variance V	F ratio	P (%)
Spindle speed	2	0.051	0.0255	1	1.61
Feed rate	2	0.614	0.307	12.04	19.3
Depth of cut	2	2.458	1.229	48.19	77.4
Error ,e	2	0.051	0.0255		1.61
Total	8	3.174			100

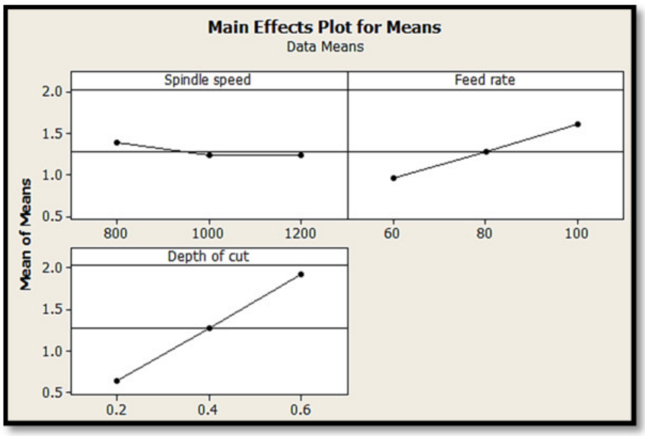

Figure 7: Effect mean plot for the MRR

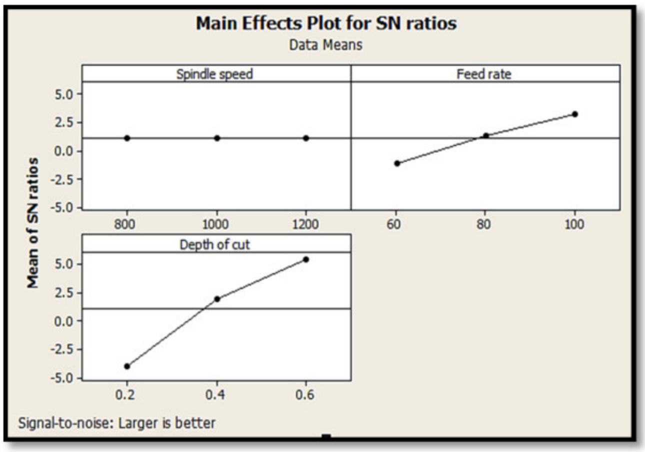

Figure 8: Single to noise ratio for MRR.

5.4 *Effect of Feed rate and Spindle speed on the Surface roughness*

Fig.(9) clarify the effecting of feed rates on surface roughness, from the figure, it can be seen, that the increase in feed rates leading to a decrease in surface roughness that gives a better quality for the machining surfaces, while increasing the spindle speed results higher Surface roughness. This causes a high rate of melting on high spindle speeds while the depth of cuts gives a little influence on surface finish as shown in table (6).

Table 6: Experimental work readings Surface roughness

NO	**Spindle speed** (rpm)	**Feed rate** mm/min	**Depth of cut** (mm)	**Ra 1** Exp.(1)	**Ra 2** Exp. (2)
1	800	60	0.2	1.27	1.73
2	800	80	0.4	1.19	1.02
3	800	100	0.6	0.69	0.82
4	1000	60	0.4	0.85	0.74
5	1000	80	0.6	0.62	1.06
6	1000	100	0.2	0.41	0.86
7	1200	60	0.6	2.09	2.51
8	1200	80	0.2	1.31	1.22
9	1200	100	0.4	1.37	1.04

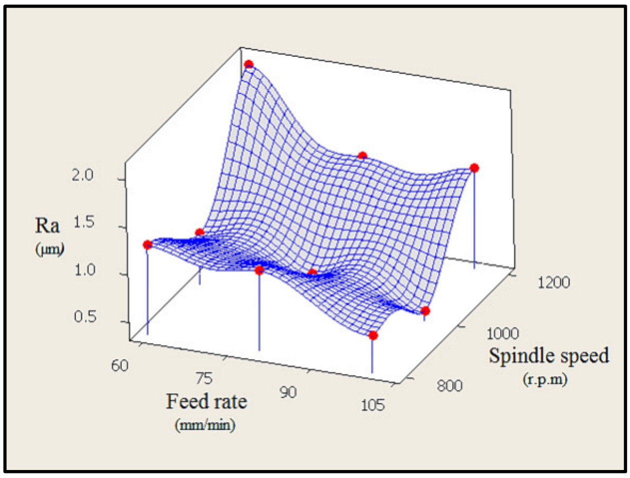

Figure 9: Effect of feed rate and spindle speed on surface roughness

5.5 *Variance Analysis*

The experimental results are analyzed using analysis of variance (ANOVA) to determine the effect of machining parameters on the surface roughness, spindle speed, feed rate and depth of cut are considered as independent variables .

The F ratio value of 11.856 for the spindle speed is reported as the greater among the parameters (see Table 7).Therefore, the most influential parameter is Spindle speed (67.57%) which is about three times of the feed rate (24.9 %). The depth of cut has a less influence with 1.85%.

In the analysis, F- ratio is a ratio of mean square error to residual, and is traditionally used to determine the significance of a factor".

