Parametric Optimization of CNC End Milling Process Using Taguchi Method

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Abstract - *Selection of optimum process cutting conditions helps to improve the performance of any manufacturing process. In the present work, a study was made to know the impact of cooling method type and process parameters on milling process performance during NC machining of Al 5082 material using Taguchi technique.*

In milling process, cutting speed, feed rate and depth of cut were taken as milling process variables and cutting temperature (CT), surface roughness (Ra) and material removal rate (MRR) were considered as outputs. Taguchi L9 orthogonal array (OA) experimental design plan was consider for carrying out the experiments. From, the obtained results, optimum process variables were selected for all the output characteristics and observed substantial improvement in the milling process performance at the Taguchi determined optimum conditions respectively.

Key Words: Al 5082 Material; Milling Process; Taguchi Method; Cutting Temperature; Surface Roughness; Material Removal Rate

1. INTRODUCTION

In today's manufacturing market, quality and productivity are crucial factors. From the perspective of the consumer, quality is crucial since it impacts how satisfied the consumer will be. In addition to quality, productivity is another crucial factor that exists and is closely linked to both the growth and profitability of an industry. Every manufacturing company wants to produce more goods within a shorter time. Productivity can be maximized by having sound knowledge of all the optimization techniques for machining.

Among various types of milling processes, end milling is one of the most important and common metal cutting techniques used for machining parts because of its capability to remove materials quickly with a decent good surface quality. Also, it is capable of producing a variety of configurations using milling cutter. Additionally, it may use a milling cutter to produce a range of designs. Computer numerically controlled (CNC) machine tools have been used recently to automate the milling operation completely. It reduces the need for operator input, boosts production, and improves the quality of machined products. These factors have led to the recent discovery that the CNC end milling technique is a very flexible and useful machining operation in the majority of modern manufacturing industries. The automation of the final milling process is not the only accomplishment. For machining to be effective and to meet industry needs, it is also essential to continuously enhance the machining process and machining performances.

Surface roughness is a key factor in the machining process while considering machining performance and that is why in many cases, industries are looking for maintaining the good surface quality of the machined parts. Surface roughness is a major determinant of production cost and quality and a gauge of a product's technological quality. It explains the geometry of the machined surface and, when paired with surface texture, can significantly impact the operational characteristics of the part.

On the other hand, another crucial element that significantly affects production rate and cost is material removal rate (MRR), which shows the work piece's processing time. Therefore, a tool that will enable the assessment of the material removal rate (MRR) and surface roughness prior to part machining is required. This tool should also be simple to use on the production floor, helping to reduce time and expense requirements while producing the desired surface quality. Changes in the cutting process parameters result in significant variations in both surface roughness and material removal rate. For this reason, accurate process parameter selection is also important with its prediction to obtain good surface finish (lower Ra value) and higher material removal rate in CNC end milling process.

Liao et al. (2007) found that MQL is the feasible cooling technique while high speed milling of NAK80 hardened steel over dry and wet condition. Da Silva et al. (2011) performed milling experiments on AISI 1047 steel with coated tungsten carbide tools under flood, reduced fluid flow rate (250 ml/min) and MQL. It was reported that reduced fluid flow rate significantly increased the cutting length and MRR due to the prevention of chipping tool wear mechanism when compared to other conditions respectively. Asiltürk and Akkuş (2011) determined the optimum cutting condition for achieving low Ra and Rz using Taguchi optimization techniques while dry turning of AISI 4140.

Zhang et al. (2012) while end milling Inconel 718, used MQCL hybrid cooling approach. MQCL involves a combination of micro droplets of vegetable-based coolant along with cryogenic compressed air. Tool life and cutting force were taken as investigative outputs under MQCL and dry cutting conditions. Experimental results showed that

MQCL significantly improves the milling performance owing to low friction between tool-chip interfaces. Duchosal et al. (2015) optimized the canalization orientations of MQL, the inlet pressure of MQL supply, feed rate and cutting velocity to achieve best milling performance using Taguchi method.

Masmiati et al. (2016) found that MQL cooling notably controlled the residual stress and Fc in down milling mode whereas flood cooling appreciably reduces the Ra under down and up milling modes respectively. Further, predictive mathematical models were developed using RSM. Hassanpour et al. (2016) Using RSM and end milling 4340 alloy steel under MQL conditions, mathematical models were created for micro hardness (Hv), white layer thickness (WLT), and Ra as a function of cutting speed, feed rate, and axial and radial depth of cut. Additionally, the ANOVA results show that feed rate is the process parameter that has the greatest influence on Ra and Hv, whereas cutting velocity has the greatest influence on WLT.

