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The Optimization of Ball End-Milling Parameters on the Surface Roughness of STD61 Steel using the Taguchi Method

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Taguchi 방법을 이용한 STD61의 표면거칠기에 대한 볼 엔드 밀링 파라미터 최적화

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ABSTRACT

When considering the proper function and life cycle length of a product, its surface finish plays an important role. This experimental study was carried out to understand the effect of input factors on surface roughness and how it can be minimized by controlling the input parameters. This experimental work was performed by machining the surface of STD 61 blocks with a surface inclined at 30° by ball end-milling and optimizing the input parameters using the Taguchi technique. Signal-to-Noise (S/N) ratio and analysis of variance (ANOVA) were applied to find the significance of the input parameters. The optimum level of input parameters to minimize surface roughness was obtained.

Keywords : Surface Roughness(표면조도), Ball Endmill(볼엔드밀), Taguchi(타구치), Orthogonal Array(직교배열)

1. Introduction

Surface roughness is an important aspect of technological quality and influences greatly on the product manufacturing cost and proper functioning of the machined part. The need for producing a smooth surface can be achieved by controlling the process of manufacturing. The mechanism behind the formation of surface roughness is very dynamic, complicated and process dependent, thus it is difficult to calculate the value through theoretical analysiss[1]. In an industrial scenario, for obtaining the desired surface finish, trial and error approach is usually applied to set the machining parameters. This approach is ineffective, poorly efficient and makes the process time- consuming. Hence, a systematic approach, by employing the optimization of input parameters is to be followed to make the process efficient with high productivity.

A number of researchers have studied experimentally the effect of input parameters on surface integrity with micro end-mill. Wang et. al.[2] used response surface methodology to investigate the effect of input parameters on surface roughness for brass material in micro milling. Emel kuram et. al.[3]

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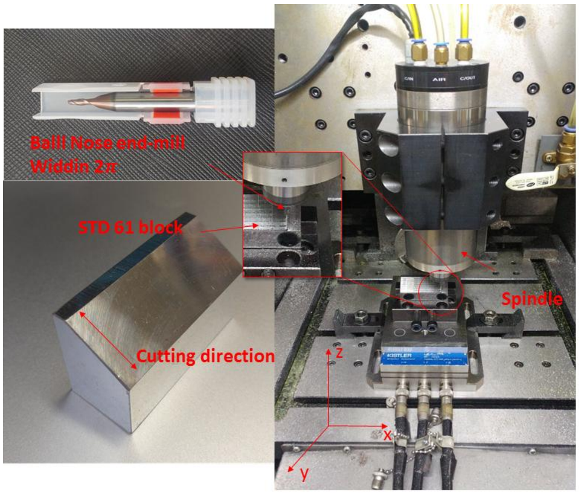

Fig. 1 Experimental Setup

performed multi-objective optimization using Taguchi based grey relational analysis for micro milling of Al 7075 material with ball end-mill. They investigated the effect of speed, feed rate and depth of cut to minimize the tool wear and surface roughness. Xiaoxiao Chen et. al.[4] studied the machined surface properties and cutting performance of high speed five-axis milling process in order to enhance the efficiency of the process. Nik Masmiati et. al. [5] optimized the cutting parameters for better surface roughness in 2.5D cutting using ball end-mill, optimization of parameters was done using the Taguchi method.

Most of the previous studies related to ball nose end-mill were carried out, taking some soft metal as the work material but as ball nose end mill is usually applied for the machining of high hardness material Thus in the present study, STD61 tool steel having hardness of 60 HRC was taken as work material

2. Experimental details

2.1 Material and machine setup

STD61 steel blocks (0.36% C, 1.2% Si, 1.25% Mo and 60 HRC) having 30° inclination on the surface being machined was selected as work material. CNC

Table 1 Output response with the corresponding input parameters

	Input parameters			Output		
Exp. No.	Depth of Cut(mm)	Spindle Speed (RPM)	Feed Rate (mm/min)	Ra(μm)	S/N Ra	Mean
1	0.04	10000	600	1.18	-1.41307	1.17667
2	0.04	10000	800	1.21	-1.6796	1.21333
3	0.04	10000	1000	1.19	-1.53524	1.19333
4	0.04	15000	600	1.12	-0.98436	1.12
5	0.04	15000	800	1.15	-1.21396	1.15
6	0.04	15000	1000	1.15	-1.2391	1.15333
7	0.04	20000	600	1.3	-2.27887	1.3
8	0.04	20000	800	1.28	-2.12155	1.27667
9	0.04	20000	1000	1.34	-2.52046	1.33667
10	0.08	10000	600	1.1	-0.80149	1.09667
11	0.08	10000	800	1.13	-1.08715	1.13333
12	0.08	10000	1000	1.16	-1.31408	1.16333
13	0.08	15000	600	1.2	-1.58362	1.2
14	0.08	15000	800	1.19	-1.53524	1.19333
15	0.08	15000	1000	1.2	-1.58362	1.2
16	0.08	20000	600	1.18	-1.43764	1.18
17	0.08	20000	800	1.29	-2.21628	1.29067
18	0.08	20000	1000	1.14	-1.112266	1.13667

