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Optimization of Process parameters for pocket milling of Al7075 Using Response Surface Methodology

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ABSTRACT

Nowadays the high quality of surface roughness is in demand to meet the market requirements. Manufacturing Industry has many complex processes that vary in nature. The current paper describes the development of a model for pocket milling on Al7075 using Response Surface Methodology (RSM). This model gives mathematical relationships in terms of Cutting speed, Feed and Step Over for Follow periphery and Zigzag tool path strategies. The surface roughness is predicted with the help of these relationships and compared with the measured surface roughness of the machined components. The error observed is less than 5%.

***Keywords*:** Pocket Milling, Aluminium, RSM, Tool Path Strategy

1. Introduction

Surface integrity is one of the most influencing factors to accept the quality of a product in many manufacturing components. In modern manufacturing world with computer numerical control machines, achieving surface quality is not a much difficult task. But with trial and error methods, much of the valuable production time and material are wasted. To overcome this problem optimization of machining parameters is necessary. Even though, there are several factors that affect the surface finish of a product, Speed, Feed, and Depth of cut are found to be the most influencing factors on surface roughness. Alauddin et al. [1] have developed a surface roughness model for milling 190BHN steel with Response Surface Methodology. In their study, the feed was found to be the most dominating factor for surface roughness. Proper selection of cutter path strategies in pocket milling saves machining time and cost. It also helps in improving surface quality [2]. In pocket milling, stepover and tool path strategy also play important roles in obtaining the required surface finish [3].

Aluminium and its alloys are the commonly used materials in many fields of engineering. Their properties such as light weight, ease of machinability, corrosion resistance etc., make them qualify for diversified applications. In molding industry surface finish is considered as one of the important parameters for manufacturing plasticcomponents [4].G1-continuous spiral path is employed by Held and Spielbergr [5], by using "POWERAPX" Package for the generation of tool path in 2D pocket milling. Michel Bouard, etal. [6] explained a new method for tool path computation. In the current study, uniform cubic B-spline curves are applied to model surface roughness with an optimization algorithm. Ali et al. [10] experimented on hardened material AISI H13 tool steel to predict surface machined quality. Response Surface Methodology (RSM) Model was used to design the prediction model with parameters generated using Central Composite Face (CCF) methods. Evolutionary algorithms also applied to optimize the cutting conditions for better surface finish [6-8]. Effect of tool path strategies and pocket geometry on surface roughness, machining time and cutting forces is measured by PE Romero et al. [11]. An Artificial neural network model was developed to predict the optimal parameters for minimum surface roughness value [12]. Wong et al. [13] studied the influence of process parameters for face milling of Semi solid Al7075 on surface quality and tool wear using factorial designs. Hashmi et al. [14] used Response surface methodology for optimizing process parameters in high-speed milling of titanium alloy. Nurhaniza et al. [15] analyzed the influence of machining parameters in CNC end milling operation for machining CFRP aluminium with PCD tool. In high-speed machining of 2D pockets, various tool path strategies can be employed.

From the above review, it is observed that most of the researchers concentrated on speed, feed and depth of cut as these are dominating factors in obtaining the required surface roughness value. In the current work a mathematical model is developed using RSM to optimize the speed, feed and step over. The combination of machining parameters for obtaining optimal surface roughness is also determined in the study for machining Al7075 for both the tool path strategies.

2. Methodology

A response surface design is a set of advanced design of experiment (DOE) techniques that help in better understanding and optimization of the responses. Response surface design methodology is often used to refine models after determining important factors using factorial designs. Response surface methodology (RSM) is one of the statistical methods for finding a relation between various input parameters and output parameters. There are two main types of response surface designs.

Central Composite designs can fit a full quadratic model. They are often used when the design plan calls for sequential experimentation because these designs can include information from a correctly planned factorial experiment.

Box-Behnken designs

Box-Behnken designs usually have fewer design points than central composite designs, thus, they are less expensive to run with the same number of factors. They can efficiently estimate the first- and second-order coefficients; however, they can't include runs from a factorial experiment. Box-Behnken designs always have 3 levels per factor and never include runs where all factors are at their extreme setting, such as all the low settings.

