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The Optimization of Machining Parameters on Surface Roughness for AISI D3 Steel

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Abstract. Surface finish is one of the most important quality characteristics in manufacturing industries which influences the performance of mechanical parts. This research is focused on the optimization of machining parameters on surface roughness for parting or cut-off operation for the turning process. In machining operations, achieving desired surface quality features of the machined product are really a challenging job. These quality features are highly correlated and are expected to be influenced directly with the effect of process parameters used. Thus, the inputs of machining parameters such as cutting speed (v), feed rates (f) and depth of cut (d) have been selected and the experimental works were designed using the Response Surface Methodology (RSM) for machining AISI D3 steel. The results revealed that at a minimum cutting speed of 140m/min, a minimum feed rate of 0.01mm/rev and a minimum of depth of cut 1 mm give better surface finish. The study concludes that the surface roughness AISI D3 steel is greatly influenced by feed rate and cutting speed which is proven its reliability to obtain the desired level of surface roughness.

1. Introduction

In the manufacturing industry, surface finish is one of the most significant quality characteristics that affect the performance of mechanical parts as well as the cost of production. In recent times, modern companies have tried to produce high-quality goods with less operator input in a very short time. Computer-controlled (CNC) machine tools with automated and scalable manufacturing systems have been introduced for this purpose.

Different production techniques are introduced in the manufacturing industry to remove the material from the workpiece. Due to its ability to remove materials faster with a relatively good surface quality, turning is the first most popular process for metal cutting. The turning process is a simple metal machining procedure that is commonly used in the metal cutting industry [1]. There are several factors that impact surface roughness in real life, e.g., cutting conditions, type of inserts and materials used. The product quality of the part using lathe operation is determined by the correct selection of cutting parameters to obtain the required level of surface roughness. The result of surface roughness is determined by three main parameters, namely cutting speed, feed rate and depth of cut [2][3][4].

However, for unique production process requirements, it is very difficult to monitor all the parameters at one time that affect the surface roughness. A product's surface finish is typically determined in terms of a parameter known as surface roughness. It is known as an index of product quality and predominant characteristic which is included in the machining drawing [6][7]. Improved strength properties such as corrosion resistance, temperature resistance and higher fatigue life of the machined

surface will result in better surface finish [5][9]. In addition to strength properties, the functional behaviour of machined parts may also be influenced by surface finish, such as friction, light reflective properties, heat transfer, lubricant distributing and holding capacity, etc.[8][10]. The cost of production is also influenced by surface finishing [5]. The minimization of surface roughness is important for the aforementioned reasons, which can in turn be accomplished by optimising some of the cutting parameters. Sanjeev Saini et. al. [8] investigated the effect of cutting parameters using ceramic tools on tool wear and surface roughness in the hard turning of AISI H11 tool steel using RSM method. They have concluded that the depth of cut did not affect the tool wear and surface roughness. Meanwhile decrease in feed rate and increase in cutting speed resulted in significant increase in surface quality.
It is a critical task to select the cutting parameters correctly in a turning operation to achieve high quality results. But modelling the surface roughness and optimization of cutting parameters will produce a better result. The objective of this paper is to optimize the effect of machining parameters on surface roughness for AISI D3 steel in wet cutting condition for parting-off process. The systematic experimental was established using RSM the influences of variables were studied to established the best option can be used.

2. Methodology
The methodology is divided into three parts: preparation of material, cutting insert and machine set-up and surface roughness measurement.

2.1. Preparation of Material
The cylindrical material used was AISI D3 steel which has a diameter of 38 mm and 6 mm in length. Due to its emerging range of applications, AISI D3 steel was chosen for precision industries such as moulds and dies or for heavy industries such as the oil and gas sectors. Table 1 shows the chemical composition of AISI D3 steel.

Table 1. Chemical composition of AISI D3 steel

Element	C	Mn	Si	Cr	Ni	W	V	P	S	Cu
Content (%)	2.00-2.35	0.60	0.60	11.00-13.50	0.30	1.00	1.00	0.03	0.03	0.25

The experimental set-up shown in Figure 1 consists of a CNC Lathe Puma 230, AISI D3 steel as a test specimen shaft with diameter of 38 mm and length of 6 mm length. Tool insert is CVD Coated Grade NC3220. The work piece is to be cut piece by piece to find the relationship between machining parameters and the machinability performance (surface roughness). This turning experiment was carried under wet machining condition using CNC Lathe Puma 230 which having spindle speed of 100 until 4000 rpm.

(a) (b)

Figure 1. Machining set-up (a) CNC Lathe and (b) experimental set-up

2.2. Cutting inserts

The CVD coated grade NC3220 of parting-off insert cemented carbide inserts tool was used without chip breaker geometry for the experimental work. The cutting inserts were clamped onto CNC Lathe Puma 230 which having a spindle speed range of 100 up to 4000 rpm as shown in Figure 1 to study the relationship between machining parameters and the machinability performance for surface roughness.