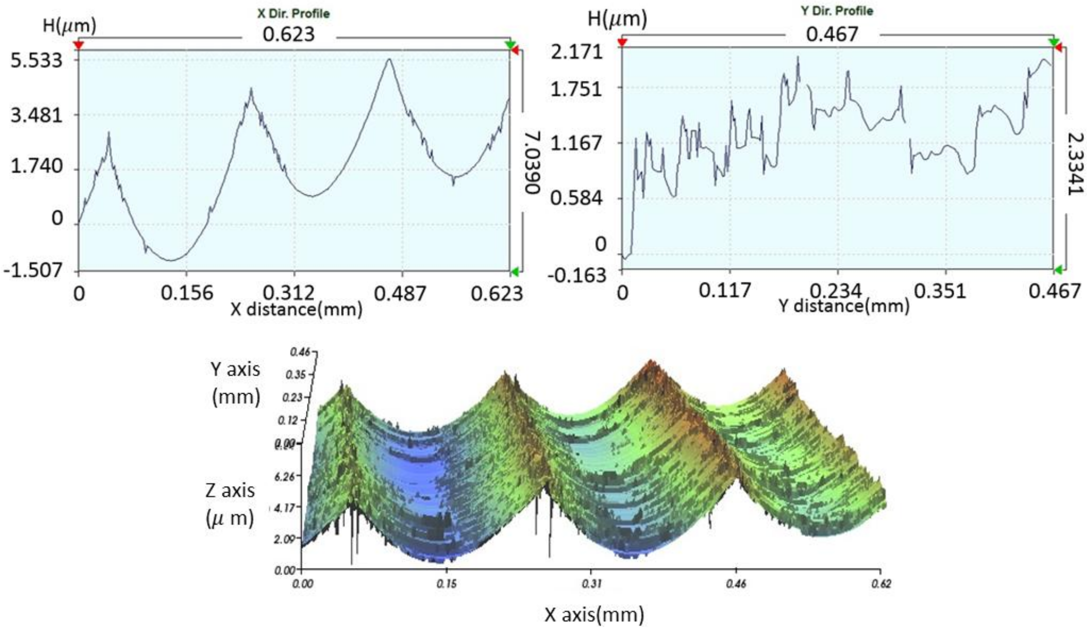

Fig. 2 Surface roughness profile and 3D surface geometry for optimal conditions

vertical End mill was used to conduct the experiments under dry environment with tool feed in y-direction (Fig. 1) Tungsten carbide ball nose end-mill with a helix angle of 30° and diameter 2mm was used for machining the work pieces.[8] Surface roughness was measured using a non-contact 3D surface measurement system (Nano system Co., Ltd., NV 2000) (Scanning range= 180μm , Scanning velocity= 7.2 μm/s, accuracy= ±0.01μm and repeatability<0.5%).

2.2 Design of Experiments

In this experiment, three input parameters i.e. spindle speed (10000, 15000, 20000 rpm), feed rate (600, 800, 1000 mm/min) and depth of cut (0.04, 0.08 mm) were considered for the optimization of surface roughness. Taguchi technique was adopted to optimize the input parameters for achieving lower surface roughness. L18(2^1X3^2) orthogonal array was selected to conduct the experiments.

3. Results and Discussion:

Experimental results were analyzed in terms of surface roughness using ANOVA. Surface roughness Ra, for the STD61 samples machined with different input parameters combinations, has been measured at three different points for each set of input parameters and an average value for each sample is reported (table 1).

Figure 2 shows the roughness profile in X and Y direction and 3D Surface profile for the optimal conditions of input parameters as suggested by Taguchi analysis (10000 rpm, 600 mm/min, 0.08 mm)[9].

Increase in spindle speed was found to decrease the Ra. Similar response for Ra was reported by Emel Kuram, et. al. [3]. On the contrary, some researchers observed increment in Ra with increase in spindle speed [2]. Decrease in Ra with increase in spindle speed can be explained by the fact that at of squares;