3. Experimental factors and data:

Design of experiments is an important tool to select the number of experiments to be conducted for the study. The response that is to be optimized is expressed in terms of unknown relation with the selected process parameters called design factors. There are several factors that can be considered for pocket milling. But in the present study the factors considered are Speed, Feed, and step over. Three levels for three factors with codes is defined in table1. The number of design runs is decided using Box-Behnken design. As the number of factors is three with three levels the experimental runs are given in table2 in a coded manner.

Table 1: Assignment of levels to factors

Symbol	**Machining Parameters**	**Units**	**Level 1**	**Level 2**	**Level 3**	**Observed Values**
S	Spindle Speed	RPM	3000	4000	5000	SR(μm)
F	Feed rate	mm/min	500	1500	2500	
SO	Step over	%	20	40	60	
CODE			-1	0	1	

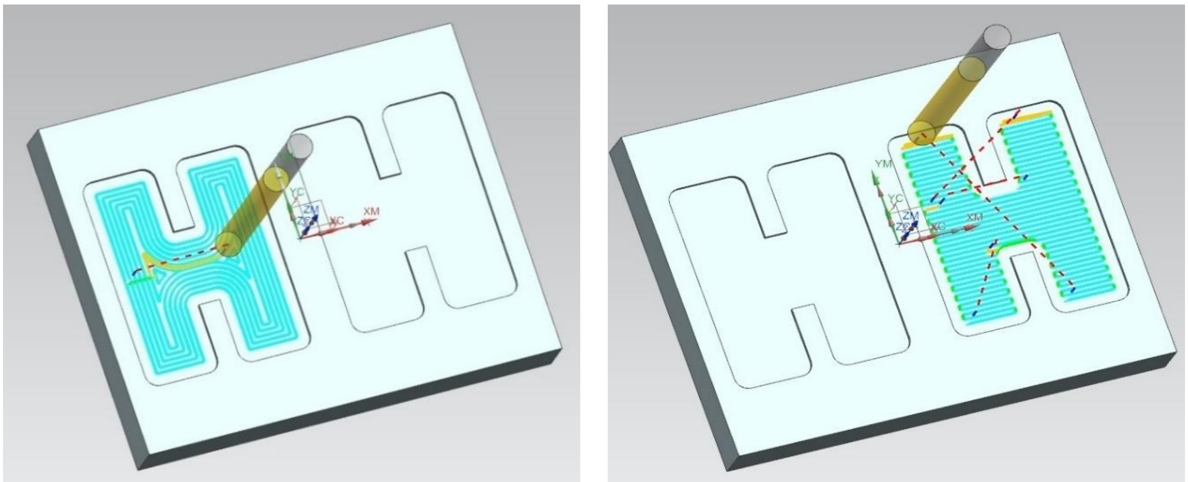
Table 2: Order of experimental run

Run Order	Std. Order	Speed	Feed	SO
1	8	1	0	1

2	7	-1	0	1
3	5	-1	0	-1
4	2	1	-1	0
5	9	0	-1	-1
6	3	-1	1	0
7	1	-1	-1	0
8	13	0	0	0
9	6	1	0	-1
10	11	0	-1	1
11	10	0	1	-1
12	12	0	1	1
13	15	0	0	0
14	4	1	1	0
15	14	0	0	0

4. Experimental setup:

The profile of the pocket that is to be cut on the workpiece surface is modeled with Siemens NX software. The tool path strategies are simulated on the pocket geometry as shown in fig. 1 and NC code was generated for each model.



a) **Follow Periphery Tool Path Strategy** b**) Zigzag Tool Path Strategy**

Fig.1**Tool path strategy for Pocket Milling**

AMC MCV-350 model CNC Vertical Axis Machining center with Fanuc series controller is used to generate the pockets. Al7075 with a specimen size of 80mm x70mm with a depth of 10mm is used in the present study. A four-flute tungsten carbide coated tool with 6mm diameter is used for machining. The experiments are conducted with coolant to reduce the thermal effects while machining. The surface roughness is measured using SJ201P Surf test. Five samples for each experiment and the average of the results are considered for analysis.

