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Determining Optimum Parameters of Cutting Fluid in External Grinding of 9CrSi Steel using Taguchi Technique

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Abstract

Grinding is an important machining process in manufacturing. It is generally the last operation performed to obtain high surface quality and dimensional accuracy. Different from other cutting methods, in grinding, the material is removed from the work surface in the phase of small chips by the process of many tiny abrasive particles of the grinding wheel. Therefore, it is difficult to study and optimize the grinding process. Compared with other cutting methods, such as milling and turning, grinding requires much higher energy to remove material. All energy is converted to heat, which is concentrated at the grinding wheel's interactions and workpiece contact zone. As a result, it is necessary to use cutting fluid to improve the grinding process's performance. This study investigates the cooling parameter optimization in cylindrical grinding 9CrSi harden steel using the Taguchi experimental evaluation method and Analysis of variance (ANOVA).

Keywords

grinding, external grinding, cutting fluid, grinding fluid.

I. INTRODUCTION

Until now, there have been a lot of studies in cutting fluid when grinding. The aim is to optimize the cutting fluid parameters, investing in the new cutting fluid or lubrication method. Z.H. Choi et al. [1] carried out a study on the effects of compressed cold air when grinding spindle shaft materials (SCM4 and SCM21) by CBN wheels. K. Q. Xiao and L.C. Zhang [2] introduced to research on the influence of compressed cold air and vegetable oil on the surface integrity and residual stresses when grinding tool steel.

The minimum quantity lubrication (MQL) method is studied and applied in the grinding process. For example, optimization of MQL when grinding with CBN wheels [3], analysis of surface integrity for MQL
in grinding [4], thermal Analysis of MQL in the grinding process [5], using a different type of vegetable oils [6] or investigate the hybrid of MQL coolant CO_2 system in grinding process [7]. The results showed that MQL affects reduced cutting thermal at low depth cut. If the cut increases, the lubricant hard to penetrate the cutting area, so the efficiency of MQL reduces. Several studies have investigated MQL by adding nanoparticles to improve the lubricant ability and reduce friction in the cutting area [8], [15]. Besides, Wei Tai Huang et al. [10] was conducted a study that used ultrasonic assistance to disperse the nanoparticles.

There are many studies on the conventional coolant method to increase efficiency and reduce the grinding cost. Rodrigo Daun Monici et al. [11] presented a study on the optimum selection of type and amount of cutting fluids to reduce the amount of fluid used in the grinding process and improve its performance. Salete Martins Alves and João Fernando Gomes de Oviveira [12] proposed a new grinding fluid formulation for the requirement of both performance and environmental impact. K. Ramesh et al. [13] noted that the coolant flux minimization through controlled jet impingement could prolong the coolant replenishment cycle. Bijoy Mandal et al. [14] presented research on improving the grinding process's performance by controlling airflow around a grinding wheel.

Nowadays, there are many new cutting fluids and new lubrication methods to improve the grinding process's efficiency. As a result, it is needed to investigate the optimal coolant parameters to increase the grinding performance and surface quality. This paper presents a study using Taguchi experimental planning and ANOVA analysis to optimize coolant condition in grinding 9CrSi with Aquatex lubricant.

Figure 1. Grinding machine

II. EXPERIMENTATION

The experiments were carried out by using an external cylindrical grinding machine CONDO-Hi-45 HTS (Figure 1). The grinding system and measuring equipment are shown in table 1.

Grinding	CONDO-Hi-45 HTS	Japan
Grinding wheel	Cn80MV1	Viet
Dressing tool	3908-0088C type 2	Russian
Surface roughness tester	Mitutoyo 178-923-2A, SJ-201	Japan

Table 1. Grinding system and measuring

Aquatex® 3180 soluble oil was used to investigate in this work. The product specifications have been presented in table 2.

Workpiece material is 9CrSi harden steel to 62÷65 HRC with chemical composition in Table 3. Workpiece dimension is Ø22x170 mm.

AQUATEX®3180 KEY PROPERTIES	
Appearance (in neat form)	Dark Red
Density kg/L @ 20°C	0.89
pH @ 5% dilution	9.4
Corrosion Protection, IP287 Break Point, %	4

Table 2. Aquatex® 3180 soluble oil specifications

A) *Experiment design*

The cutting and dressing condition had been kept constant during the process, as in Table 4. The input parameters were flow rate, coolant

Steel grade: 9CrSi						
Carbon (C)	Silicon (Si)	Manganese (Mn)	Chromium (Cr)	Phosphorous (P)	Sulphur (S)	Cobalt (Co)
0.85-0.95	12-1.6	0.3-0.6	0.95-1.25	≤0.03	≤0.03	≤1

Table 3. Chemical composition of 9CrSi steel

Pressure and concentration of lubricating fluid with three different levels (Table 5). The Taguchi Method was used to design the experiment to optimize the input parameter using the L_9 orthogonal array. The result of the experiment design by Minitab® 16 software has been shown in table 6.

