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A STUDY ON MULTI-OBJECTIVE OPTIMIZATION OF PLUNGE CENTERLESS GRINDING PROCESS

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ABSTRACT

Round component with the minimum value of surface roughness and roundness error is the goal of most of the fine machine processes. This paper presents the research on optimization of plunge centerless grinding process when grinding the 20X-carbon infiltration steel (ГОСТ standard - Russia) to achieve the minimum value of surface roughness and roundness errors. The input parameters are center height angle of the workpiece (β), longitudinal dressing feed-rate (S_{sd}), plunge feed-rate (S_k) and control wheel velocity (v_{dd}) using the result of 29 sets in central composite design matrix to show the two second orders of surface rounghness and roundness error models. The final goal of this work focuses on the determination of optimum centerless grinding above the parameters for the minimization of surface roughness ($Ra_{\min} = 0{,}3090\mu m$) and roundness errors ($\Delta_{\min} = 1{,}3493\mu m$).

Keywords: Plunge Centerless Grinding, Optimization, Surface Roughness, Roundness Error.

1. INTRODUCTION

Centerless grinding is widely used in industry for precision machining of cylindrical components because of its high production rate, easy automation, and high accuracy. 20X - carbon infiltration steel is a common alloy steel that is usually used in mechanical engineering using centerless grinding process.

To improve the centerless grinding process, it is necessary to optimize surface roughness and roundness errors, the most critical quality constraints for the selection of grinding factors in process planning.

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Researches on the optimization of centerless grinding process were published by many authors: Minimizing the surface roughness and roundness errors of workpiece by selecting the optimization levels of control wheel speed, feed rate and depth of cut [1]. Minimizing the roundness error of workpiece and carrying out the regression analysis to model an equation to average out roundness error [2]. Predicting the set-up conditions to analyze the dynamic and geometrical instabilities, making it possible to study the influence of different machine variables in stability of the process [3]. Minimizing the surface roughness by developing an empirical model for it [4]. Minimizing the lobing effect by developing a stability diagram for workpiece and thereby selecting the grinding parameters and having found out that the characteristic root distribution of the lobing loop is periodic [5]. Investigating the workpiece roundness based on process parameters by both simulation and experimental analysis and finding out that a slower worktable feed rate and a faster workpiece rotational speed result in better roundness error [6]. Minimizing the roundness error of workpiece by selecting the optimization levels of dressing feed, grinding feed, dwell time and cycle time [7]. Minimizing the roundness error of workpiece by selecting the optimization range of the center height angle [8]. Giving a method of how to select the optimal stable geometrical configuration in centerless grinding [9]. Giving an algorithm for providing the optimum set-up condition [10]., etc.

This paper presents the research on the optimization of plunge centerless grinding process when grinding the 20X-carbon infiltration steel to achieve the minimum value of surface roughness and roundness errors. The input parameters include center height angle of the workpiece (β), longitudinal dressing feed-rate (S_{sd}), plunge feed-rate (S_k) and control wheel velocity (v_{dd}).

2. EXPERIMENT SYSTEM

2.1. Centerless grinding model

Plunge centerless grinding model is illustrated in figure 1. The value of center height angle (β) can be adjusted by the value of A. The relationship between (β) and A in equation 1 is:

$$\beta = \arcsin\left(\frac{A - R_{ct} - H}{R_{dm} + R_{ct}}\right) + \arcsin\left(\frac{A - R_{ct} - H}{R_{dd} + R_{ct}}\right) \quad (1)$$

Where, H is the distance from the grinding wheel center, control wheel center to the bottom of the workrest blade.

