International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-1, October, 2019

Influence of Cutting Parameters and Tool Path Strategies on Surface Roughness in Pocket Milling of UNS A96082 Alloy

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Abstract: CNC Pocket Milling is the commonly employed machining process in molding, aircraft building, and shipbuilding industries. Surface integrity is one of the main quality parameters considered to accept the component. In the present work, an attempt is made to optimize the cutting factors in pocket milling of UNS A96082 using two different tool path strategies to get a better surface finish. Speed, Feed and Step over are considered as influencing parameters in the present study for measuring surface roughness. Taguchi experimental design method is employed to conduct experiments and to optimize the cutting parameters. It is observed that the results obtained from confirmation experiments also show nearer value for predicted surface roughness

Index Terms : Optimization, pocket milling, Taguchi method, Tool Path strategy, UNS A96082.

I. INTRODUCTION

Pocket milling is one of the widely used machining processes in plastic molding, aerospace and port industries. It is commonly employed in plastic molding industry to prepare injection molds. UNSA96082 is one of the commonly used alloys in molding industry with conventional machining but preferred for molding because of its strength, polishing ability, corrosion resistance, and wear resistance. Increasing productivity with quality is a big challenge faced by manufacturing industry. Surface integrity is one of the parameters for quality. To obtain better surface finish for the plastic components, the surface finish of the molds should be in acceptable range. Surface finish in milling is affected by various controllable and non-controllable parameters viz., spindle speed, table feed, depth of cut, tool material, tool geometry, properties of cutting fluid, etc., These parameters have different levels of influence on surface integrity. In pocket milling, to generating the given profile, Tool path strategy also plays an important role. Selection of proper tool path leads to good surface finish and reduces the machining time. There are two tool path strategies viz., linear and nonlinear. In linear tool path, the tool moves in straight line either in one direction or in both directions (Zig Zag). In nonlinear path strategy, tool moves along the profile or in spiral path. Optimization of machining parameters for good surface roughness is necessary to increase productivity. Taguchi orthogonal array is the widely known technique for optimization of process parameters with a limited number of experiments.

Many researchers made useful work related to optimization of various milling processes for various materials and on various parameters. The influence of cutting factors and tool path strategies in pocket milling, on surface roughness using Taguchi parameter design was studied by Gologlu et al. They identified Feed rate is the influencing factor for one direction and spiral tool path strategies whereas the depth of cut influences back and forth strategy[1]. Routara et al.[2] conducted an experimental investigation on three different materials to study the effect of process parameters as well as material properties on five types of surface roughness factors and identified that roughness modeling is specific to the roughness parameter. Using PCA based Taguchi method for multi-objective optimization, Sanjit et al. [3] studied the effect of CNC end milling process parameters on surface finish and material removal rate (MRR). They identified that this method gave effective results for multi-objective optimization. Jabbaripour et al. [4] used four tool path strategies in machining thin parts of Al7075 with 3-axis milling to study the surface integrity under variable speeds to optimize the optimal speed range. The impact of profile of the pocket and tool path strategy on machining time, surface roughness and cutting forces were described by Romero et al.[5] in pocket milling of UNS A96063 alloy. A relationship was developed between the cutting parameters and the quality parameters to analyze the effect. Perez et al., [6] developed and analyzed an average-chip-thickness based cutting force model, to check the effect of different strategies for peripheral milling, on hard to cut and soft materials. They identified a significant difference in the cutter path strategies for hard to cut materials whereas no significant difference for soft material. Surasit et al.

[7] studied the effects of process parameters in face milling on the surface integrity and tool wear in semi-solid AA 7075. A linear equation was developed to understand surface integrity and they observed that tool wear was like mechanical fatigue cracking. Pang et al. [8] used Taguchi method to optimize surface quality and cutting force in end milling for machining halloysite Nanotubes with Al reinforced epoxy hybrid composite material under dry condition. They showed that Taguchi orthogonal array gives best combination of machining parameters in optimizing the surface roughness. Sukumar et al.[9] tried to optimize cutting factors, in face milling, using Taguchi & Artificial neural Networks

Revised Manuscript Received on October 30, 2019.
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approaches on Al 6061. They realized that even though both strategies give different combination of parameters, experimental results showed almost near value of surface roughness value. To analyze the influence of cutting parameters for Material Removal Rate, Surface integrity, and parallelism after end milling operation on OHNS steel, Malvade et al.[10] used Taguchi method. They observed that Depth of cut effects Material removal rate and speed effects surface roughness. Taguchi Grey Relational Analysis technique was used by Shunyao et al.[11] to find the impact of tool geometry to get good surface finish in milling Titanium alloy TB17. A linear equation is formed, to study the effect of machining factors in end milling of AISI P20 steel, with the experimental results by Wasim et al.[12] and informed that surface integrity is more effected by speed than other factors considered. With the help of a Mathematical model, Burlacu et al. [13] tried to minimize surface roughness in micro-milling of C45W steel. Using Taguchi L9 orthogonal array in end milling of hardened steel block, João et al. [14] tried to find the control factor to optimize the surface roughness. They identified that Radial depth of cut is the most influencing factor in minimizing surface roughness. Similar work was also proposed by Rajyalakshmi and Suresh Babu [15] while pocket milling of SAE304.

