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Investigation on the Effect of Tool Coating Thickness in Pocket Milling using Austenite Ss316

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Abstract

Objective: This paper presents the research work done in Pocket milling operation using Stainless steel 316 materials. The most critical process parameters namely, Coating thickness (µm), Depth of Cut [DOC] (mm), Spindle Speed [SS] (rev/min) and Feed Rate (mm/min) are taken into consideration to improve the quality of the output characteristics. The required output characteristics are Cycle time (min), Surface quality measurement, i.e., Roughness of the surface (R_a), Wear of the Tool (mm), Microhardness (HV) and Material Removal Rate (mm^3/min). **Methods/Analysis:** The Taguchi method was used to tabulate the Design of experiments (DOE) of L_9 orthogonal array. According to the study, the required Material Removal Rate is considered 'higher the better' and other required output characteristics are 'lower the better.' To determine to a most significant process parameter, Taguchi's grey relation analysis is used. To determine the significance and shift of each parameter to the total variation observed, Signal to Noise Ratio (S/N) was used. The contributions of each process parameters to obtain the required output characteristics are studied. **Findings:** From the grey relation grade, the highest maximum – minimum value shows that the depth of cut is the most influential input parameter for the obtained output characteristics. The optimum input parameters are tool coating thickness of 10 µm, the speed of the spindle being 2500 rev/min, feed rate being 1000 mm/min and depth of cut being 0.7 mm. A verification test was performed conducive to determine the veritableness of the obtained optimal input parameters. The test proves that the optimum input process variables satisfy the required output characteristics for pocket milling operation in AISI Stainless Steel 316 material.

Keywords: Coating Thickness, Design of Experiments (DOE), Grey Relational Analysis, Material Removal Rate (MRR), Signal to Noise Ratio

1. Introduction

Milling is an important industrial machining process which is also one of the most common techniques of the material removal from the workpiece. The job is fed against a set of rotary cutters which contain several cutting edges. Pocket milling operation is used to machine workpieces in this experiment. In this competitive world, the reduction of manufacturing time and producing good quality materials is an important aspect. Pocket milling operation is used. The material inside an arbitrary closed boundary on a flat surface of a workpiece to a certain required depth is pocket milling. Mastercam X6modeling software is used to generate, simulate and produce NC codes which help to fabricate the necessary component using vertical CNC machine. This research study contains the optimization of input process parameters are, Coating thickness (µm), Cutting Depth (mm), SS (rev/min) and Feed Rate (mm/min) to minimize the output characteristics such as Cycle time (min), Tool wear (mm), Surface roughness (R_a), Microhardness (HV) in SS 316 material. Many researchers have studied that how to optimize and improvise the machined products.

The current study is based on the featuring of different levels of speed and feed rate on the workpiece material of Austenitic Stainless Steel (316 L).The increase in flank wear takes place for both coated and uncoated tool as it results in the increase in cutting speed and feed rate. However, machining with coated tools gives less flank wear due to excellent resistance to high-temperature

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oxidation. Coated tools show better surface finish than uncoated because frictional coefficient and thermal conductivity of the tool coating are low.[1] This study based on the objective is to produce more production with less time constraint. The machining parameters play a significant role in this objective. The conclusion gives an idea that when the depth of cut is low, SS is high, and the feed rate is considerably normal; a better surface finish can be obtained[2]. The process variables' optimization is studied using Taguchi Grey Relation analysis method[3]. The optimization of input process and studied about different tool path strategies and their effect on machining components was presented[4]. The influence and response of different cutting tool path strategies on the surface quality, i.e., roughness of the material in pocket milling operation were studied[5]. The process variables' optimization using Taguchi - Grey relation analysis method was conducted a study on[6].

The optimization of input process and studied about different tool path strategies and the nominal the better was presented[4]. The relationship between cutting forces, cutter path plans, pocket geometry, machining time and surface roughness of A96063 aluminium alloy was presented[7]. Studied the different cutting strategies for difficult-to-cut components such as corners and pockets extracted from aircraft components using end mill cutter[8]. The conclusion of a conducted study revealed that the factors affecting the surface roughness were the feed rate ratio and the speed whereas the depth of cut was a factor which kept the surface roughness unaffected during the machining of AA 7075 by face milling operation[9].

