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An investigation of dressing conditions when external cylindrical grinding to maximize material removal rate

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ABSTRACT

In this paper, we present a research on optimizing dressing condition parameters in order to achieve the maximum material removal rate when grinding the cylindrical parts. The input parameters are surveyed based on the box-bhenken experimental planning method with high reliability. The Minitab R19 software has been apply to analysis the effect of input parameters on material removal rate and the regression equation describes the relationship between the input parameters and material removal rate was determined. Furthermore, the optimum dressing condition to reach the maximum material removal rate when external cylindrical grinding SKD11 tool steel was determined.

Keywords—*external grinding; dressing condition; material removal rate; SKD11 tool steel*

I. INTRODUCTION

Up to present, grinding process is still an important and irreplaceable processing method in the machine manufacturing industry[1].The characteristics of the grinsding method are high precision and surface quality. Moreover, the advantage of the grinding process is that it can process difficult-to-machine materials such as tempered steel. However, grinding is also a complex and expensive process, requiring a reasonable technological regime to improve efficiency and quality[2].Among the technological parameters of the grinding wheel, the dressing process is one of the important processes to form the profile of the cutting edge and grinding wheel topography.The grinding wheel dressing condition has been studied by many scientists and many previous researches shows the performance of the grinding wheel is greatly influenced by the way the grinding wheel is dressed [3, 4].

With the development of manufacturing technology and modern research facilities. The research on dressing grinding wheel is also interested and developed, such as studies on grinding wheel and dressing process are modeled and simulated to adjust the dressing condition appropriately to improve grinding productivity[5, 6], the resonable dressing condition is also researched and proposed by Xun Chen [7].

Previous studies have shown that the dressing condition has a significant effect on the surface quality of the workpiece. Specific as speed ratio, depth of dressing and cross-feed rate of dressing process had been investigate and the proposed model related to surface roughness is presented [8]. The effect of dressing strategy on the mircostructral of cylindrical surface in grinding also have been study. Dressing and grinding models has been developed to describe relationship between the features of microstructural surface and the dressing and grinding conditions, the features of ground microstructure can be depected by the length and width of grinding gouses and the pitch length in axis and peripheral directions of the cylindirical component [9]. The influence of dressing parameters on the topography, morphology and characteristics of the ground surface when grinding by different vitrified grinding wheel is aslo presented[10]. The effect of dressing condition on the qualities of ground parts had been confirmed by previous studies. Therefore, research to optimize the dressing process is necessary. Some of research applied new technology to improve the quality of dressing process as: ultrasonic assisted dressing [11], otherwise, this technology is difficult to control and expensive.

The application of experimental planning in the study of optimizing the dressing process is also interested by many authors and the positive results in improving the efficiency of the grinding process are presented. For example, the research the dressing condition to obtain the minimum flatness tolelance when grinding SKD11 tool steel [12], or multi-objective optimization the dressing parameters of grinding wheel when flalness grinding 90CrSi harden steel to minimum surface roughness and flatness tolerances has been presented [13], the research results have evaluated the influence of dressing parameters and given a specific set optimum dressing parameters to meet the initial goals.Optimizing the dressing parameters when external cylindrical grinding SKD11 steel has also been carried out. In which, the influence of the dressing parameters on the surface roughness and grinding wheel lifetime is determined by the Taguchi experimental planning method [14, 15].

Previous studies have shown that dressing parameters have a significant influence on the productivity and quality of grinding process. In this study, the Box-Behnken response surface experiments design method is applied to study the influence of dressing parameters in external cylindrical grinding in order to achieve the precise optimization dressing mode.

II. EXPERIMENTAL DESIGN

Analytical results from previous studies have shown the dressing mode is divided into coarse and fine dressing mode which obtain good efficiency to improving productivity. Therefore, in this study, the six input parameters including depth of rough dressing, rough dressing time, depth of fine dressing, fine dressing time, non-feeding dressing time, and dressing speed on material removal rate when external grinding 90CrSi. The input parameters and their levels were shown in table 1.

TABLE 1.INPUT PARAMETERS AND INVESTIGATED LEVELS

No.	Input parameters	Symbol	Unit	Level of investigating	
				Low	High
1	Depth of rough dressing	a_r	mm	0.02	0.04
2	Rough dressing time	n_r	-	1	5
3	Depth of fine dressing	a_f	mm	0.005	0.015
4	Fine dressing time	n_f	-	0	4
5	Non-feeding dressing time	n_0	-	0	4
6	Feed speed	S_d	m/min	1	2

Other grinding process parameters are kept constant when conducting the experiment include: lubrication: Context Aquatex 3810 with a concentration of 3% and a flow-rate of 10 l/min was used for coolant condition; the grinding condition is: feed rate at 1.8 m/min, depth per cut is 0.005 per single stroke, total depth of cut is 0.05 mm and the speed of grinding wheel is 29.3 m/s; Grinding machine: CONDO-Hi-5 HTS (Japan origin); grinding wheel: Ct80MV1-G 400x40x203 35m/2 (Vietnam origin); dressing tool: 3908-0088C type 2 (Russian origin); The work piece material properties are described in table 2.