From the above discussion, it was understood that the Taguchi method is one of the economical and best methods to select the optimum machining parameters with a minimum number of experiments. As the UNSA96082is one of the important materials used for molding in plastic industry, in the present work, an attempt is made to optimize the process parameters in pocket milling to minimize surface roughness, using Taguchi method. ANOVA is also applied to find the most influencing parameter in both strategies.

II. METHODOLOGY PROPOSED FOR THE WORK

Minimum number of experiments required to find the effect of maximum number of machining parameters on a given response can be given by Taguchi orthogonal array. With this minimum number of experiments a researcher can gather maximum information. Choice of input parameters and their level combinations greatly influence the selection of orthogonal array that fits for these level combinations. The minimum number of experiments that are required to conduct the Taguchi method can be calculated based on the degrees of freedom approach.

In Taguchi Method, the word "optimization" means "identification of BEST combinations of machining parameters". In turn, the BEST combination of parameters maximizes the Signal-to-Noise ratios. With the help of suitable orthogonal Arrays, minimum in number experiments are designed to balance the control factor levels, and hence the resources (materials and time) required to conduct the experiments are also minimized.

In the present study, the influence of cutting parameters on surface roughness in pocket milling is observed using two tool path strategies viz Follow periphery (FP) and Zigzag (ZZ). The parameters, Speed (S), Feed(F) and Stepover (SO) are defined with three levels each based on literature review as given in Table 1.

Table 1: Assignment of levels to factors

Symbol	Machining Parameters	Units	Level 1	Level 2	Level 3	Observed Values
S	Spindle Speed	RPM	2000	3000	4000	
F	Feed	mm/min	500	1000	1500	SR (μm)
SO	Step over length	%	20	30	40	

Based on No. of factors and levels, the No. of experiments required is decided by L9Taguchi orthogonal Array. Based on the experimental result S/N Ratio is calculated and larger is better was selected for the present study. ANOVA is applied on the Experimental Results to identify the most significant factor for surface finish.

Table 2: Factor assignments in L9 orthogonal array

S. No	Run Order	Speed (RPM)	Feed (mm/Min)	Step Over (%)
1	3	2000	500	20
2	2	2000	1000	30
3	5	2000	1500	40
4	4	3000	500	30
5	8	3000	1000	40
6	9	3000	1500	20
7	1	4000	500	40
8	6	4000	1000	20
9	7	4000	1500	30

The workpiece material is UNSA96082 one of the Aluminium alloy, having 80mm x 70mm x 10mm size. The chemical composition of the selected material is given in table 3.

III. Simulation and Experimental setup

The profile of the pocket as shown in figure1is modeled using Siemens NX software version 3.1 at CIPET. The selected path strategies are simulated on the profile geometry and the NC code is generated.

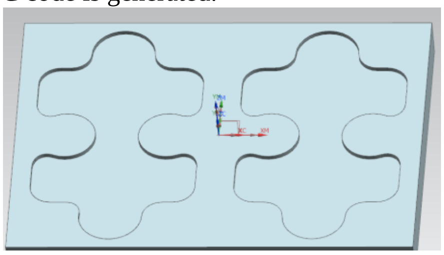

Figure1: Profile for Pocket Milling

Figure 2(a) indicates the Zigzag tool path strategy whereas Figure 2 (b) indicates follow periphery. In zigzag strategy, the material cannot be removed completely to achieve the given profile.

Hence, finishing operation is also required to obtain the profile.

Table3: Chemical composition (Wt.%) of UNS A96082

Weight%	Al Si	Fe Cu	Mn Cr	Mg	Zn Ti	Other
UNS A96082	Al: 97.506 Si: 0.903	Fe:0.223 Cu: 0.002	Mn:0.411 Cr:0.016	Mg:0.852	Zn:0.071 Ti:0.010	0.05 max