The control machining parameters and the levels used in experiment and conditions are given in the Tables 2.

Table 2. Machining parameters and levels

Machining Parameters	Level
Cutting speed (v) m/min.	140 - 170
Feed rate (f) mm/rev.	0.015 - 0.05
Depth of cut (d) mm	1.0 - 2.0
Condition	wet cutting

2.3. Surface Roughness Measurements

Measured surface roughness value, Ra and Rmax using surface profilometers (Mitutoyo Surftest SJ 210) as per ISO 4287:1997. The calculation took place approximately three times at three different locations with the stylus tip travelling straight in a parallel direction to feed for all cutting conditions at different cutting intervals.

In the assessment of machining precision and the surface condition of a machined part, surface roughness plays an important role. For a given cutting tool and workpiece configuration, machining parameters such as cutting speed, feed rate, and cutting depth have a major impact on the surface roughness. Values of surface roughness using parting-off NC3220 CVD coated insert cemented carbide inserts at different cutting speed, feed rate, and cut depth are shown in Table 3.

Table 3. Values of surface roughness of the work pieces machined using carbide inserts

Run Expt.	Cutting Speed, V(m/min)	Feed Rate, f(mm/rev)	Depth of Cut, C (mm)	Response Output (Surface Roughness)
1	170	0.01	1.00	1.11
2	155	0.03	1.50	1.64
3	155	0.03	1.50	1.52
4	140	0.01	1.00	0.01
5	170	0.05	2.00	0.75
6	155	0.01	1.50	1.34
7	140	0.05	1.00	1.02
8	155	0.03	2.00	1.17
9	155	0.03	1.50	1.41
10	140	0.03	1.50	1.47
11	140	0.05	2.00	1.37
12	170	0.05	1.00	1.05
13	170	0.03	1.50	1.66
14	155	0.05	1.50	1.71
15	170	0.01	2.00	1.85
16	155	0.03	1.50	1.92
17	140	0.01	2.00	1.88
18	155	0.03	1.50	1.39

19	155	0.03	1.50	1.49
20	155	0.03	1.00	0.12

3. Results and Discussion

The result will discuss on Analysis of Variance (ANOVA), regression equation and parameters optimization.

3.1. Analysis of Variance (ANOVA)

Using variance analysis (ANOVA), which was used to determine the variables that had a significant impact on performance measurements, the experimental findings from Table 3 were evaluated. This research was carried out for a significance level of alpha= 0.1, i.e. for a confidence level of 90 percent. It is understood that a statistically relevant contribution to performance measures is from sources with a P-value below 0.1.

The final column of the tables, as shown in Table 4, indicates the percentage contribution of the substantial source of the total variance and the degree of impact on the result. The residuals could be said to follow a straight line, as shown in Figure 2, suggesting that the errors were normally distributed for surface roughness.

This gives the support that the model of surface roughness is significant. The experiment therefore produced a desirable value that fulfilled the usual hypothesis. Figure 3 shows the contour surface roughness indicating that the desired recovery was within the range of 0.02 mm/rev to 0.05 mm/rev and cutting speed at the condition feed rate reflecting less surface roughness obtained at the condition feed rate in the range 140 m/min to 170 m/min.

3.2. Regression equation

The relationship between the variables (cutting speed, cut depth and feed rate) and the output measure (surface roughness) was modelled using multiple linear regressions. The following equations, in terms of coded parameters, are the final regression models for:

$$\text{Surface roughness} = +1.49 + 0.067 * A - 0.029 * B + 0.37 * C + 0.1 * A^2 + 0.15 * B^2 - 0.73 * C^2 - 0.21 * A * B - 0.22 * A * C - 0.32 * B * C$$

where; A – cutting speed, B – feed rate and C – depth of cut

Table 4. The ANOVA results of the experiment for the Surface roughness

Source		**Sum of squares**	**DF**	**Mean Square**	**F Value**	**Prob > F**	**Remarks**
Model		4.61	9	0.51	9.94	0.0006	Significant
	A	0.045	1	0.045	0.87	0.3728	
	B	8.410E -003	1	8.410E -003	0.16	0.6948	
	C	1.38	1	1.38	26.69	0.0004	
	A^2	0.10	1	0.10	1.96	0.1915	
	B^2	0.063	1	0.063	1.23	0.2935	
	C^2	1.46	1	1.46	28.28	0.0003	
	AB	0.34	1	0.34	6.68	0.0272	
	AC	0.40	1	0.40	7.68	0.0197	
	BC	0.82	1	0.82	15.89	0.0026	
Residual		0.52	10	0.052			
Lack of fit		0.32	5	0.064	1.66	0.2959	Not significant
Pure error		0.19	5	0.039			

Cor Total	5.13	19

The Model F-value of 9.94 implies the model is significant. There is only a 0.06% chance that a "Model F-Value" this large could occur due to noise.