TABLE 2.90CrSi STEEL PROPERTIES

Steel grade: 90CrSi						
C	Si	Mn	Cr	P	S	Co
0.85-0.95	12-1.6	0.3-0.6	0.95-1.25	≤0.03	≤0.03	≤1

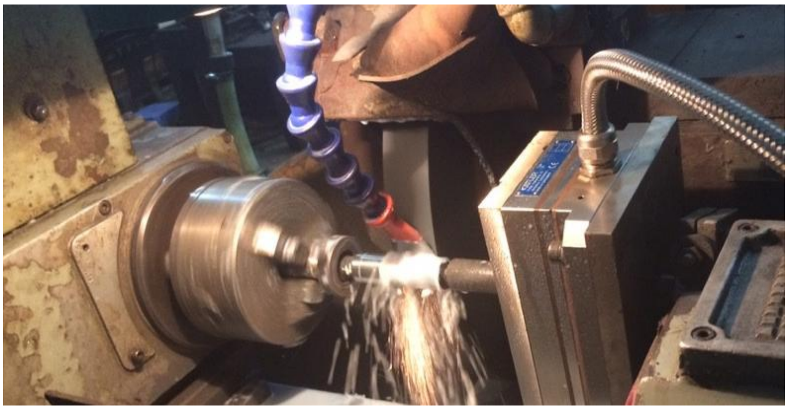

Fig 1. Experiment setup

Based on the defined input parameters and investigated level. Minitab R19 software was applied to design experiments according to the Box-Behnken method, the experiment design table with 54 runs is listed in table 3. The material removal rate of each run is also described in table3.

TABLE 3.EXPERIMENT DESIGN AND MEASUREMENT RESULTS

Std Order	Run Order	Pt Type	Blocks	a_r	n_r	a_f	n_f	n_0	S_d	Mean of MRR(g/sec)
16	1	2	1	0.03	5	0.015	2	4	1.5	0.188
28	2	2	1	0.04	3	0.010	4	0	1.5	0.280
24	3	2	1	0.03	3	0.015	4	2	2.0	0.262
44	4	2	1	0.04	3	0.015	2	2	1.0	0.316
26	5	2	1	0.04	3	0.010	0	0	1.5	0.168
21	6	2	1	0.03	3	0.005	0	2	2.0	0.188
27	7	2	1	0.02	3	0.010	4	0	1.5	0.261
49	8	0	1	0.03	3	0.010	2	2	1.5	0.354
10	9	2	1	0.03	5	0.005	2	0	1.5	0.248
2	10	2	1	0.04	1	0.010	0	2	1.5	0.310
32	11	2	1	0.04	3	0.010	4	4	1.5	0.291
35	12	2	1	0.03	1	0.010	2	4	1.0	0.241
20	13	2	1	0.03	3	0.015	4	2	1.0	0.258
30	14	2	1	0.04	3	0.010	0	4	1.5	0.176
42	15	2	1	0.04	3	0.005	2	2	1.0	0.343
8	16	2	1	0.04	5	0.010	4	2	1.5	0.280
3	17	2	1	0.02	5	0.010	0	2	1.5	0.288
53	18	0	1	0.03	3	0.010	2	2	1.5	0.345
40	19	2	1	0.03	5	0.010	2	4	2.0	0.266
6	20	2	1	0.04	1	0.010	4	2	1.5	0.294
51	21	0	1	0.03	3	0.010	2	2	1.5	0.355
54	22	0	1	0.03	3	0.010	2	2	1.5	0.341
29	23	2	1	0.02	3	0.010	0	4	1.5	0.276
43	24	2	1	0.02	3	0.015	2	2	1.0	0.280
50	25	0	1	0.03	3	0.010	2	2	1.5	0.359
12	26	2	1	0.03	5	0.015	2	0	1.5	0.192
48	27	2	1	0.04	3	0.015	2	2	2.0	0.314