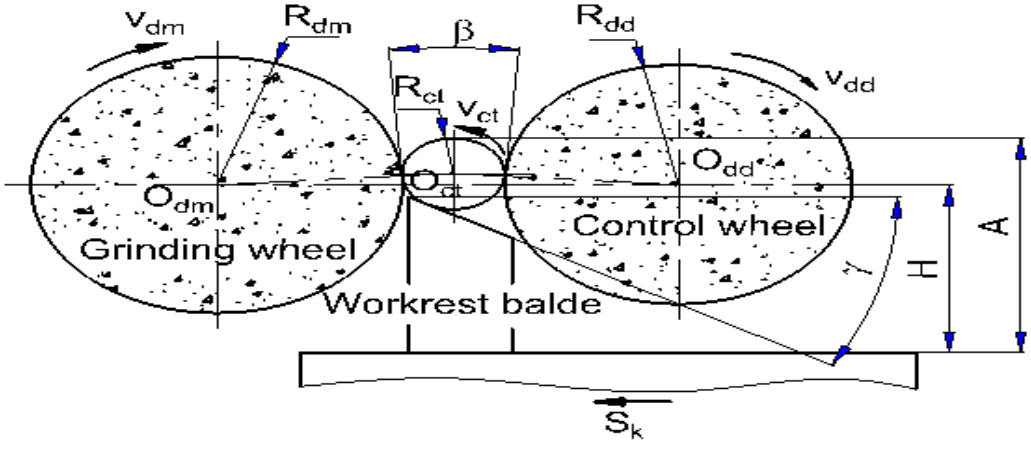

Fig 1: Plunge centerless grinding model

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2.2. Components

The component material was the 20X-carbon infiltration steel (62HRC), applied to the serial production elements for diesel engine and attachments. The experimental component, shown in Fig 2, was supported by specially made workrest blade with a 30^0 angle. The chemical composition of experimental component is in Table 1.

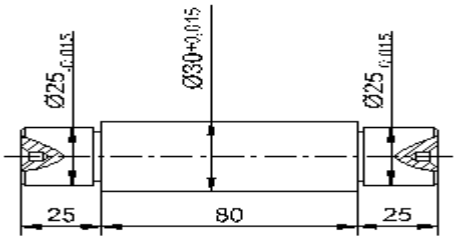

Fig 2: Experimental component

Table 1: Chemical composition of experimental component

C(%)	Si(%)	Mn(%)	P(%)	S(%)	Cr(%)	Ni(%)	Cu(%)
1,02	0,212	0,51	0,018	0,017	0,78	0,017	0,021

2.3. Grinding wheels

Using the Al_2O_3 grinding wheel of Hai Duong Grinding Wheels Joint Stock Company, Viet Nam, $Cn80.TB_1.G.V_1.500.150.305x35m/s$.

Besides, the standard rubber bonded control wheel of 273 mm x 150 mm x 127 mm dimesions was employed.

2.4. Experimantal machine tool

The grinding experiments were conducted on a M1080B centerless grinder with H = 210 mm, shown in Fig 3.

Fig 3: Experimantal machine tool

2.4. Measuring equipment

The surface roughness was measured by a Mitutoyo Surftest SJ-401 at 0,8 mm cutoff value. The roundness error was measured by a dial gage with a precision of 5/10.000. Each ground component was measured three times. The surface roughness and roundness error response, summarized in Table 2, are the average reading of three consecutive measurements.

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3. EXPERIMENT MATRIX

The experiment matrix was conducted under chatter free conditions to keep the grinding wheel speed (34 m/s), the grinding depth (0,05 mm), the depth of dressing (0,01 mm), the spark-out time (1 s) and the coolant flow constant.

In this work, using the central composite design with four input paremeters (β, S_{sd}, S_k, v_{dd}), their levels are presented in Table 2. This experimental matrix with 29 sets; these sets include 16 single-replicated orthogonal factorial points, 8 axial points located and 5 centre points, shown in Table 3.

Table 2: Input parameters and theirs levels

Input parameters	Symbol	Parameter levels				
		-2	-1	0	1	2
Center height angle (^{0})	β	4,8	6,0	7,2	8,4	9,6
Dressing feed-rate (mm/min)	S_{sd}	100	200	300	400	500
In-feed speed (μm/s)	S_k	2	6	10	14	18
Control wheel velocity (m/min)	v_{dd}	18,9	24,25	29,6	34,95	40,3