In this work, the tool life, cutting force, power consumption and cutting condition are obtained by optimization methods by using Ti-Ni coated carbide tools[10]. A study states the effect of process variables like feed rate, depth of cut, lubrication pressure and the cutting speed on surface roughness[11]. The study investigated the quality improvement of end milled slots using Titanium Nitride Coated tools[12]. This paper presents a study of the application of the Taguchi – Grey Design for the optimization of surface quality in a face milling operation programmed under CNC machine[13]. Multiple performance characteristics like surface quality and flank wear were taken as process variables for the applicative study of Grey – Taguchi method after end milling process is taken into consideration[14]. An optimization technique for process performance on stainless steel based on the Taguchi method with multiple performance characteristics for the operation of face milling is proposed in this paper[15]. The principal of this work on machining SS316 with different process parameters are:

1. To analyze the effect of process parameters on machining characteristics
2. To find the optimal combination of process input parameters for obtaining better multiple response parameters
3. To identify the most influencing input process parameter in pocket milling process

To conduct experiments, many different factors contribute to the result of the test. Thus, in this experimental research the study of the contribution of different input parameters to obtain output characteristics and to explore their individual relationship between the output parameters. To investigate this relationship between factors and parameters, a systematic method of Design of Experiments (DOE) is used. Taguchi method is used to determine the L_9 orthogonal array of experiments[16]. Grey relational analysis method is used to determine the most optimal solution, and max-min of the average grey coefficient is used to find out the most influential parameter to determine the output characteristics[17].

2. Properties of Workpiece and Tool used

The current study features the use of Austenitic Stainless Steel 316 as the workpiece material. The composition is shown in Table 1. Stainless Steel 316 has many applications involving pharmaceuticals, architectural and marine applications, medical implants, heat exchangers and also as fasteners. It consists of higher corrosion resistance, along with excellent pitting resistance and resistance to most chemicals. Figure 1 shows the end mill cutter tool is carbide tipped tool coated with aluminium titanium nitride coating.

They are nonhardenable and can be readily formed and drawn. SS316 possess poor weld ability as compared to other grades of stainless steel. The density of SS316 is 7.99 g/cm^3. The cutting tool used for machining the workpieces in this research is ending mill cutter of 6mm diameter having four flutes each of 40^o helix angle.

3. Experimental Work

The machining is done using three axis CNC machining center having Sinumerik 820d with 8000 revs/min of maximum SS and 10000 mm/min of maximum feed rate.

Figure 2 shows the completed machining. Morph spiral tool path is used in this method.

Figure 1. Carbide flat end mill cutter with AlTiN coating.

Table 1. Properties of SS316

Elements	Weight %
C	0.063
Mn	1.59
Si	0.51
S	0.019
P	0.028
Ni	12.59
Cr	16.51
Mo	2.33

Figure 2. Wet Machining Condition.

4. Experimental Parameters

Table 2 shows the input process parameters as SS (rev/min), Coating thickness (µm), Depth of Cut (mm) and Feed rate (mm/min) are considered with different levels. Cycle time (min), Wear of the tool (mm), Surface quality, i.e., roughness (R_a), Micro hardness (HV) and Material Removal Rate (mm^3/min) are considered as an output response characteristic.

Table 2. Input Parameters with Levels

S.NO	PARAM-ETER	LEVEL 1	LEVEL 2	LEVEL 3
1	Coating thickness (µm)	3	5	10
2	Spindle speed (rpm)	2000	2500	3000
3	Feed rate (mm/min)	1000	1200	1400
4	Depth of cut (mm)	0.3	0.5	0.7

5. Measuring Output Parameters

Cycle time: The time to complete one cycle of an operation.

Surface roughness: The measurement of surface roughness of the workpiece was performed using Surfcom 1400G as shown in Figure 3. The Surfcom 1400G has a diamond tipped stylus which has a travel range of ±400µm.