Mia et al. (2017) identified the optimum cutting parameters and achieved low Ra and feed force using Gray Taguchi approach over RSM desirability analysis while end milling of hardened AISI 4140. In the literature, milling experiments were carried out with MQL using nano fluids and observed improved performance when compared to MQL without nano fluids and flood cooling technique (Najiha, Rahman and Kadirgama, 2016; Yin et al., 2018). Kurt et al. (2017) employed Taguchi methods in the optimisation of cutting parameters for surface finish, and hole- diameter accuracy in a dry drilling process. The orthogonal array (OA), the S/N ratio, the analysis of variance, and regression analyses were used to determine the optimal levels and the effects of the drilling parameters on surface roughness and hole diameter. One of the most important machinability metrics is machined surface quality since it influences how well a product performs functionally (Sivaiah and Chakradhar, 2017). Further, from the customer point of view, the most demanded requirement from the machined product is surface quality. It was reported that conducting experiments at the optimum cutting conditions significantly improves any process performance. Optimum cutting conditions can be determined by using meta and non-meta heuristic techniques.

Mia (2018) optimized the Fc and Ra while milling of AISI 4140 material using Taguchi and RSM under MQL condition. Further, mathematical models have been developed o predict the outputs.

Okafor and Jasra(2018) due to the improved lubricating effect, low Fc was found in high-speed end milling of Inconel-718 under MQL cutting conditions compared to cryogenic and cryo+MQL cutting conditions, respectively. Li et al. (2019) optimized the nano fluid diffuse MQL process parameters while milling of titanium alloy (TC4) using PCA and GRA.

The aim of this investigation is to optimize the end milling process during machining of Al 5082 material using Taguchi optimization technique.

2. EXPERIMENTAL WORK

One of the most essential and abundantly found metals in the world is Aluminium that comprises 8% of the total earth crust. Aluminium 5082 Plates exhibit good mechanical properties, great strength, excellent corrosion resistance in marine environments and good weldability. The aluminium 5082 plates are medium strength plates with magnificent corrosion resistance. The other name of it is structural alloy. The grain structure got control due to a specified amount of manganese that in turn offers stronger alloy manufacturing.

Table 1 displays the process parameters that were taken into consideration for this work. As seen in Figures 1 & 2, a CNC milling machine was utilized to carry out the milling process both before and during. The material was machined using an end bit tool made of tungsten carbide. Throughout the machining process, Castrol cool edge cutting oil was used.

Table 1 Milling process parameters and their levels

Symbol	Process parameters	Units	Levels		
			1	2	3
A	Cutting speed	m/min	900	1300	1700
B	Feed rate (*f*)	mm/tooth	100	150	200
C	Depth of cut	mm	0.2	0.4	0.6

In any machining operation, material removal rate is an important factor to enhance the productivity. Hence the characteristics for Material Removal Rate is “larger the better”. Eqn (1) was used to calculate the MRR.

$$MRR = (D \times W \times F / 1000) \text{ cc/min} \quad \text{-------- (1)}$$

Where, D: Depth of cut, mm
W: Width of cut, mm
F: Feed rate, mm/tooth

Surface Roughness characteristics are mostly aimed to achieve better surface finish. The surface roughness was measured using SJ 301 model Talysurf tester, where as machining zone temperature was measured by using thermal image camera. Table 2 shows the obtained experimental results.

Figure 1 Before end milling operation

Figure 2 Workpiece during milling operation

Table 2 Experimental results

S. No.	Spindle Speed (RPM)	Feed rate (mm/ tooth)	Depth of cut (mm)	Temp (°C)	Surface roughness (μm)	MRR (mm³/ min)
1	900	100	0.2	35.6	0.362	200
2	900	150	0.4	36.6	0.648	600
3	900	200	0.6	35.8	0.503	1200
4	1300	100	0.4	36.7	0.918	400
5	1300	150	0.6	36.2	0.922	900
6	1300	200	0.2	36.5	0.493	400
7	1700	100	0.6	35.9	0.346	600
8	1700	150	0.2	36.8	0.993	300
9	1700	200	0.4	38	0.299	800

3. RESULTS AND DISCUSSION

The objective of this work is to understand the creation of a product or process design that is insensitive to all possible combinations of uncontrollable noise factors and is at the same time effective and cost-efficient as a result of setting the key controllable factors at certain levels. The central purpose of this study is to understand and evaluate the impact of Taguchi methods in quality engineering and management for product or process parameters optimization both in the manufacturing industry and service industry.