Table 3: Experimetal matrix

Set	β	S_{sd}	S_k	v_{dd}	$R_a(\mu m)$	$R_a^*(\mu m)$	$\Delta(\mu m)$	$\Delta^*(\mu m)$
1	1	-1	-1	1	0.44	0.42	2,67	2.84
2	0	0	-2	0	0.69	0.69	2,33	2.11
3	-2	0	0	0	0.91	0.90	2,50	2.28
4	-1	1	-1	-1	1.26	1.27	3,33	3.46
5	-1	1	-1	1	1.01	1.02	2,67	2.81
6	0	0	0	0	0.42	0.41	1,00	1.23
7	-1	-1	1	-1	0.52	0.52	2,50	2.58
8	1	-1	1	1	0.58	0.58	3,00	3.05
9	-1	-1	-1	-1	0.51	0.51	2,17	2.29
10	1	1	1	1	0.73	0.73	1,00	1.15
11	0	0	0	-2	0.64	0.63	3,33	3.14
12	-1	-1	1	1	0.48	0.47	1,83	2.00
13	-1	1	1	-1	1.12	1.14	2,67	2.76
14	1	1	1	-1	1.02	1.03	1,17	1.30
15	0	0	0	0	0.40	0.41	1,33	1.23
16	0	0	0	0	0.42	0.41	1,00	1.23
17	0	0	0	0	0.39	0.41	1,33	1.23
18	0	0	0	2	0.40	0.40	3,33	3.08
19	1	-1	-1	-1	0.29	0.29	1,50	1.58
20	1	-1	1	-1	0.57	0.56	2,33	2.45
21	1	1	-1	1	0.70	0.71	1,83	1.94
22	-1	-1	-1	1	0.57	0.57	2,33	2.38
23	-1	1	1	1	0.77	0.78	1,33	1.44
24	2	0	0	0	0.63	0.64	1,50	1.28
25	0	2	0	0	1.35	1.32	2,00	1.75
26	0	-2	0	0	0.39	0.41	2,67	2.48
27	1	1	-1	-1	0.89	0.89	1,33	1.42
28	0	0	2	0	0.73	0.73	1,83	1.61
29	0	0	0	0	0.44	0.41	1,50	1.23

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3. EFFECT OF INPUT PARAMETERS ON OUTPUT PARAMETERS

3.1. Effect of input parameters on surface roughness

Fig 4 depicts the main effect on surface roughness. The interaction effect of input parameters on surface roughness are shown in Figs 5-10. In each of these graphs, two input parameters are varied while the third and fourth parameters are the help as its mid value. The graphs show that all of the input parameters have a significant effect on the surface roughness.

