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ABSTRACT

This paper presents a study on the effect of dressing parameters on the material removal rate (MRR) in external cylindrical grinding 90CrSi harden steel. The six dressing parameters such as coarse dressing depth, coarse dressing time, fine dressing depth, fine dressing time, non-feeding dressing time, and dressing cross-feed rate have been investigated to determine their optimum value to obtain maximum MRR. The experiment was set up using Taguchi and the analysis of variance method (ANOVA). The results indicated that the coarse dressing depth has the greatest effect on the MRR and the set of optimum dressing parameters have been determined. The predicted value of optimal MRR is calculated and the confidence level of the proposed experimental model has been tested for the result satisfy with 95% confidence.

Keywords*—external cylindrical grinding; dressing condition; material removal rate;*

I. Introduction

Grinding is an important process in mechanical manufacturing to achieve precision and surface quality that difficult or impossible for other operations. Grinding is a complex process since the grinding wheel is considered as a set by numerous randomly small cutting tools. The productivity and quality of the grinding process are highly dependent on technological factors [1, 2].

Therefore, studying the grinding process is interested in research by a lot of scientists. There are researches focus on investigated the effect of grinding parameters such as wheel speed, work speed, feed rate, depth of cut to surface roughness [3-7], or material remove rate [3-5, 7-9]. These studies all show a set of grinding parameters to significantly reduce surface roughness and improve the material removal rate. Research to reduce grinding costs and increase grinding performance is also mentioned [10]. The other technological parameters are also investigated such as lubrication condition [11] or structure of grinding wheel [12].

The dressing condition of the grinding wheel is very important to determine the topography of the grinding wheel. So it directly affects on cutting performance of the grinding wheel. There are many studies to optimization of dressing conditions to minimize the surface roughness [13-15] or minimize cutting force [13]. In these studies, many dressing parameters have been investigated, for example, the dressing speed ratio, the dressing depth of cut, the dressing cross-feed rate, the number of passes, the drag angle of the dresser. By the researches above, it shows that, besides the grinding process parameters, dressing condition has an important role in determining the performance and quality of the grinding process.

Although a lot of researches about the optimization of dressing conditions. There is non of study to optimize dressing parameters to maximum material removal rate (MRR) in external cylindrical grinding. In this study, six dressing parameters are investigated including coarse dressing depth, coarse dressing times, fine dressing depth, fine dressing time, non-feeding dressing time, and dressing cross-feed rate to maximize the material remove rate when grinding 90CrSi harden steel.

II. Experiment design

The experiments are conducted based on the equipment which is listed in table 1. The grinding process parameters are fixed in every test with a total cutting depth of 0.1 mm, cross-feed rate of 1 m/min, radial feed rate of 0.01 mm/stroke, and cutting speed of 29 m/s.The experiment system is shown in figure 1.

Table 1. Experiment equipment

Experiment equipment	
External cylindrical grinding machine	CONDO-Hi-45 HTS (Japan)
Grinding wheel	Cn80MV1 400x40x203 (Vietnam)
Dress tool	Multi-point diamond dresser 3908-0088C type 2 (Russia)
Workpiece	90CrSi harden steel, 58-62 HRC, ∅22x115

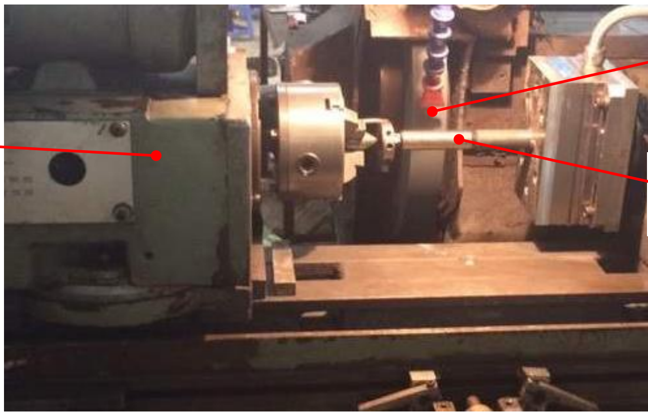

Figure 1. Experiment system

To evaluate the effect of dressing parameters on MRR. Six dressing parameters have been selected including coarse dressing depth, coarse dressing times, fine dressing depth, fine dressing time, non-feeding dressing time, and dressing cross-feed rate. The experiment design is based on Taguchi method which orthogonal array L16 (44x22) was chosen. The input parameters and their investigated level are listed in table 2.