15	28	2	1	0.03	1	0.015	2	4	1.5	0.184
5	29	2	1	0.02	1	0.010	4	2	1.5	0.263
38	30	2	1	0.03	5	0.010	2	0	2.0	0.199
17	31	2	1	0.03	3	0.005	0	2	1.0	0.259
31	32	2	1	0.02	3	0.010	4	4	1.5	0.283
36	33	2	1	0.03	5	0.010	2	4	1.0	0.293
9	34	2	1	0.03	1	0.005	2	0	1.5	0.228
33	35	2	1	0.03	1	0.010	2	0	1.0	0.277
22	36	2	1	0.03	3	0.015	0	2	2.0	0.132
14	37	2	1	0.03	5	0.005	2	4	1.5	0.296
4	38	2	1	0.04	5	0.010	0	2	1.5	0.303
37	39	2	1	0.03	1	0.010	2	0	2.0	0.137
45	40	2	1	0.02	3	0.005	2	2	2.0	0.285
1	41	2	1	0.02	1	0.010	0	2	1.5	0.125
34	42	2	1	0.03	5	0.010	2	0	1.0	0.296
18	43	2	1	0.03	3	0.015	0	2	1.0	0.202
52	44	0	1	0.03	3	0.010	2	2	1.5	0.339
19	45	2	1	0.03	3	0.005	4	2	1.0	0.303
23	46	2	1	0.03	3	0.005	4	2	2.0	0.282
7	47	2	1	0.02	5	0.010	4	2	1.5	0.298
41	48	2	1	0.02	3	0.005	2	2	1.0	0.284
25	49	2	1	0.02	3	0.010	0	0	1.5	0.110
47	50	2	1	0.02	3	0.015	2	2	2.0	0.282
39	51	2	1	0.03	1	0.010	2	4	2.0	0.225
13	52	2	1	0.03	1	0.005	2	4	1.5	0.272
46	53	2	1	0.04	3	0.005	2	2	2.0	0.318
11	54	2	1	0.03	1	0.015	2	0	1.5	0.133

III. RESULT AND DISCUSSIONS

In order to estimate the effect of dressing parameters to MRR, the experiment results are analysed by Minitab software and ANOVA method. The analysis results is presented in figure 2. In the figure 2, the effect degree of input parameters are described as the blue column. The parameters which exceed the reference line are significant effect parameters on MRR.

The chart in the figure 2 indicated the parameters that affect to MRR in order are n_0*n_0, n_f*n_f, n_f, a_f*a_f, a_f, S_d, n_0, n_r, n_r*n_r. a_r has small significant effect to MRR.

The influence trend of input factors are also analysed. The analysis results are presentd in the figure 3. Observe the figure 3, the parameters n_f, n_0, n_r have possitive effect to MRR; otherwise, the parameters n_0*n_0, n_f*n_f, a_f*a_f, a_f, S_d and n_r*n_r have negative effect to MRR.