5. Results and Discussion:

It was found that the surface roughness decreases with an increase in spindle speed, increases as feed rate and step over increases. The variation in the surface roughness for different combinations of speed, feed and stepover is represented in Table 4. Using these experimental results, empirical equations have been obtained to estimate surface roughness with the significant parameters considered for experimentation i.e. cutting speed, feed rate and step over. The second-order response equations have been fitted using Design expert software for the response variable Ra, for the two tool path strategies separately.

The coded second order equations were developed using design expert 11 and they were as follows:

i) **For Follow-periphery tool path strategy**

$$SR= 1.411+0.137375S-0.36375F+0.006SO+0.151SF+0.13625SSO+0.13975FSO-0.03875S^2-0.12125F^2-0.296SO^2 \quad \text{-------------1}$$

ii) **For Zigzag tool path strategy**

$$SR= 1.51-0.015S-0.0007F+0.1227SO-0.1579SF-0.148SSO+0.055FSO-0.1979S^2-0.2301F^2-0.2907SO^2$$

The roughness value is also predicted with the equations 1 and 2. The error between the predicted and the measured values of the surface roughness is given in table 4, for the chosen tool path strategies. It is observed that the error in the predicted value of the surface roughness is less than 5% when compared with the measured value

Table 4: Surface roughness values for the two tool path strategies

Run	Speed	Feed	SO	Measured SR (FP)	Predicted SR (FP)	% Error	Measured SR (ZZ)	Predicted SR (FP)	% Error
1	-1	-1	0	1.277	1.2986	1.7711	0.91	0.9337	2.6044
2	0	0	0	1.425	1.41	1.0526	1.522	1.51	0.7884
3	0	0	0	1.425	1.41	0.7741	1.506	1.51	0.2656
4	-1	0	1	0.792	0.8061	1.7803	1.361	1.3213	2.9169
5	-1	0	-1	1.103	1.0717	2.8377	0.767	0.7663	0.0913
6	1	0	1	1.322	1.3535	2.3827	0.98	0.9819	0.1939
7	0	-1	1	0.938	0.9014	3.9019	1.033	1.0508	1.7231
8	1	1	0	1.528	1.5056	1.4659	0.938	0.9159	2.3873
9	1	0	-1	1.088	1.0739	1.2959	0.978	1.0729	3.9632
10	0	0	0	1.384	1.41	1.8786	1.5	1.51	0.6667
11	1	-1	0	1.266	1.2714	0.4265	1.251	1.2331	1.4308
12	0	1	-1	0.79	0.8266	4.6329	0.834	0.8174	1.9904
13	-1	1	0	0.934	0.9288	0.5567	1.229	1.2481	1.5541
14	0	-1	-1	1.155	1.164	0.7792	0.949	0.9288	2.2316
15	0	1	1	1.112	1.1032	0.7913	1.137	1.1594	1.9701

From fig.2, it is observed that the variation in surface roughness for follow periphery is more when compared with that of variation in zigzag strategy. Even though some combinations of factors show less variation between the two strategies, the required surface roughness values for both strategies are obtained at different levels of the parameters. From the experimental results, it is observed that for follow periphery, the minimum surface roughness value is obtained at medium speed, high feed and low stepover, whereas for zigzag strategy low speed, medium feed and low stepover gives minimum surface roughness value