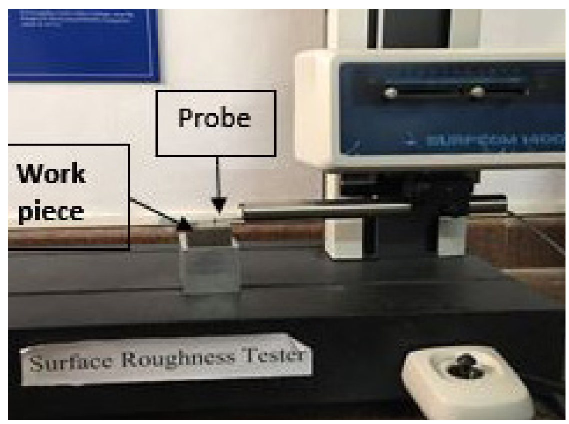

Figure 3. Surface roughness tester.

Material removal rate: It is calculated by weighing the component before and after machining by a formula as

$$MRR = \frac{\text{Intial weight} - \text{Final weight}}{\text{Density} * \text{cycle time}}$$

Tool wear: It was measured using Zoller presenter as illustrated in figure 4.

The measured output parameters are shown in Table 3. The machined components are shown in Figure 5.

Figure 4. Tool wear measurement in Zoller Presetter.

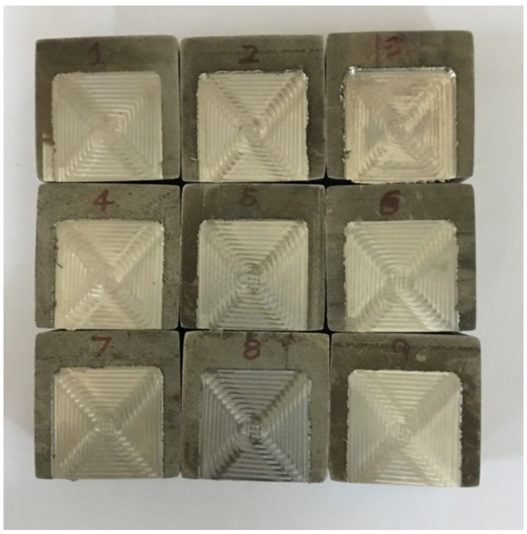

Figure 5. Machined components.

6. Grey - Taguchi Method

6.1 Design of Experiments (DOE)

To optimize different process variables in a meticulous manner, the design of experiments methodology is used. The methodology gives the same precise result with a minimum number of experiments as with the originally required number of experiments. Since four input parameters were chosen with three various levels in our study, L_9 orthogonal array is chosen as per the corresponding Design of Experiments table. Table IV shows that constructed L_9 orthogonal array with four parameters and three different levels.

6.2 Signal to Noise Ratio

The obtained value in each experiment is converted into S/N ratio. Since the material removal rate is supposed to be high, 'the higher - the better' characteristic is chosen. Hence the Signal to Noise ratio for Material Removal Rate is calculated by the formula,

$$S/N = -10 \log \frac{1}{n\left(\Sigma\left(\frac{1}{y^2}\right)\right)}$$

Surface roughness, tool wear, cycle time are considered smaller the better, and their values are converted into Signal to Noise ratio using formula,

$$S/N = -10 \log \frac{1}{n(\Sigma(y^2))}$$

Where 'n' is the number of experimental replication and 'y' is the value of each experiment.

The S/N ratio is the ratio of mean (signal) to the standard deviation (noise) which takes the mean variability into consideration too. There are three kinds of quality characteristic features in this analysis, 'the lower - the better', 'the higher - the better' and 'the nominal - the better.' Based on the preferred effect of output parameters this S/N analysis is selected. The calculated S/N ratio is tabulated in Table 5.

7. Grey Relational Analysis

When multiple responses are considered which hold significant relationships among them, Grey relation analysis is used. The report contains following approaches and rules:

1. Change the obtained values into S/N ratio using the appropriate equations based on the required output characteristics.