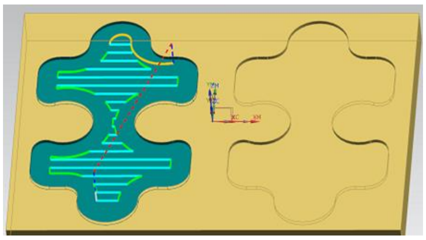

Figure 2(a): Zigzag Tool Path Strategy

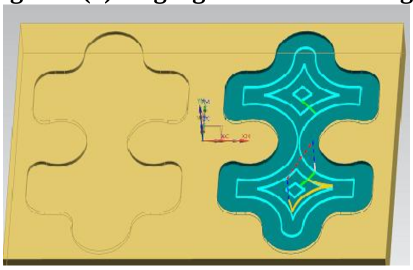

Figure 2(b): Follow Periphery Tool Path Strategy

A vertical machining center with Fanuc O controller is used to perform pocket milling operation. Depth of cut is 0.5 mm, with multi-pass cutting. A four-flute tungsten carbide coated tool with 10mm diameter is used for cutting operation. Each experiment was selected as per the experimental run order specified by Minitab from table 2 and conducted for five times. A new tool is used for different path strategies. SJ201P Surf test is used to measure the surface roughness of the machined workpiece. The finished workpieces for zig zag and follow periphery are shown in figure 3(a) and 3 (b).

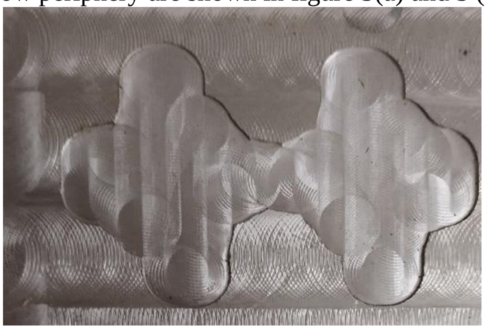

Fig. 3 (a) Zigzag Tool path

Fig. 3(b) Follow periphery Tool path

The experimental results of UNSA96082are as shown in the following table 4. Each experiment is repeated for five times for accuracy in data. The average of the experiment results is considered for calculation. The signal to noise ratio for both the tool path strategies is calculated by considering larger the better ratio, using the following equation 1.

$$S/N\ Ratio = -10 \log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \text{-------1}$$

Where, y_i^2 is the observed value at ith experiment and n is the no of experiments.

The highest signal to noise ratio for different levels of the parameters calculated using Taguchi analysis (Table 5 & 6) also gives the optimum combination of process parameters for low surface roughness. From table 5 it was observed that minimum surface roughness can be obtained with a combination of

S. No	Follow Periphery		Zigzag	
	Average Surface roughness	S/N Ratio	Average Surface roughness	S/N Ratio
1	1.8134	-5.1874	1.9536	-5.81671
2	2.1364	-6.5972	1.8276	-5.23763
3	2.898	-9.244	2.3222	-7.3759
4	2.008	-6.0559	1.8448	-5.31899
5	2.783	-8.8969	1.9416	-5.7632
6	2.7866	-8.9083	2.8416	-9.07126
7	2.1178	-6.5662	2.0608	-6.28097
8	2.152	-6.6573	2.0236	-6.12399
9	2.31	-7.2799	2.9508	-9.3988

third level of speed, first level of feed and second level of step over for follow periphery.

Table5: Taguchi Method for Follow Periphery

S. No	Speed (S) (RPM)		Feed (F) (MM/Min)		Stepover (SO) (%)	
	Raw Data	S/N Ratio	Raw Data	S/N Ratio	Raw Data	S/N Ratio
1	2.2826	-7.009	1.9797	-5.93 65	2.25 07	-6.9177
2	2.5259	-7.9537	2.3571	-7.38 38	2.15 15	-6.6443
3	2.1933	-6.834	2.6649	-8.47 74	2.59 96	-8.2357

The mean plot for the selected strategies is shown in figure 4 and figure 5. From Figure 4, it was understood that the combination given in the Taguchi analysis was reflected in the plot. From the main effects plot for follow periphery, it is observed that Feed has more influence on surface quality than the other parameters. Step over also shows some influence on the response attribute when compared to speed.

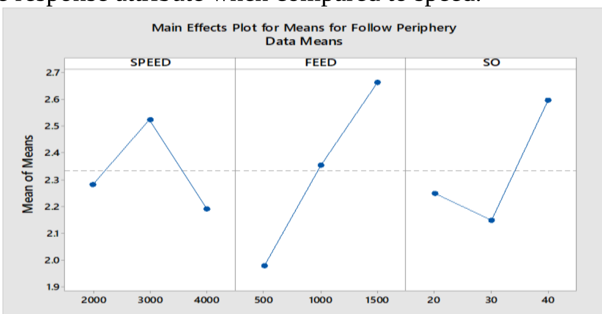

Fig. 4: Influence of process parameters on surface roughness for follow periphery Tool path strategy.

From table 6 it was identified that minimum surface roughness can be obtained with a combination of lower speed, medium feed and higher step over.