Table 2. Input parameters and investigated level

Input parameter	Symbol	Unit	Level			
			1	2	3	4
Coarse dressing depth	ac	mm	0.02	0.025	0.03	0.035
Coarse dressing time	nc	time	1	2	3	4
Fine dressing depth	af	mm	0.005	0.01	-	-
Fine dressing time	nf	time	0	1	2	3
Non-feeding dressing time	n0	time	0	1	2	3
Dressing cross-feed rate	Sd	mm/min	1.5	1.8	-	-

The experimental planning is designed by using Minitab 18 software with 4 parameters in 4 levels and 2 parameters in 2 levels. L16 (4^4x2^2) is set up to investigate the effects of input parameters on MRR. Each experiment was carried out with the fixed grinding process parameters as above. The experimental planning table and the measured results are described in table 3.

Table 3. Experimental orthogonal array with input factors and response.

Exp. No	Input parameter						Material removal rate (g/min)			Mean	SNRA
	a_c	n_c	n_f	n_0	a_f	S_d	Trial 1	Trial 2	Trial 3		
1	0.020	0	0	0	0.005	1.5	0.880	0.941	0.992	0.9377	-0.5904
2	0.020	1	1	1	0.005	1.8	1.927	1.895	1.912	1.2113	1.6638
3	0.020	2	2	2	0.010	1.5	1.525	1.462	1.559	2.1153	6.5022
4	0.020	3	3	3	0.010	1.8	1.149	1.212	1.188	1.8163	5.1814
5	0.025	0	1	2	0.010	1.8	1.778	1.756	1.814	2.3827	7.5400
6	0.025	1	0	3	0.010	1.5	1.215	1.198	1.202	1.2050	1.6193
7	0.025	2	3	0	0.005	1.8	1.624	1.650	1.672	1.5487	3.7971
8	0.025	3	2	1	0.005	1.5	1.534	1.614	1.588	1.5787	3.9599
9	0.030	0	2	3	0.005	1.8	2.544	2.589	2.572	2.6683	8.5242
10	0.030	1	3	2	0.005	1.5	2.250	2.218	2.232	2.2333	6.9786
11	0.030	2	0	1	0.010	1.8	2.624	2.601	2.656	2.4603	7.8177
12	0.030	3	1	0	0.010	1.5	1.985	1.944	2.023	1.9840	5.9474
13	0.035	0	3	1	0.010	1.5	1.728	1.636	1.640	1.6680	4.4357
14	0.035	1	2	0	0.010	1.8	1.877	1.793	1.756	1.8087	5.1371
15	0.035	2	1	3	0.005	1.5	2.715	2.708	2.792	2.6050	8.3160
16	0.035	3	0	2	0.005	1.8	2.228	2.265	2.294	2.6623	8.5039

III. Results and Discussions

The testing results were analyzed by analysis of variance (ANOVA) method to calculate the effect of input factor on response. By the goal to determine the set of dressing parameters to obtain the maximum MRR. The target function is in equation 1.

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \tag{1}$$

The S/N ratios calculated result are also shown in table 3. The ANOVA the effect of input factor to S/N ratio is analyzed by using Minitab 18 software. The result of the analyses is described in table 4 and figure 2 show that: the coarse dressing depth has the greatest impact on the MRR of 40.51%, followed by the non-feeding dressing time of 29.88%, the coarse dressing time of 15.25%, dressing cross-feed rate and fine dressing time have small impact on MRR of 6.74% and 6.49% in respectively. The effect of fine dressing depth on MRR is very small and can be negligible.

Table 4. ANOVA table of input factors affect to SN ratio

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	C (%)
ac	3	45.405	45.4045	15.1348	21.62	0.157	40.51
nc	3	17.089	17.0895	5.6965	8.14	0.251	15.25
nf	3	7.271	7.2713	2.4238	3.46	0.372	6.49
n0	3	33.490	33.4903	11.1634	15.94	0.182	29.88
af	1	0.573	0.5730	0.5730	0.82	0.532	0.51
Sd	1	7.558	7.5576	7.5576	10.79	0.188	6.74
Residual Error	1	0.700	0.7001	0.7001			0.62
Total	15	112.086					