Cutting condition	
Depth of cut	0.01 (mm)
Feed rate	1 (m/min)
Radial feed	0.01 (mm/stroke)
Cutting speed	30 (m/sec)
Dressing condition	
Rough dressing	0.07 (mm/stroke)
Finish dressing	0.02 (mm/stroke)
Non-feeding dressing	3 times

Table 4. Cutting and dressing condition

Symbols	**Controlled parameters**	**Level 1**	**Level 2**	**Level 3**
F	Flow rate (l/min)	5	10	15
P	Coolant Pressure (at)	3	4	5
C	Concentration (%)	3	4	5

Table 5. Coolant parameters and control levels

Experiment No.	**Flow rate** (l/min)	**Coolant pressure** (at)	**Concentration** (%)
1	5	3	3
2	5	4	4
3	5	5	5
4	10	3	4
5	10	4	5
6	10	5	3
7	15	3	5
8	15	4	3
9	15	5	4

Table 6. Design Matrix of L_9 (3^3) orthogonal array

III. RESULTS AND DISCUSSIONS

A) Surface roughness

Surface roughness after grinding is measured by Mitutoyo surface tester 178-923-2A, SJ-201 (Figure 2). Each workpiece is tested three times, and the average of them was taken to minimize the error. The experiment results for surface roughness obtained using the Taguchi optimization technique are presented in table 7.

B) Analysis of Variance

For getting better surface finish roughness, rate and coolant pressure are 1, 2, 3.

Figure 2. Mitutoyo Surface Roughness tester SJ-210

Experiment No.	Flow rate (l/min)	Coolant pressure (at)	Concentration (%)	Surface Roughness (µm)			SNRA	MEAN (µm)
				Trial 1	Trial 2	Trial 3		
1	5	3	3	0.325	0.314	0.310	9.9954	0.316333
2	5	4	4	0.276	0.278	0.272	11.2025	0.275333
3	5	5	5	0.295	0.299	0.288	10.6320	0.294000
4	10	3	4	0.267	0.266	0.267	11.4806	0.266667
5	10	4	5	0.278	0.276	0.281	11.1085	0.278333
6	10	5	3	0.287	0.287	0.292	10.7918	0.288667
7	15	3	5	0.289	0.274	0.288	10.9413	0.283667
8	15	4	3	0.302	0.295	0.296	10.5249	0.297667
9	15	5	4	0.276	0.278	0.275	11.1712	0.276333

Table 7. Experiment results for surface roughness

the value of surface roughness should be minimum. The criterion for evaluation, "Smaller is better $S/N=10\log[1/n(\sum y_i^2)]$ (n=1)" has been used. The results of surface roughness are analyzed by using ANOVA in Minitab® 16.

Table 8 shows summarize the information of ANOVA indicates that flow rate and

the concentration of lubricating fluid is more influence surface roughness, and coolant pressure is negligible impact.

The specific percent contribution of these factors is shown in Figure 3. The concentration of lubricating fluid is the most influence to surface roughness, about 68.19%. Flow rate percent contribution is 25.34%, and coolant pressure has the least contribution, about 1.86%.

Respond table 9 for the signal to noise ratio also indicates the rank respectively of concentration, flow

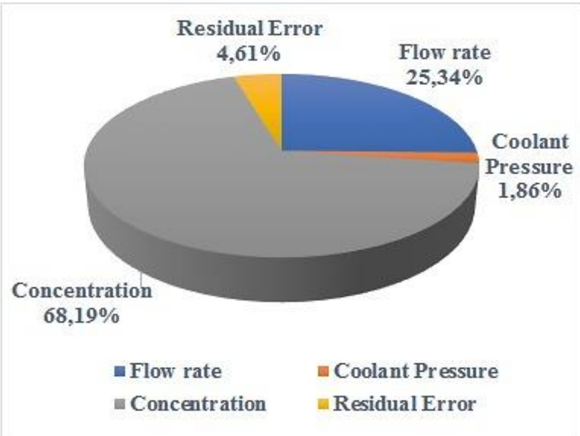

Figure 3. Percentage contribution of parameters towards surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Flow rate	2	0.40117	0.40117	0.20058	5.50	0.154
Coolant pressure	2	0.02942	0.02942	0.01471	0.40	0.713
Concentration	2	1.07934	1.07934	0.53967	14.80	0.063
Residual Error	2	0.07294	0.07294	0.03647		
Total	8	1.58287				