Table 6: Taguchi Method for Zigzag

S. No	Speed (S) (RPM)		Feed (F) (MM/Min)		Stepover (SO) (%)	
	Raw Data	S/N Ratio	Raw Data	S/N Ratio	Raw Data	S/N Ratio
1	3.3908	-6.1434	3.2551	-5.8056	3.7882	-7.0039
2	3.6822	-6.7178	3.2182	-5.7082	3.6796	-6.6518
3	3.9084	-7.2679	2.7028	-8.6153	2.1077	-6.4734

From the mean plot for Zigzag strategy (Figure 5), it is observed that the slope of the line in surface roughness Vs feed graph is very steep. Hence it is observed that feed has much influence on surface finish. The optimum conditions in zigzag strategy are lower speed, medium feed and higher step over to get a better surface finish.

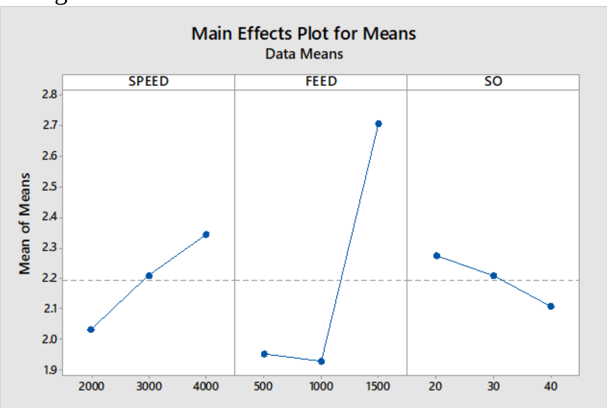

Fig. 5: Influence of process parameters on surface roughness for Zigzag Tool path strategy.

ANOVA: Analysis of variance is applied to the selected tool path strategies to identify the most significant parameter. Tables from 7-8 show the analysis of variance for the tool path strategies.

Table7: ANOVA table for FP Tool path

Parameters	DOF	SS	MS (Variance)	F	F-CRIT	% Contribution
Speed (RPM)	2	2.1747	1.0873	22.619	19	13.29
FEED (mm/min)	2	9.7468	4.8734	101.374	19	59.56
Step over (%)	2	4.3443	2.1721	45.1850	19	26.55
ERROR	2	0.0961	0.0480			0.6

The F ratio for the Feed (101.3745) is higher when compared to other parameters. Hence Feed is the most influencing factor in Follow periphery tool path strategy. The percentage contribution of feed is 43.006, Step over is 26.55 and that of speed is only 13.29115 for minimum surface roughness

Table8: ANOVA table for Zigzag Tool path

	DOF	SS	MS (Variance)	F	F-CRIT	% Contribution
Speed (RPM)	2	1.8971	0.9485	22.0207	19	10.10377
FEED (mm/min)	2	16.3551	8.1776	189.8465	19	87.1075
Step over (%)	2	0.4375	0.2187	5.0778	19	2.3299
ERROR	2	0.0862	0.043075			0.45883

For the zigzag tool path strategy also feed (189.8465) has more F value. Hence it is the most influencing parameter. The percentage contribution for various factors is given as speed 22.0207, Feed 189.8465 and step over is 5.0778.

Confirmation test results: Based on the predicted optimal values of the parameters, confirmation experiments were conducted to test the results for the two tool path strategies. Each test was repeated for two times and the average of each experiment is considered. The confirmation results are compared with predicted values to check the accuracy.

Table 9: Comparison between confirmation experiments results and calculated values

Tool Path strategy	Ex pt. No	Confirmation test results		Predicted values		Differences	
		Ramean (µm)	S/N (ηmean)	Ramean (µm)	S/N (ηmean)	|Ramean −Racal|	|ηmean −ηcal|
Follow Periphery	1	1.7286	-4.7755	1.7546	-4.8835	0.026	0.108
	2	1.7407	-4.7956	1.7546	-4.8835	0.0139	0.088
Zigzag	1	1.7847	-5.021	1.7591	-4.9056	0.0256	0.115
	2	1.79	-4.9964	1.7591	-4.9056	0.0309	0.091

Table 9 shows that better surface finish can be obtained by follow periphery. Even though confirmation test result shows a little higher surface roughness, the variation between the test results and the predicted values is compromising with in the given conditions.

IV. Conclusions

The surface roughness in pocket milling is measured for UNS A96082 material with one linear and one nonlinear cutter path strategies with the help of Taguchi orthogonal array. From the study it is understood that the average surface roughness value for Zigzag is a little bit higher than the follow periphery. The variation of surface roughness in zigzag is steeper than that of follow periphery. It may be because of free cutter movement in follow periphery compared to that of zigzag path movement. It is also observed that the most influencing factor is feed for both the tool path strategies and follow periphery gives better surface finish when compared to zigzag tool path within the limits defined for the parameters.

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