Model Summary

S	R-Sq	R-Sq(adj)
0.8367	99.38%	90.63%

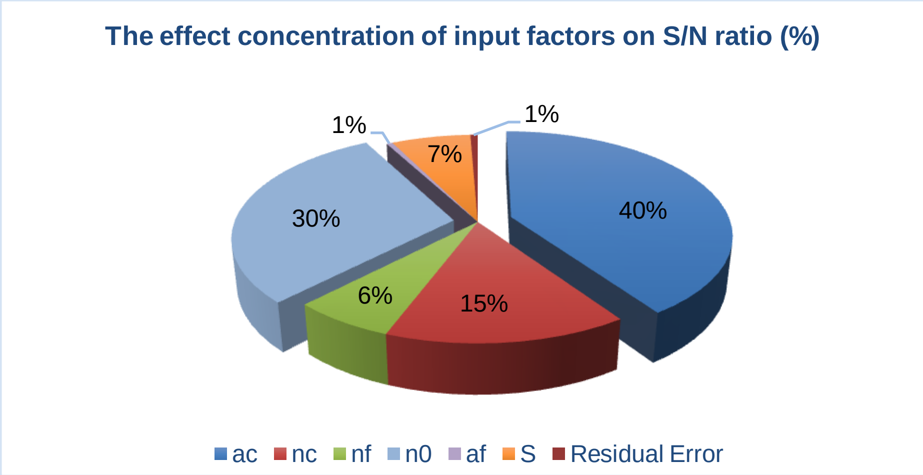

Figure 2. The effective concentration of input factors on the S/N ratio

Response Table for Signal to Noise Ratios

Larger is better

Level	ac	nc	nf	n0	af	Sd
1	3.189	4.977	4.338	3.573	5.144	4.646
2	4.229	3.850	5.867	4.469	5.523	6.021
3	7.317	6.608	6.031	7.381		
4	6.598	5.898	5.098	5.910		
Delta	4.128	2.759	1.693	3.808	0.378	1.375
Rank	1	3	4	2	6	5

Table 5. The effect of dressing parameters on S/N ratios at their level

To obtain the maximum material removal rate, the S/N ratio which is calculated in equation 1 must be the largest value at each input factor. The effect of dressing parameters on the S/N ratio is described in figure 3 and table 5.

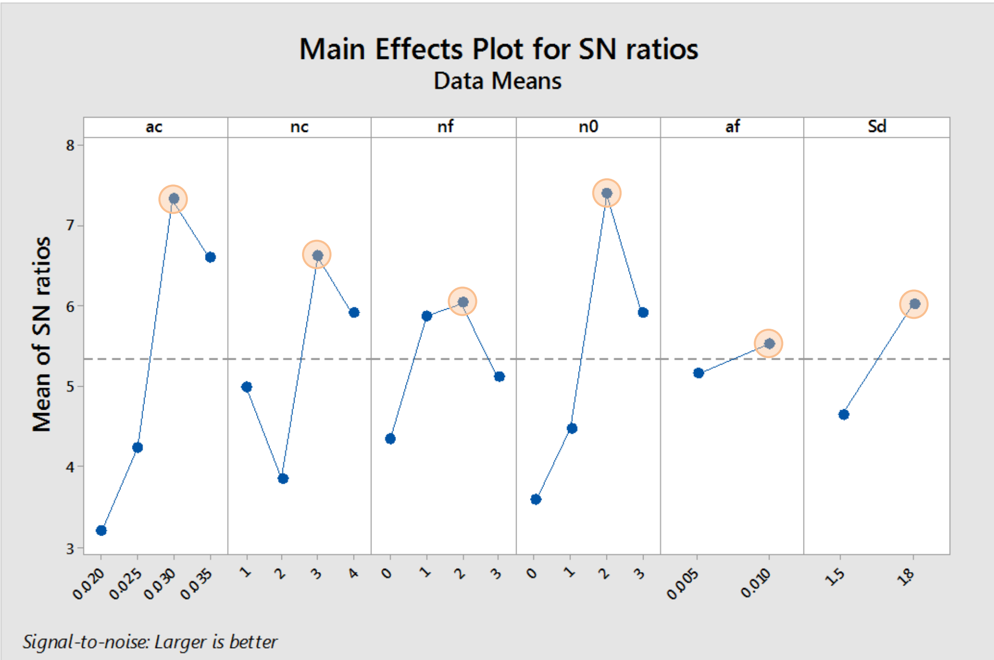

Figure 3. Effect of dressing parameter on S/N ratios

Observed figure 3 to determine the optimum level and value of the dressing parameters. The set of optimum dressing parameters is listed in table 6.