2. Normalize the S/N ratio to make it even in scale for further calculations. The normalization can be done using the following formulae. The normalized S/N ratio is shown in Table 6.

Z=(y-max y) / (max y-min y)
[For 'the larger - the better' case]
Z= (max y-y) / (max y-min y)
[For 'the smaller - the better' case]

3. The grey coefficient for the normalized S/N ratio values is calculated using the formula

$GC= (\Psi_{min} + \delta\Psi_{max}) / (\Psi_y + \delta\Psi_{max})$

Where GC is the grey coefficient, δ is the quality loss, and Ψ is the distinct coefficient (Ψ values ranges from 0 to1. Calculate Grey Relation Grade (Gg) by the formula,

$G_g = (1/N)\,\Sigma GC$

Table 3. Measured output characteristics

Experiment	Coating thickness(μm)	Spindle speed(rpm)	Feed rate(mm/min)	Depth of cut(mm)	Cycle time (min)	Tool wear (mm)	Surface roughness(R_a)	MRR (mm^3/min)
1	3	2000	1000	0.3	1.93333	0.005	0.4440	129.47
2	3	2500	1200	0.5	1.83333	0.006	0.5688	204.8
3	3	3000	1400	0.7	1.60000	0.002	1.0793	312.89
4	5	2000	1200	0.7	1.78333	0.004	0.5132	421.08
5	5	2500	1400	0.3	1.56667	0.030	0.5480	159.78
6	5	3000	1000	0.5	1.93333	0.001	0.4043	193.99
7	10	2000	1400	0.5	1.55000	0.010	0.5641	242.23
8	10	2500	1000	0.7	1.96667	0.007	0.5476	318.18
9	10	3000	1200	0.3	1.81667	0.003	0.5363	137.79

Where N is number of output characteristics (as shown in Table 7)

Table 4. Design of experiments (L_9)

Experiment	Coating thickness (μm)	Spindle speed (rpm)	Feed rate(mm/min)	Depth of cut (mm)
1	3	2000	1000	0.3
2	3	2500	1200	0.5
3	3	3000	1400	0.7
4	5	2000	1200	0.7
5	5	2500	1400	0.3
6	5	3000	1000	0.5
7	10	2000	1400	0.5
8	10	2500	1000	0.7
9	10	3000	1200	0.3

Table 5. S/N Ratio for Output Parameters

S. no	Cycle time	Tool wear	Surface roughness	MRR
1	-5.72612	46.02060	7.05234	42.24503
2	-5.26481	44.43697	4.90081	46.22824
3	-4.08240	53.97940	-0.66284	49.90786
4	-5.02463	47.95880	5.79427	52.48760
5	-3.89955	30.45757	5.22439	44.07050
6	-5.72612	60.00000	7.86593	45.76550
7	-3.80663	40.00000	4.97288	47.68486
8	-5.87463	43.09804	5.23073	50.05370
9	-5.18552	50.45757	5.41184	42.78447

Table 6. Normalized Values

S. No	Cycle time	Tool wear	Surface roughness	MRR
1	0.92819	0.47320	0.09539	0.00000
2	0.70510	0.52680	0.34766	0.38889
3	0.13335	0.20380	1.00000	0.74814
4	0.58897	0.40759	0.24290	1.00000
5	0.04493	1.00000	0.30972	0.17822
6	0.92819	0.00000	0.00000	0.34371
7	0.00000	0.67699	0.33921	0.53110
8	1.00000	0.57212	0.30898	0.76237
9	0.66677	0.32301	0.28774	0.05267

Table 7. Grey Relational Coefficient with Grade

Cycle time	Tool wear	Surface roughness	MRR	Grading	Rank -ing
0.87442	0.48695	0.35597	0.33333	0.51266	5
0.62901	0.51377	0.43390	0.45000	0.50667	6
0.36586	0.38574	1.00000	0.66502	0.60416	2
0.54883	0.45770	0.39774	1.00000	0.60107	3
0.34363	1.00000	0.42007	0.37828	0.53550	4
0.87442	0.33333	0.33333	0.43242	0.49336	7
0.33333	0.60753	0.43074	0.51605	0.47191	8

1.00000	0.53886	0.41981	0.67785	0.65913	1
0.60007	0.42481	0.41245	0.34546	0.44570	9

The average Gg is obtained to find out the influence of each factor on its range. The difference between the maximum and minimum average Gg tells us about the most influential input parameter. The average grey relation class for each input process variable and its levels are shown in Table 8.