Any process is the combination of one or more factors and will give the best possible output when all these factors operate at the optimum values. If total number of factors and levels involved is more, then the number of experiments will become very large because of this Taguchi design of experiments is used which uses Orthogonal Array (OA) which is the shortest possible matrix of combinations.

Taguchi used the term signal and noise which represents wanted value (mean) for the response and unwanted value (standard deviation) for the response respectively. Based on the requirements of response, Taguchi has divided the S/N ratio into to three categories namely medium-the-better, higher-the-better and lower-the-better. In the present study, the quality characteristics like cutting temperature & R_a are the lower-the-better requirement whereas MRR is higher-the-better to enhance the machinability. So, equation (2) and equation (3) have been used to calculate the S/N ratio and results have been shown in Table 3. Taguchi analysis was done using Minitab 17.0 software tool, means of S/N ratio plots results were obtained and presented in the upcoming discussions.

S/N ratio for smaller the better = $-10 \log \frac{1}{n} \sum (R)^2$ ------(2)

S/N ratio for larger the better = $-10 \log_{10} \frac{1}{n} \sum_{i=1}^{n} \left(\frac{1}{R^2}\right)$----(3)

Table 3 Experimental results and respective calculated S/N ratios.

S. No.	Spindle Speed (RPM)	Feed rate (mm/tooth)	Depth of cut (mm)	Temp (°C)	Surface roughness (μm)	MRR (mm³/min)
1	900	100	0.2	-31.0290	8.825	46.0206
2	900	150	0.4	-31.2696	3.768	55.5630
3	900	200	0.6	-31.0777	5.968	61.5836
4	1300	100	0.4	-31.2933	0.743	52.0412
5	1300	150	0.6	-31.1742	0.705	59.0849
6	1300	200	0.2	-31.2459	6.143	52.0412
7	1700	100	0.6	-31.1019	9.218	55.5630
8	1700	150	0.2	-31.3170	0.061	49.5424
9	1700	200	0.4	-31.5957	10.48	58.0618

3.1 Determination of optimum cutting conditions for cutting temperature

The obtained S/N ratio response table for the cutting temperature is shown in Table 4. Figure 3 represents the mean S/N ratio graph obtained in Minitab software tool. Higher S/N ratio represents the minimum variation difference between the desirable output and measured output. From Figure 3, it was noticed that the highest mean S/N ratio obtained for cutting temperature are cutting speed at 900RPM, feed rate at 100 mm/tooth, depth of cut 0.6mm mm respectively. Therefore, the predicted optimum process parameters for obtaining the low cutting temperature using Taguchi method were found as cutting speed at 900RPM, feed rate at 100 mm/tooth, depth of cut 0.6mm respectively. Figure 4 shows the impact of individual process variables on cutting temperature.

Table 4 Mean S/N ratio response table for cutting temperature

Symbol	Process parameters	Mean S/N ratio				
		Level 1	Level 2	Level 3	Max-Min	Rank
v	Cutting speed (RPM)	**-31.13**	-31.24	-31.34	0.21	2
f	Feed rate (mm/tooth)	**-31.14**	-31.25	-31.31	0.16	3
d	Depth of cut	-31.20	-31.39	**-31.12**	0.27	1