Table 7: ANOVA for Ra

Source of variance	DOF	Sum of squares	Variance V	F ratio	P (%)
Spindle speed	2	1.399	0.6995	11.85	67.5
Feed rate	2	0.515	0.2575	4.364	24.9
Depth of cut	2	0.038	0.019	0.322	1.85
Error ,e	2	0.118	0.059		5.68
Total	8	2.07			100

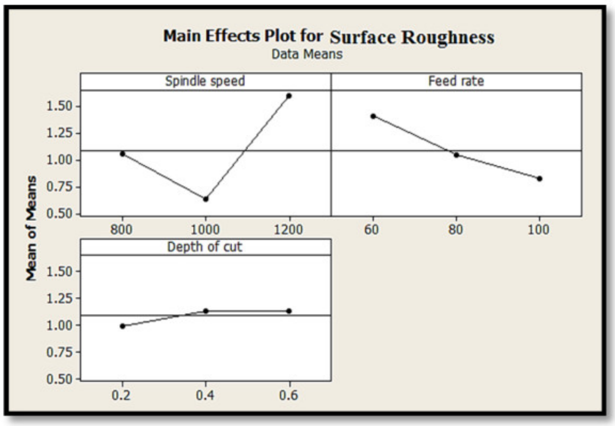

Figure 10: Mean affect plot for Ra.

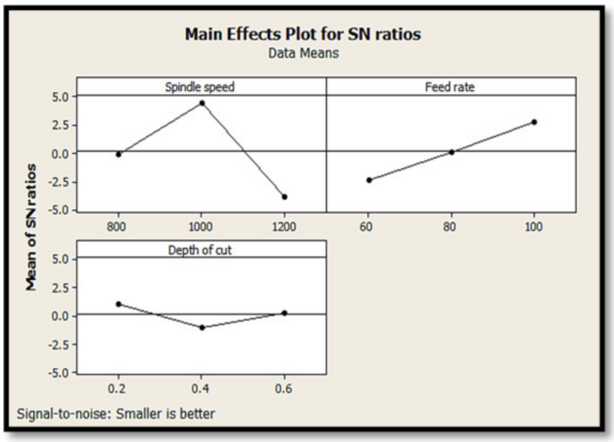

Figure 11: Single to noise ratio for surface roughness.

After analyzing the results and making the prediction procedures for the best parameters that gave the best metal removal rate and surface roughness. These variables are:

1- The largest metal removal rate (2.40) mm3/min is achieved with the values (800 r.p.m), (100 mm/min) and (0.6 mm), for the spindle speed, feed rate and depth of cut respectively .

2- The best surface roughness (0.41 µm) is achieved with the values (100 mm/min), (1000 r.p.m), and (0.2 mm) for the feed rate, spindle speed, and depth of cuts respectively.

6. Conclusions

To summarize the concluded influences that deduced from these experiments could be sum up in :

• At high spindle speeds value (1000 rpm) more accurate machining is obtained but max machining time (17.15 min) is reported using flat-end tool, while this process gives best surface roughness with slight effect on MRR

• The error between experimental and predicted values at the optimum combination of parameter settings for MRR, and surface roughness lies within 1.1544% and 2.122% respectively. Obviously, this confirms excellent reproducibility of the experimental conclusions.

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الحصول على افضل معدل ازالة المعدن وخشونة السطحية لسبيكة المنيوم نوع 7024 في عملية تفريز التجاويف

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نشر في: 31 آذار 2019

الخلاصة – ان الهدف من البحث الحالي هو تحقيق عوامل التشغيل لعملية التفريز بالمكائن المبرمجة و التي تعطي افضل قيم للخشونة السطحية و الاجهادات المتبقية عند تشغيل سبيكة الالمنيوم نوع 7024 ان تاثير العوامل المختارة على المخرجات المقترحة قد تم حسابه باستخدام طريقة تاكوجي لحساب الامثلية بالاضافة الى طريقة تحليل التباين. وباستخدام معدلات تغذية مختلفة (60, 80, 100) ملم/دقيقة, قد وجد عند اعلى معدل تغذية نحصل على اعلى معدل ازالة مادة و خشونة سطحية جيدة في الجانب الاخر بإستخدام ثلاثة مستويات لسرعة دوران المحور وجد ان عند استخدام أعلى سرع دوران محورنحصل على خشونة سطحية افضل بتأثير طفيف على معدل ازالة المعدن . وتبين من نتائج الجانب العملي ان افضل معدل إزالة مادة عند معدل تغذية (100)ملم/ دقيقة, سرعة دوران محور (800) دورة بالدقيقة و عمق قطع (0,6) ملم وافضل خشونة سطحية عند معدل تغذية (100)ملم/ دقيقة , وسرعة دوران محور (1000) دورة بالدقيقة و عمق قطع (0,2) ملم, بالاضافة الى ذلك تم تحديد مستوى تاثيرظروف القطع على الخشونة السطحية ومعدل ازالة المعدن باستخدام تحليل التباين . ANOVA.

الكلمات الرئيسية – طريقة تاكوشي، معدل ازالة المعدن، الخشونة السطحية، طريقة تحليل العناصر، تفريز التجاويف.