Table 8. Average Grey Relational Grade

Control Factor	Average Grey Relational Grade			Max - Min
	Level 1	Level 2	Level 3	
Tool Coating thickness	0.54116	0.54331	0.52558	0.01773
Spindle speed	0.52855	0.56710	0.51441	0.05269
Feed rate	0.55505	0.51781	0.53719	0.03724
DOC	0.49795	0.49065	0.62145	0.13080

Table 9. Experimental Result

Cycle time (min)	Tool wear (mm)	Surface roughness (R_a)	MRR (mm^3/min)
2.05	0.007	0.5369	318.18

Figure 6 as given depicts the effect of various input factors on the cycle time. Tool coating thickness of 3µm, spindle speed of 2500 rev/min, 1000 mm/min feed rate, 0.7 mm DOC are the most effecting values of factors.

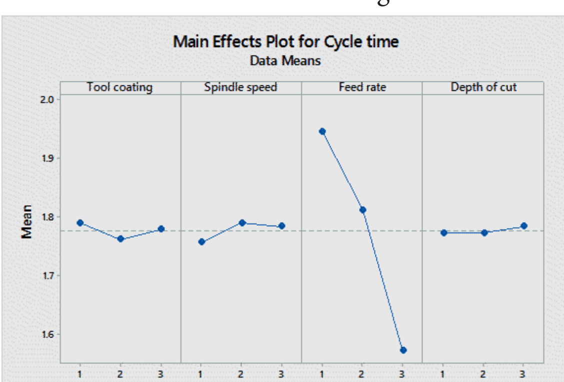

Figure 6. Main effects diagram for Cycle Time.

Figure 7 depicts the effect of various input factors on the Material removal rate. Tool coating thickness of 5 µm, spindle speed of 2000 rpm, 1200 mm/min feed rate, 0.7 mm DOC are the most effecting values of factors.

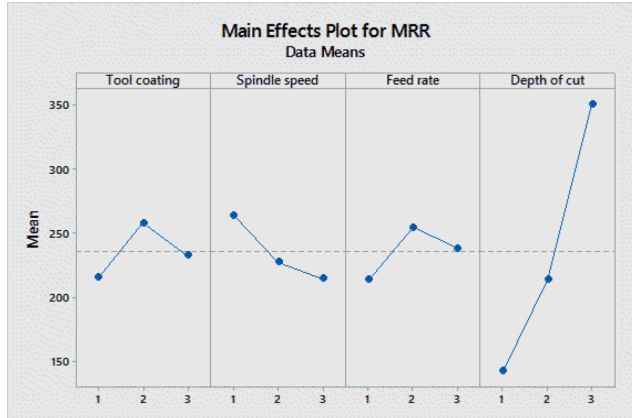

Figure 7. Main effects diagram for MRR.

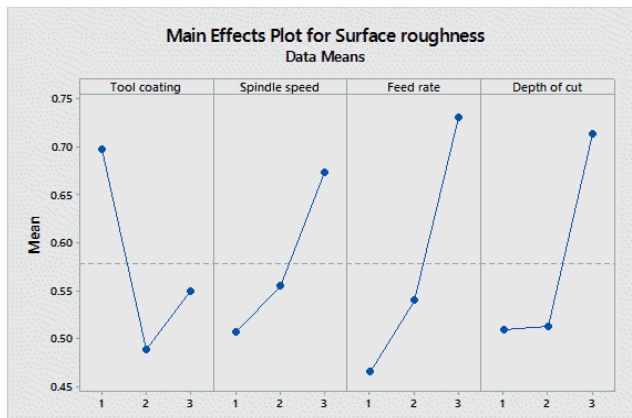

Figure 8. Main effects diagram for Surface Roughness.