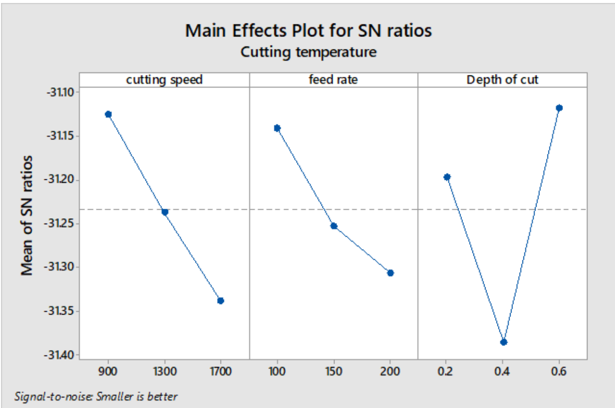

Figure 3 Mean S/N ratio of cutting temperature

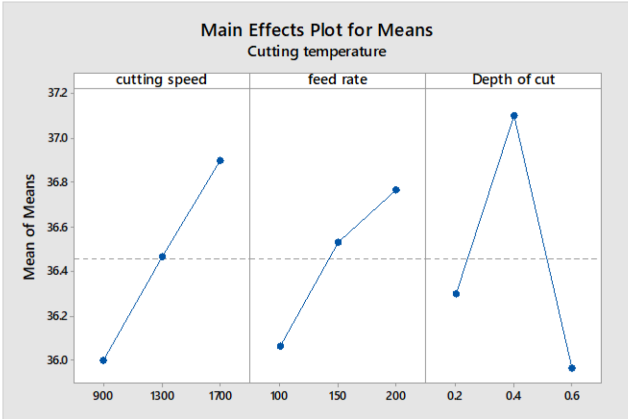

Figure 4 Effect of individual process variables on cutting temperature

3.2 Determination of optimum cutting conditions for surface roughness

The obtained S/N ratio response table for the surface roughness is shown in Table 5. Figure 5 represents the mean S/N ratio graph obtained in Minitab software tool. Higher S/N ratio represents the minimum variation difference between the desirable output and measured output. From Figure 5, it was noticed that the highest mean S/N ratio obtained for surface roughness are cutting speed at 900RPM, feed rate at 200 mm/tooth, depth of cut 0.6mm respectively. Therefore, the predicted optimum process parameters for obtaining the low surface roughness using Taguchi method were found as cutting speed at 900RPM, feed rate at 200 mm/tooth and depth of cut 0.6mm respectively. Figure 6 shows the impact of individual process variables on surface roughness.

Table 5 Mean S/N ratio response table for surface roughness

Symbol	Process parameters	Mean S/N ratio				
		Level 1	Level 2	Level 3	Max-Min	Rank
v	Cutting speed (RPM)	6.188	2.531	**6.589**	4.058	2
f	Feed rate (mm/rev)	6.262	1.512	**7.533**	6.021	1
d	Coolant type	5.010	4.999	**5.297**	0.298	3

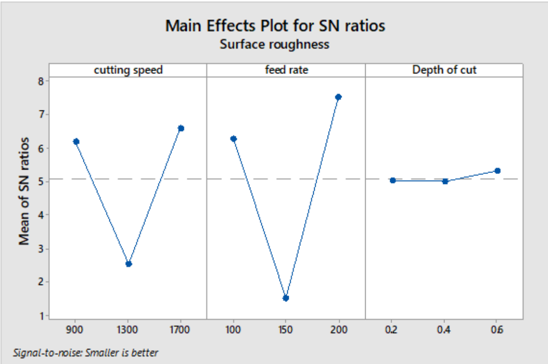

Figure 5 Mean S/N ratio of surface roughness

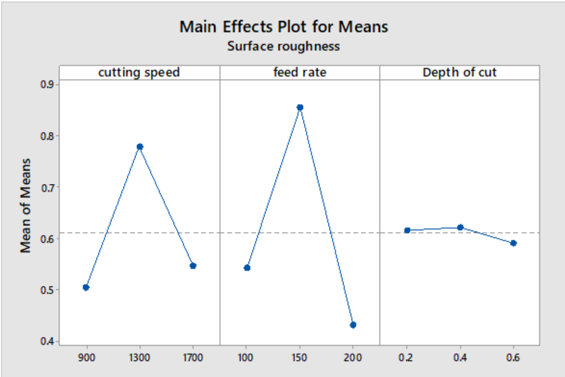

Figure 6 Effect of individual process variables on surface roughness

3.3 Determination of optimum cutting conditions for MRR:

The obtained S/N ratio response table for the MRR is shown in Table 6. Figure 7 represents the mean S/N ratio graph obtained in Minitab software tool. Higher S/N ratio represents the minimum variation difference between the desirable output and measured output. From Figure 7, it was noticed that the highest mean S/N ratio obtained for MRR are cutting speed at 900RPM, feed rate at 200 mm/tooth, depth of cut 0.6mm respectively. Therefore, the predicted optimum process parameters for obtaining the maximum MRR using Taguchi method were found as cutting speed at 900RPM, feed rate at 200 mm/tooth, depth of cut 0.6 mm respectively. Figure 8 shows the impact of individual process variables on surface roughness.