Table 6. Optimum level and value of dressing parameters

Dressing parameter	Symbol	Unit	Optimum level	Optimum value
Coarse dressing depth	ac	mm	3	0.03
Coarse dressing time	nc	time	3	3
Fine dressing depth	af	mm	2	0.01
Fine dressing time	nf	time	3	2
Non-feeding dressing time	n0	time	3	2
Dressing cross-feed rate	Sd	mm/min	2	1.8

The predicted value corresponding to the set of optimal dressing parameters is determined by using Minitab 18 software. The result is shown in table 7.

Table 7. Predict value of MRR corresponding to optimum dressing parameters

Predicted values

Prediction

S/N Ratio	Mean	StDev	Ln(StDev)
12.2137	3.25810	0.0423857	-3.06236

Settings

ac	nc	nf	n0	af	Sd
3	3	3	3	2	2

The confidence interval of the experiment model is tested by Anderson-Darling method. The testing result is shown in figure 4.

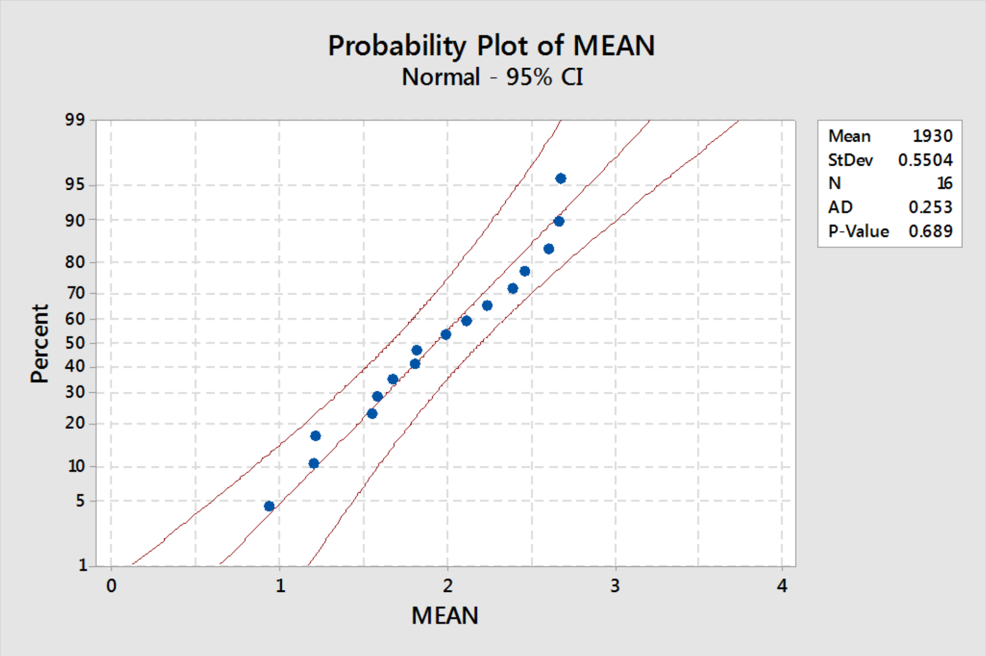

Figure 4. Probability plot of the fit of experimental model for the response of MRR

Observe figure 4, all the data represented by blue point is sited inside two limiting lines when the p-value of 0.689 greater than α value of 0.05. This testing result indicates that the proposed model is fitted and the optimum data set follows the distribution.

IV. Conclusions

In this study, an experimental model was built for optimization of the dressing parameters when external cylindrical grinding of 90CrSi steel. By using the Taguchi method to design the experiment, the study has determined a set of dressing parameters to achieve the maximum material removal rate.

The result indicated that coarse dressing depth has the greatest effect on MRR (40.51%). The effect of other dressing parameters such as non-feeding dressing time (29.88%), coarse dressing time (15.25%), dressing cross-feed rate (6.74%) fine dressing time (6.49%) decreases respectively. Fine dressing depth has an insignificant effect on MRR.

The optimum values of the dressing paramters have been determined as ac = 0.03 mm, nc = 3 times, af = 0.01 mm, nf = 2 times, n0 = 2 times, Sd = 1.8 mm/min. Base on these optimum dressing parameters, the MRR can be predict about 3.258 g/min with the confident level 95% ($\alpha = 0.05$).

The results show that the proposed experimental model has practical significance and can apply to the grinding process of external cylindrical 90CrSi harden steel.

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