Table 8. Analysis of Variance for means of SN ratios for Surface roughness

Level	Flow rate	Coolant Pressure	Concentration
1	10.61	10.81	10.44
2	11.13	10.95	11.28
3	10.88	10.87	10.89
Delta	0.52	0.14	0.85
Rank	2	3	1

Table 9. Response Table for Signal to Noise Ratios (Smaller is better)

C) *Experiment of verification*

Using predict Analysis in Minitab® 16 with optimum values of flow rate (10 l/min), the concentration of lubricating fluid (4%), coolant pressure (4 at). The result in figure 5 shows the predicted surface roughness value is 0.2616778 µm. The verification test using those optimum factor values was conducted, the result measuring by Mitutoyo Surface Roughness tester SJ-210 is 0.268 µm. The experimental work is satisfactory since the error between the experimental and predicted value is 2.3%.

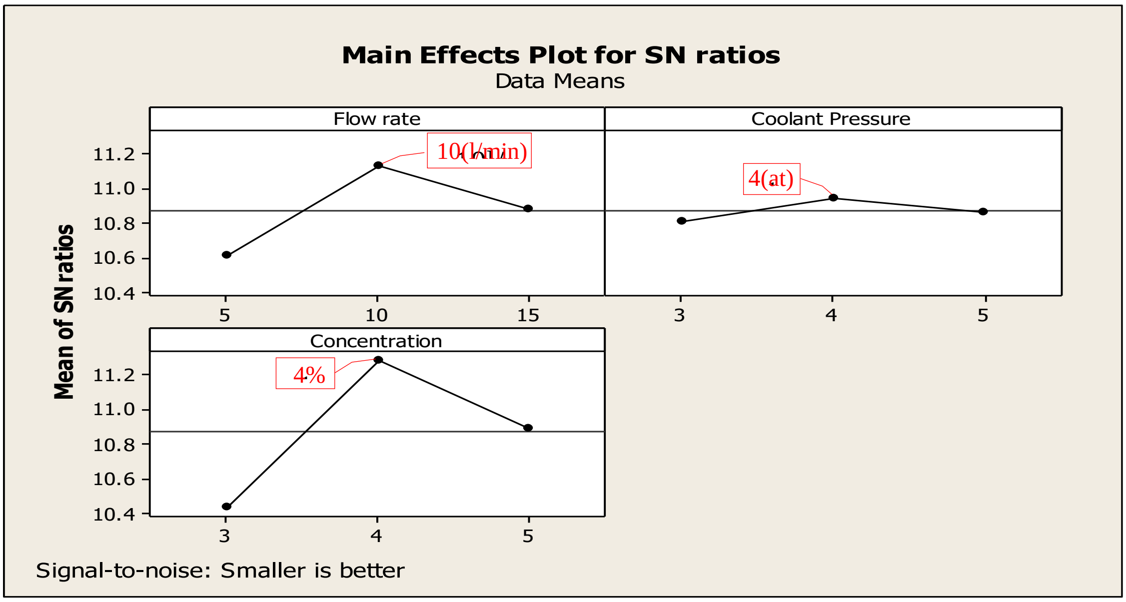

Figure 4. Main effect plot for mean of SN ratios

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Predicted values

S/N Ratio       Mean        StDev   Ln(StDev)
  11.6130   0.261778   -0.0011830    -7.24225


Factor levels for predictions

Flow    Coolant
rate   Pressure   Concentration
  10          4               4
```

Figure 5. Predicted values at optimum values of process parameters

IV. CONCLUSIONS

The experimental work and verification test was The experimental work and verification test was carried out successfully. Base on the results of the analytical result, the following conclusions can be made:

- The optimized parameters for minimum surface roughness are flow rate (10 l/min), the concentration of

Lubricating fluid (4%), coolant pressure (4 at). With the optimum parameters, the minimum surface roughness of 0.268 µm can be get.

- Optimization of coolant conditions can be done by using the Taguchi technique and ANOVA analysis. The test's verification was conducted with only 2.3%, showing that the experiment work is satisfied.

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