Table 6 Mean S/N ratio response table for MRR

Symbol	Process parameters	Mean S/N ratio				
		Level 1	Level 2	Level 3	Max-Min	Rank
v	Cutting speed (RPM)	54.39	54.39	**54.39**	0.00	3
f	Feed rate (mm/rev)	51.21	54.73	**57.23**	6.02	2
d	Coolant type	49.20	55.22	**58.74**	9.54	1

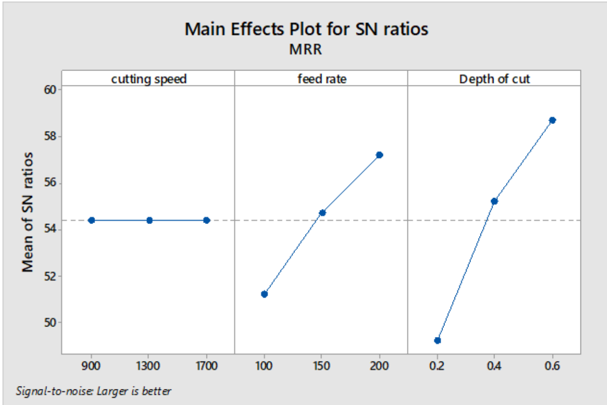

Figure 7 Mean S/N ratio of MRR

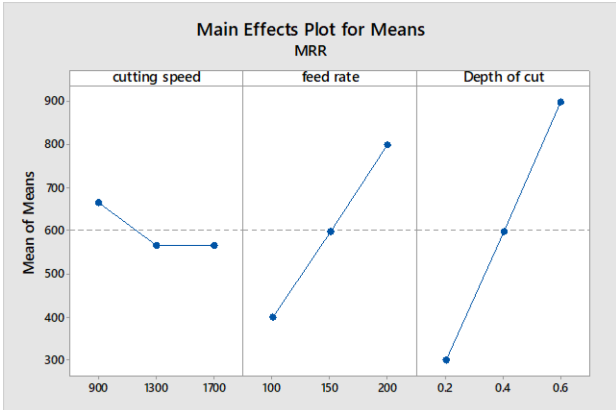

Figure 8 Effect of individual process variables on MRR

3.4 Confirmation Test

Confirmation tests must be performed in order to validate the Taguchi predicted optimal conditions. The confirmation experiments were carried out at the necessary positions at the Taguchi predicted optimum cutting conditions. The findings were displayed in Table 7 for each output, accordingly. The performance characteristic results show an improvement when predicted optimum cutting conditions are met for all outputs.

The Taguchi projected optimum cutting circumstances yield better outcomes than the initial parameter conditions, according to the confirmation experiments. As a result, when end milling Al 5082 material under the specified conditions, the Taguchi predicted optimum cutting conditions were considered to be the best cutting conditions. Based on the findings, it was determined that, for the given process parameters, the Taguchi optimization method considerably enhanced the machinability properties of the Al 5082 material.

Table 7 Conformation test results for Cutting temperature, surface roughness and MRR

	Initial process parameter	Predicted optimal process parameters
Cutting temperature (°C)		
Level	N=900RPM, f=100 mm/tooth, depth of cut = 0.2 mm	N=900RPM, f=100 mm/tooth, depth of cut = 0.6 mm
Cutting temperature (°C)	*35.6*	*35.6*
Surface roughness (μm)		
Level	N=900RPM, f=100 mm/tooth, depth of cut = 0.2 mm	N=900RPM, f=200 mm/tooth, depth of cut = 0.6mm
Surface roughness(μm)	0.362	*0.252*
MRR (*cc/min*)		
Level	N=900RPM, f=100 mm/tooth, depth of cut = 0.2 mm	N=900RPM, f=200 mm/tooth, depth of cut 0.6 mm
MRR (*mm^3/min*)	200	1200

4. CONCLUSIONS

Optimum process variables were selected for all the outputs using Taguchi technique and observed substantial improvement in the end milling process performance during machining of Al5082 material at the Taguchi determined optimum conditions respectively.

- The optimum process parameters for obtaining the low cutting temperature using Taguchi method were found as cutting speed at 900RPM, feed rate at 100 mm/tooth, depth of cut 0.6 mm respectively.
- The optimum process parameters for obtaining the low surface roughness using Taguchi method were found as cutting speed at 900RPM, feed rate at 200 mm/tooth, depth of cut 0.6mm respectively.
- The optimum process parameters for obtaining the high MRR using Taguchi method were found as cutting speed at 900RPM, feed rate at 200 mm/tooth, depth of cut 0.6 mm respectively.

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