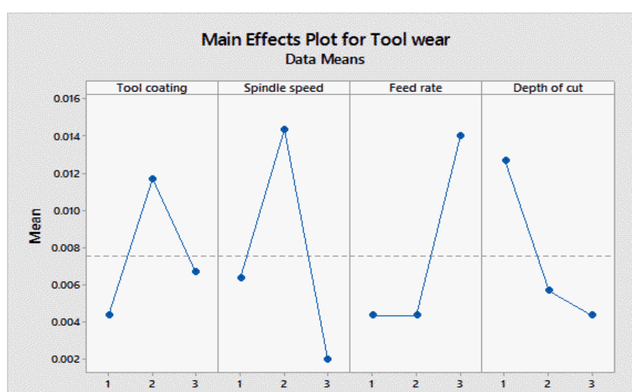

Figure 9. Main effects diagram for Tool Wear.

Figure 8 depicts the effect of various input factors on the surface quality of the material. Tool coating thickness of 3 µm, spindle speed of 3000 rpm, 1400 mm/min feed rate, 0.7 mm DOC are the most effecting values of factors

Figure 9 shows the effect of various input factors on the tool wear. Tool coating thickness of 5µm, spindle speed of 2500 rpm, 1400 mm/min feed rate, 0.3 mm DOC are the most effecting values of factors.

Figure 10 shows the response graph for optimized input parameter for cumulative required output characteristics. The graph of reply have input parameters such as (A1, A2, A3) shows the three different levels of tool coating thickness (B1, B2, B3) shows three varying levels of spindle speed (C1, C2, C3) shows the three levels of feed rate (D1, D2, D3) shows the three levels of DOC.

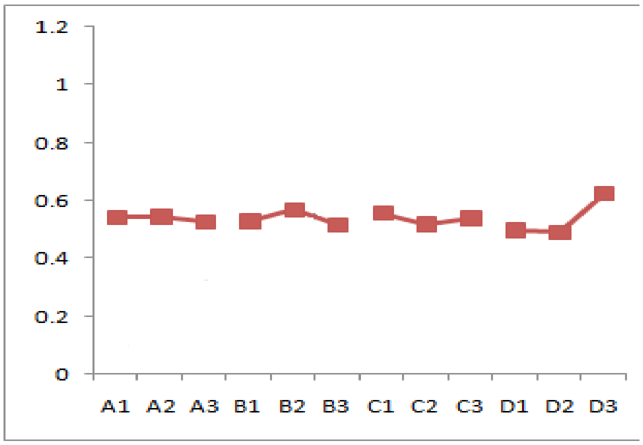

Figure 10. Response Graph for average grey relational grade.

It is examined from the response graph that the optimum value are level 2 for tool coating thickness, level 2 for spindle speed, level 1 for feed rate and level 3 for depth of cut. The confirmation test is done using obtained optimum input parameters.

8. Confirmation Test

The acceptance test is carried out by using obtained optimum input parameters from grey relation analysis method. The acceptance test was done with a tool of coating thickness having 10 µm, SS of 2500 rev/min, the feed rate of 1000 mm/min and 0.7mm DOC. Table 9 shows the output characteristics for the confirmation test.

9. Conclusion

The current study features the use of Grey – Taguchi analysis method to find out the optimum input machining parameters for machining pocket milling operation in AISI stainless steel 316 material.

1. From the grey relation grade, the highest maximum – minimum value shows the depth of cut is the most influential input parameter for the obtained output characteristics.
2. The optimum input parameters are the tool of coating thickness having 10 µm, spindle speed of 2500 rev/min, the feed rate of 1000 mm/min and 0.7 mm depth of cut.
3. The verification test has proved that the obtained optimum input parameters satisfy the required output characteristics for pocket milling operation in AISI stainless steel 316 material.

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