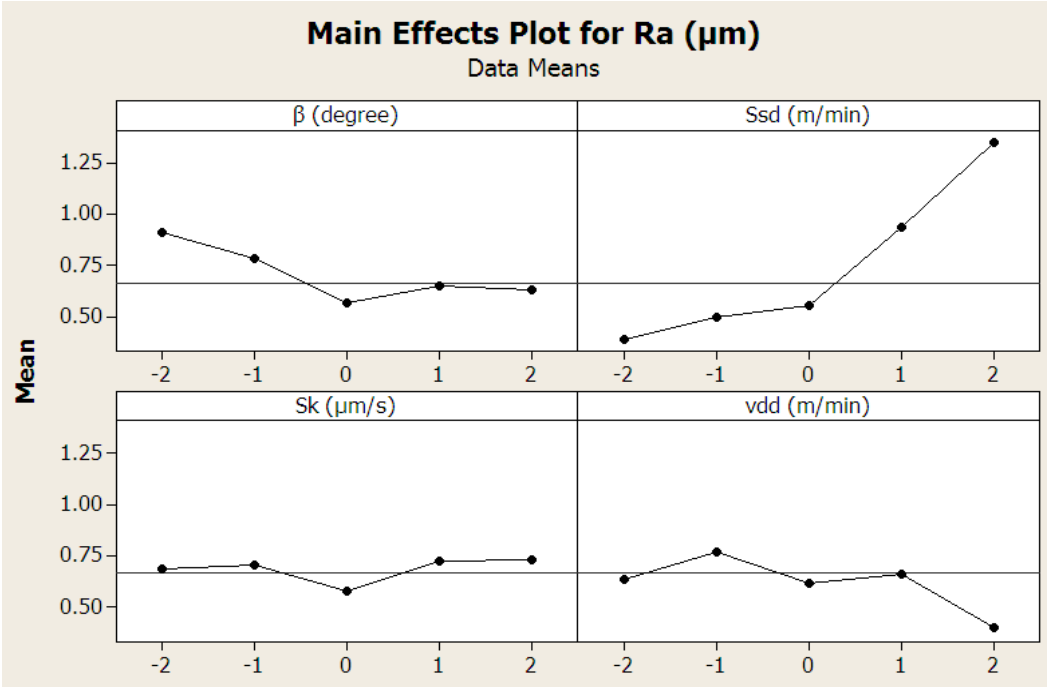

Fig 4: Main effect of input parameters on *Ra*

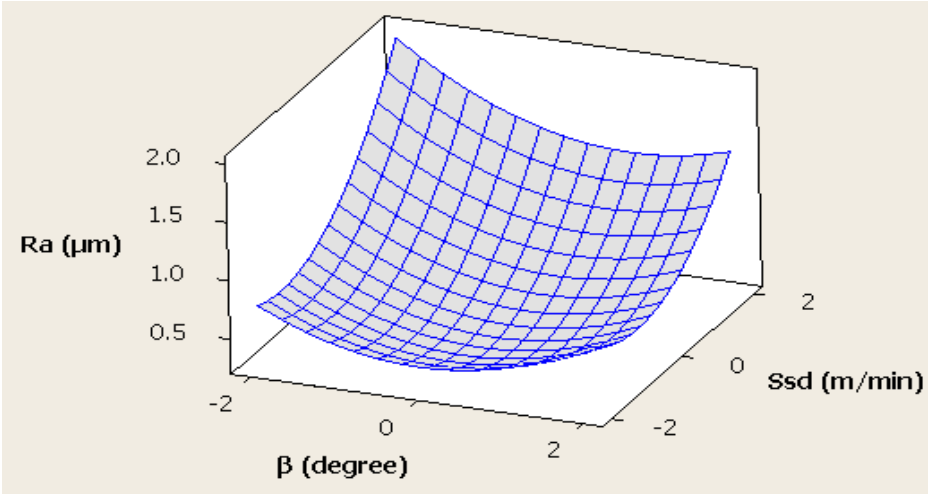

Fig 5: Interaction effect of β and S_{sd} on *Ra*

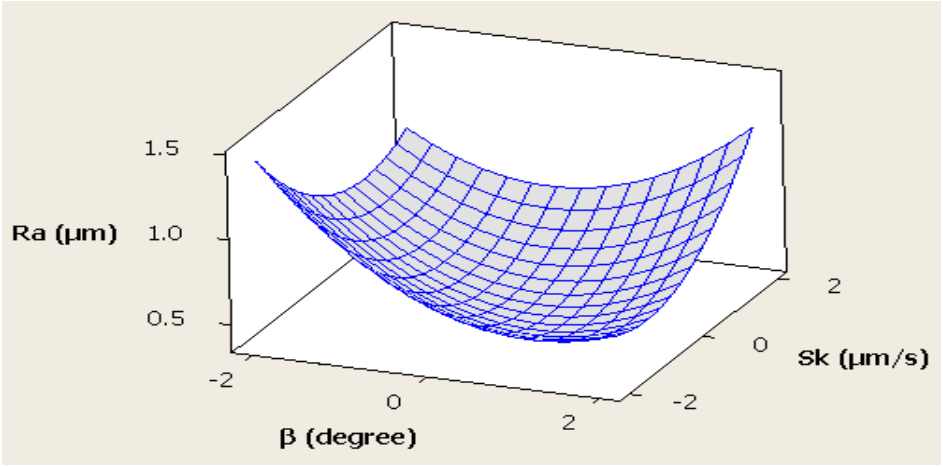

Fig 6: Interaction effect of β and S_k on Ra