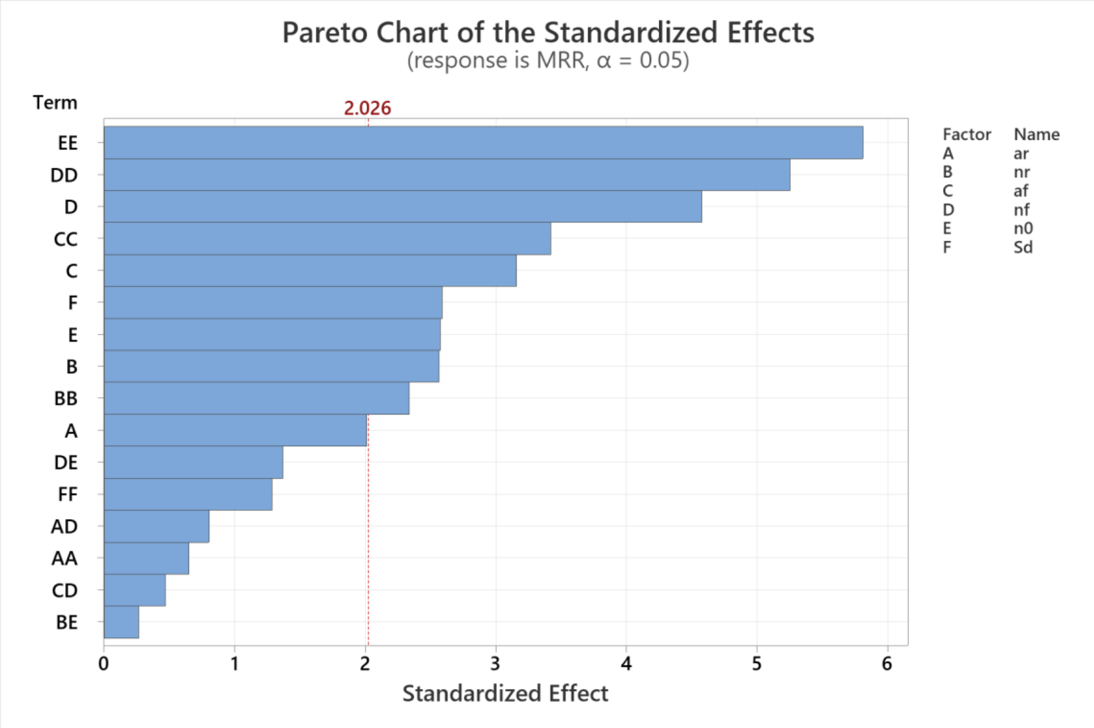

Fig 2.Effect degree of input factors on material removal rate

Observing the analysis result in figure 2 shows all of the input parameters affect the response in the quadratic form. This result indicated that investigated area has extreme value and the optimal value of the input parameter can be determined.

The influence degree of input factors is described in the Pareto chart in figure 3.

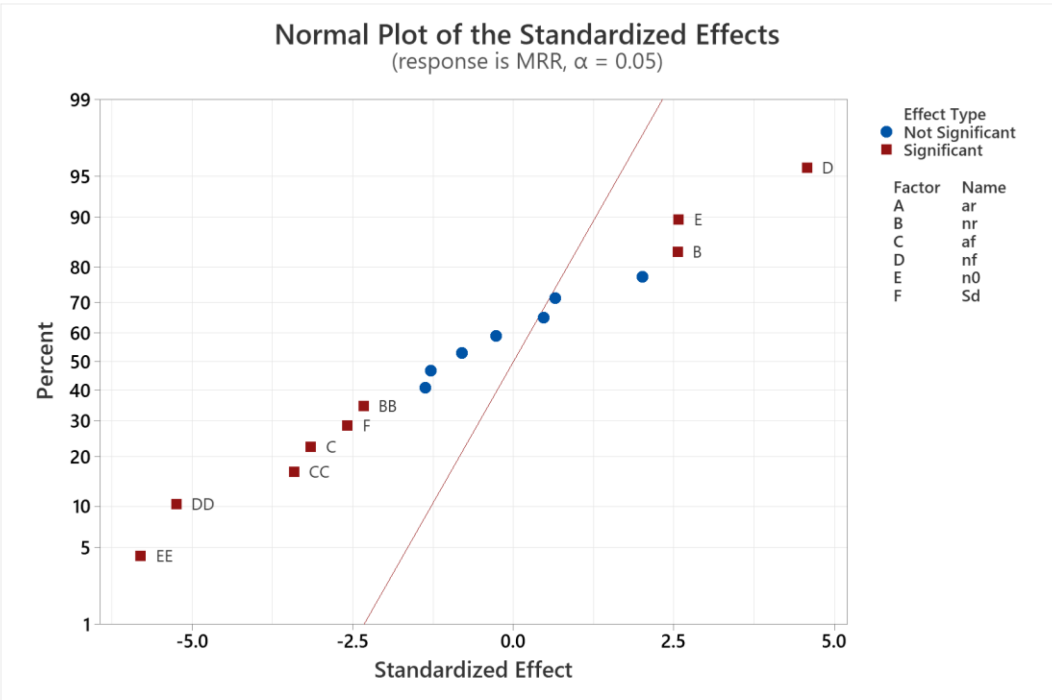

Fig 3. The influence trend of input factor on MRR

After determining the influence of the input factor on MRR and then remove the negligible influence factors. The regression equation coefficients are determined by using Minitab R19 software. The calculated results are shown in Table4.

TABLE 4.THE ESTIMATED COEFFICIENTS OF INPUT PARAMETERS AND THEIR INTERACTION

Coded Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.3489	0.0149	23.46	0.000	
ar	0.01494	0.00744	2.01	0.052	1.00
nr	0.01905	0.00744	2.56	0.015	1.00
af	-0.02346	0.00744	-3.16	0.003	1.00
nf	0.03401	0.00744	4.57	0.000	1.00
n0	0.01913	0.00744	2.57	0.014	1.00
Sd	-0.01925	0.00744	-2.59	0.014	1.00
ar*ar	0.0074	0.0114	0.65	0.520	1.30
nr*nr	-0.0265	0.0114	-2.33	0.025	1.30
af*af	-0.0388	0.0114	-3.42	0.002	1.30
nf*nf	-0.0597	0.0114	-5.25	0.000	1.30
n0*n0	-0.0660	0.0114	-5.81	0.000	1.30
Sd*Sd	-0.0146	0.0114	-1.29	0.206	1.30
ar*nf	-0.00731	0.00911	-0.80	0.428	1.00
nr*n0	-0.00241	0.00911	-0.26	0.793	1.00
af*nf	0.0060	0.0129	0.47	0.642	1.00
nf*n0	-0.0176	0.0129	-1.37	0.180	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0364328	77.37%	67.59%	46.56%