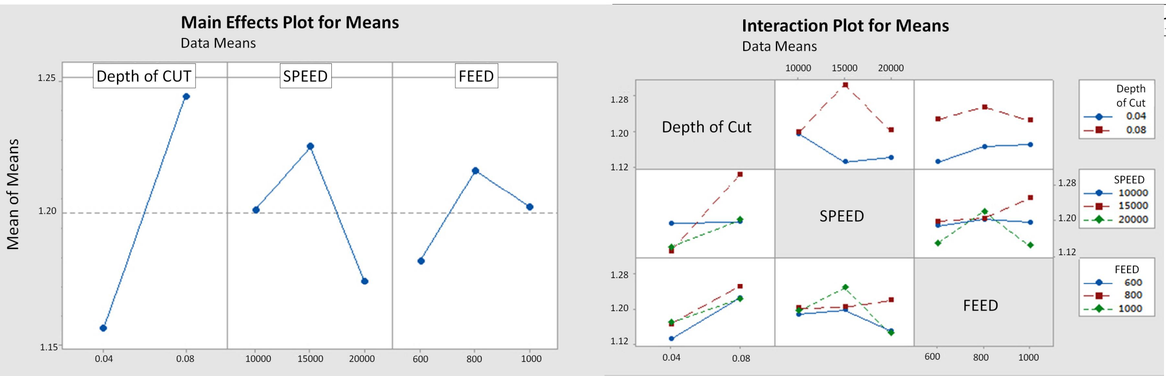

Fig. 3 Main effect and interaction plot for Means

higher speeds, cutting becomes more stable and the chips getting formed, comes in contact with the newly formed surface for a very short duration of time and hence, have little or no negative effect on the machined surface.

3.1 Statistical Analysis of Surface roughness using ANOVA and effects plots:

The main objective of conducting this experimental work was to optimize the input parameters to get the better surface finish. From response table (Table 2), it was observed that the most significant factor was the Spindle speed as it was having the highest delta value followed by the depth of cut and feed rate. Minitab assigns the rank according to the increasing order of delta value. This was also verified from the ANOVA table in which the spindle speed was having the highest level of contribution (32.62%) and then the depth of cut and feed rate. Analysis of Variance was performed for the experimental data as shown in Table 3. From the table contribution of individual parameter and p-value was obtained. In this study, p-value obtained for all the input parameters, is more than 0.05, therefore, the input parameter values need to be reassigned.[6,7,10]

3.2 Analysis of S/N ratio and means:

Table 2 Output response table

Level	Depth of Cut	Spindle speed	feed rate
1	1.213	1.163	1.179
2	1.177	1.169	1.210
3		1.253	1.197
Delta	0.036	0.091	0.031
Rank	2	1	3

Table 3 ANOVA table

Source	DF	seq SS	Adj SS	Adj MS	F-Valuse	P-Value	Contribution
Depth of Cut	1	0.005904	0.000479	0.000479	0.13	0.727	7.86%
Speed	1	0.024661	0.001073	0.001073	0.29	0.603	32.82%
Feed	1	0.001008	0.002965	0.002965	0.80	0.394	1.34%
Speed×Speed	1	0.005980	0.005980	0.005980	1.62	0.235	7.96%
Feed×Feed	1	0.001849	0.001849	0.001849	0.5	0.497	2.46%
DOC×Speed	1	0.001121	0.001121	0.001121	0.3	0.595	1.49%
DOC×Feed	1	0.000334	0.000334	0.000334	0.09	0.770	0.44%
Speed×Feed	1	0.001012	0.001012	0.001012	0.27	0.613	1.35%
Error	9	0.033260	0.033260	0.003696			44.27%
Total	17	0.075132					100.00%
Total	35	15346.3					100.00%

S/N ratio measures the quality characteristics deviating from the desired values and higher S/N ratio means an optimal level of the process parameter. As getting the minimum surface roughness is the desired outcome, smaller-the-better S/N quality characteristic was used. Parameter with the lowest value in the main effect plots for means gives the optimum level of input parameter (Figure 3). So the optimal parameters for surface roughness was spindle speed of 10000 rpm, depth of cut 0.08mm and feed rate of 600mm/min. Lower value of feed rate as suggested by S/N ratio can be explained by the fact that at higher feed rate, there will be larger cross-sectional area of the uncut chip. Consequently, greater will be resistance of work-piece to chip formation and larger cutting forces and hence will lead to poor surface finish. From interaction plot for means relation between various input parameters as well as changes in response of one parameters with respect to other parameters and output response can be obtained. the non parallel lines of interaction plot indicates a greater interaction between the factors. However, in case of depth of cut and feed rate, interaction effect is low as lines can be observed to be near parallel.

4. Conclusion

In this study, the optimal cutting conditions for end milling using the ball end mill were determined by varying cutting parameters through the Taguchi parameter design method. With L_{18} orthogonal array, a total of 18 experiments were conducted by varying the combination of all the three input parameters. From the experimental work carried out and the analysis of results using Taguchi and ANOVA approach following can be concluded:

1. From ANOVA table, it is observed that spindle speed is having the maximum contribution. (32.82 %), followed by the depth of cut and then feed rate.
2. The same is also observed from the response table, which gives speed, the 1st rank.
3. From the main effect plot for means, it is found out that depth of cut 0.08 mm, spindle speed of 10000 rpm and Feed rate 800mm/min is the set of parameters most suitable for getting the lowest surface roughness.
4. From the interaction plots for means, it is observed that speed, feed rate and depth of cut are highly interdependent and have a significant effect on the roughness with the change in levels of these input parameters.

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