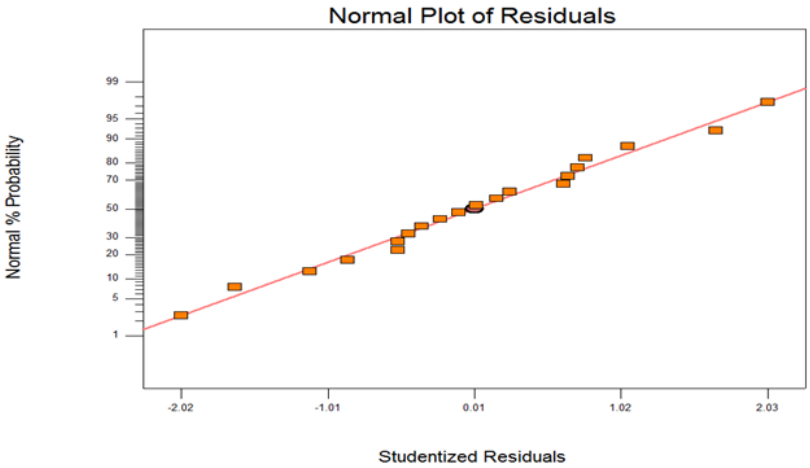

Figure 2. Normal Probability Plot of resident of cutting speed and feed rate on surface roughness parameter

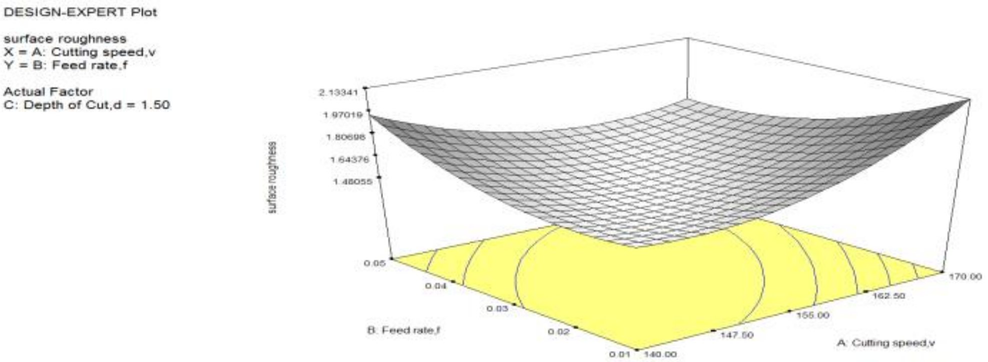

Figure 3. Three (3) D Surface graph of cutting speed and feed rate on surface roughness parameter

3.3. Parameter optimization

The optimization section looks for simultaneous combination factor levels to meet the requirements laid out. In this research, numerical methods of optimization are used by choosing the optimal objectives for each factor and reaction. The optimization process starts with a mathematical model built using software from Design-Expert. For this purpose, the procedures performed in performing numerical optimization.

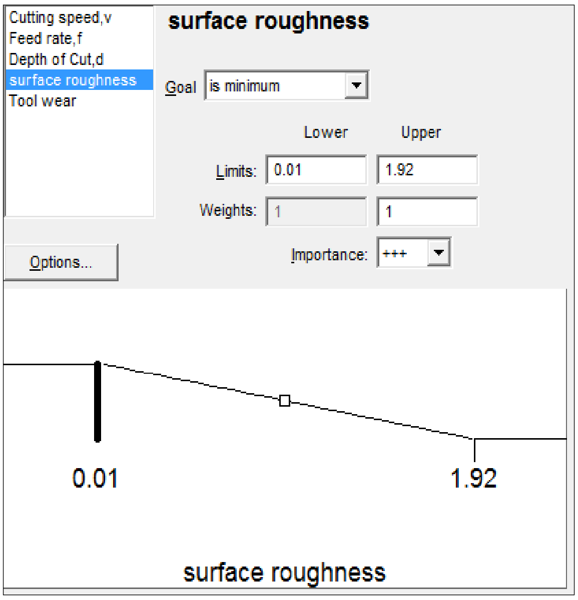

Figure 4. Surface Roughness Setting Criteria

Figure 4 indicates that the lower and upper bound settings were respectively 0.01 and 1.92. This limit suggests that, in order to reach the minimum value, the most suitable range is 0.01 or 1µm for surface roughness. These constraints suggested that the minimum value of the establishment parameters was the optimal range to be reached.

4. Conclusions

The response surface methodology was used in this study to find the optimal process parameters that reduce the surface roughness using Analysis of Variance (ANOVA) during the wet turning of AISI D3 steel. It was found that the key factors affecting surface roughness and tool wear were the depth of cut and speed, which can be improved with increased cutting speed. Better surface finishing was found at lower feed rates, as expected. At a cutting speed of 140 m/min, a feed rate of 0.01 mm/rev and a cut depth of 1.0mm, good surface roughness has been observed in the meantime. The forecast values and measured values are reasonably similar; suggesting that the surface roughness prediction models built can be used effectively to predict the surface finish. It can be concluded that the experimental data is in good agreement with estimated equations produced in mathematical/regression modelling.

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