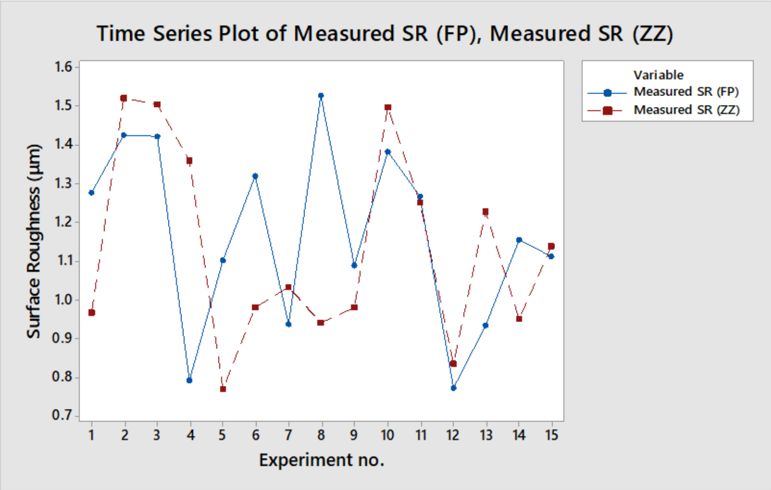


Fig2. Measured Surface roughness plot for the tool path strategies

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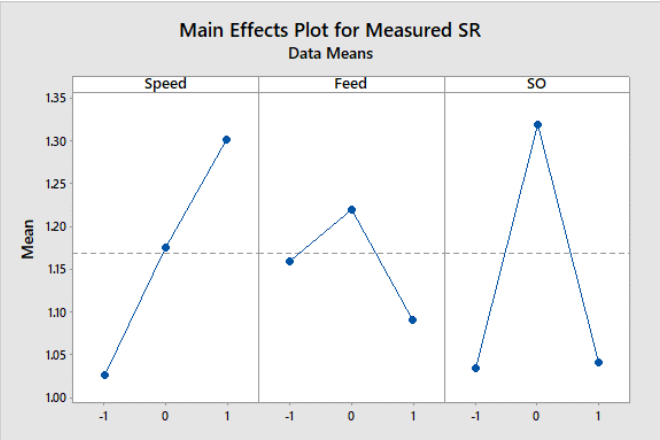

Fig. 3 Main effects plot for measured Surface roughness in follow periphery tool path

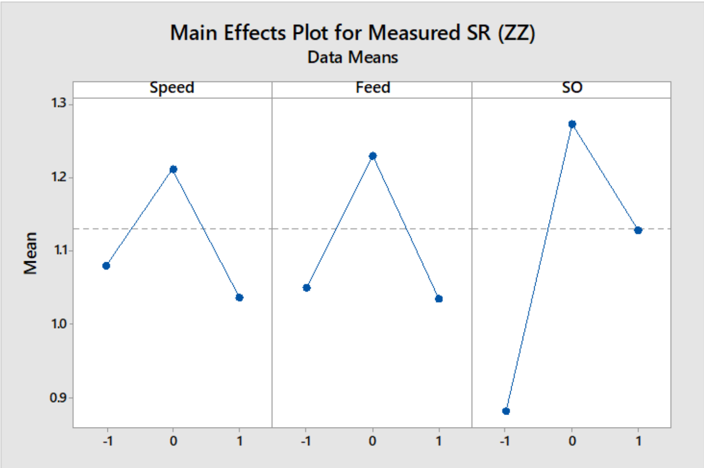

Fig. 4 Main effects plot for measured Surface roughness in Zigzag tool path

From the fig 3, It can be understood that we can obtain minimum surface roughness at minimum speed, maximum feed and minimum step over. The effect of speed is more as the slope is steeper when compared to other parameters viz. feed and step over. The effect of change in step over is also considerable as it shows much variation in the surface roughness value. The rate of change of surface roughness with respect to change of feed is less when compared to speed and feed. The main effects graph, fig4, for Zigzag tool path shows higher speed, higher feed and lower stepover gives minimum surface Roughness. It is observed that, out of the three parameters, stepover has definite influence on the surface roughness in this process.

Confirmation experiments were conducted for both the tool path strategies based on main effects plots.The obtained results are compared with that of predicted values and found that the error is within 5% limit.

Table 7: Confirmation test results

	Cutting parameters (Coded Values)			**Surface Roughness (µm)**		
Tool Path	**Speed**	**Feed**	**SO**	**Predicted**	**Measured**	**% Error**
Follow periphery	-1	1	-1	0.6338	0.6293	0.71508
Zigzag	1	1	-1	0.6224	0.6179	0.7282

Conclusions

Process parameters for required surface roughness are analyzed using Response Surface methodology for pocketing of given profile on Al7075 using carbide coated tool. Two tool path strategies viz., Follow periphery and Zigzag are used for machining the profile. The conclusions from the results are as follows:

1. For the range of the parameters considered, follow periphery shows more variation in surface roughness when compared to that of zigzag strategy.
2. Zigzag tool path strategy gives better surface finish when compared to follow periphery within the range defined for the parameters. But require finishing operation.
3. The error between predicted and measured surface roughness values is within the ±5%. Hence the response surface equations can be used to optimize the machining parameters.

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