The regression equation of material removal rate is described by the following model:

Regression Equation in Uncoded Units

MRR = -0.110 - 2.20 ar + 0.0505 nr + 25.15 af + 0.0904 nf + 0.0862 n0 + 0.137 Sd + 74 ar*ar
- 0.00663 nr*nr - 1553 af*af - 0.01492 nf*nf - 0.01649 n0*n0 - 0.0585 Sd*Sd
- 0.365 ar*nf - 0.00060 nr*n0 + 0.60 af*nf - 0.00440 nf*n0

Based on the determined regression equation, the calculate the optimal plot are descibed in figure 4 and optimal value of the input parameters to achieve the maximum MRR is determined by Minitab R19 software are shown in table 5.

TABLE 5.THE CALCULATED OF THE OPTIMAL VALUE OF THE INPUT PARAMETERS

Solution

Solution	ar	nr	af	nf	n0	Sd	MRR Fit	Composite Desirability
1	0.04	3.70707	0.0085354	2.38384	2.22222	1.17172	0.387930	1

From the optimal calculation results in table 5, an optimal set of dressing condition parameters can be obtained to achieve the maximum MRR based on the adjustment range of the machine are a_r = 0.04 mm, n_r = 4 times, a_f = 0.009 mm, n_f = 2 times, n_0 = 2 times and S_d = 1.2 m/min. The predicted value of MRR corresponding to optimum dressing condition is 0.388g/s.

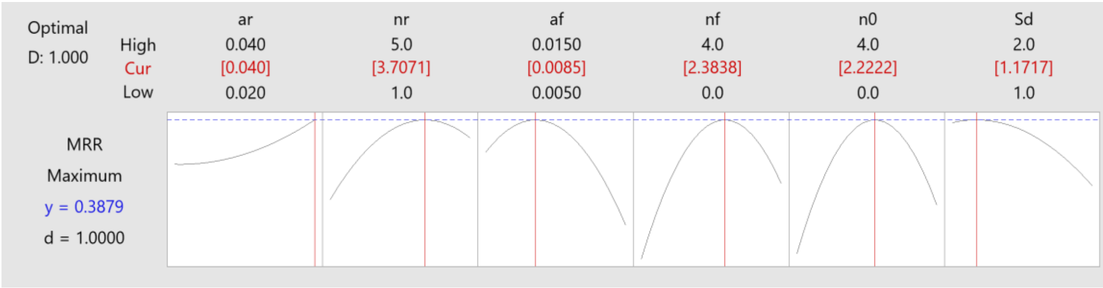

Fig 4. Otimal plot of input factor to maximize MRR

IV. CONCLUSION

The current study presents the optimization to achieve the maximum material removal rate with the optimum dressing condition when external cylindrical grinding SKD11 tool steel. The response surface method and ANOVA are applied to find the orthogonal array for the experimental plan. The following conclusions can be made:

- The dressing parameters investigated have sign cant affect to material removal rate. Among them, the quadratic effect of (EE) n_0*n_0 is the most effect to MRR, and then followed by the effect of DD (n_f*n_f), D (n_f), CC (a_f*a_f), C (a_f), F (S_d), E (n_0), B (n_r) and BB (n_r*n_r). A (a_r) has small significant effect to MRR.

- The regression equation for the relationship between dressing parameters and material removal rate is determined as follows:

$$\begin{aligned} MRR \;=\; & -0.110 - 2.20\,ar + 0.0505\,nr + 25.15\,af + 0.0904\,nf + 0.0862\,n0 + 0.137\,Sd + 74\,ar*ar \\ & - 0.00663\,nr*nr - 1553\,af*af - 0.01492\,nf*nf - 0.01649\,n0*n0 - 0.0585\,Sd*Sd \\ & - 0.365\,ar*nf - 0.00060\,nr*n0 + 0.60\,af*nf - 0.00440\,nf*n0 \end{aligned}$$

- The optimum dressing condition is determined to be a_r = 0.04 mm, n_r = 4 times, a_f = 0.009 mm, n_f = 2 times, n_0 = 2 times and S_d = 1.2 m/min. And the optimum predicted value of MRR corresponding to optimum dressing condition is 0.388g/s.

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