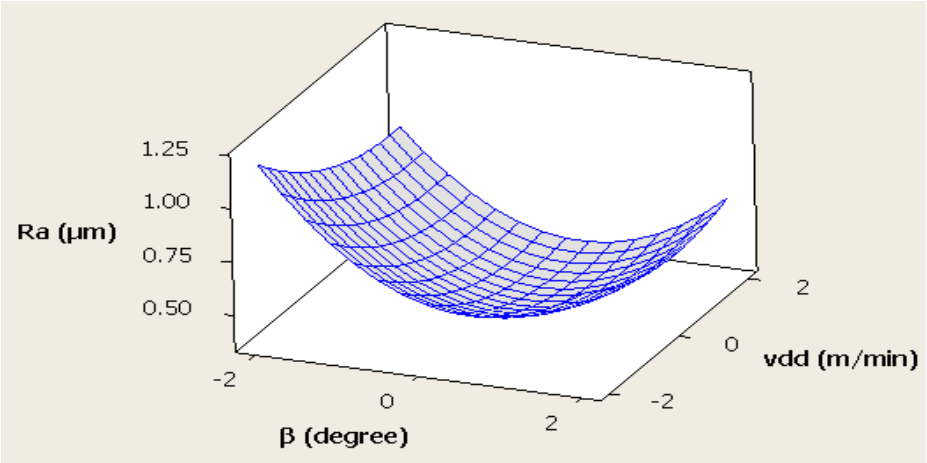

Fig 7: Interaction effect of β and v_{dd} on Ra

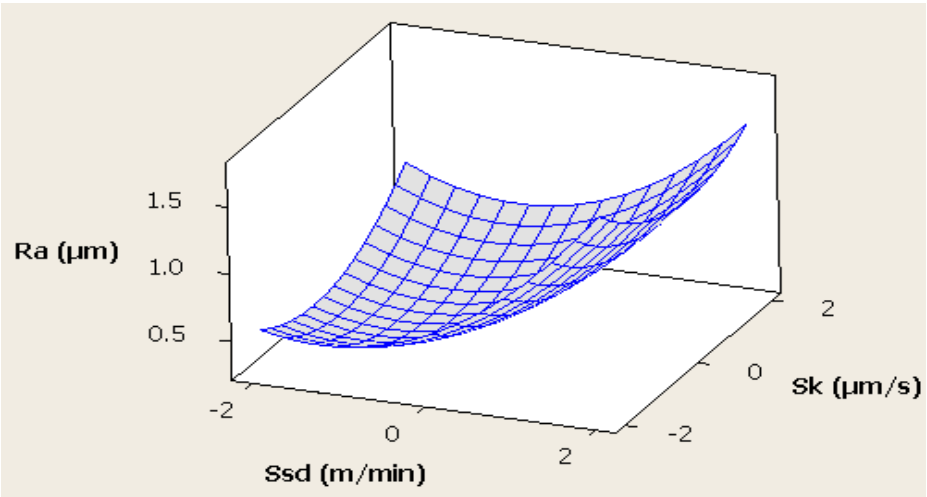

Fig 8: Interaction effect of S_{sd} and S_k on Ra

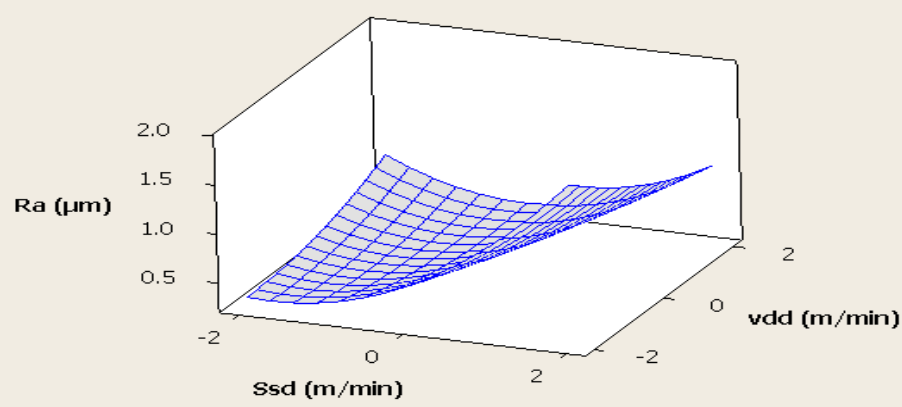

Fig 9: Interaction effect of S_{sd} and v_{dd} on Ra

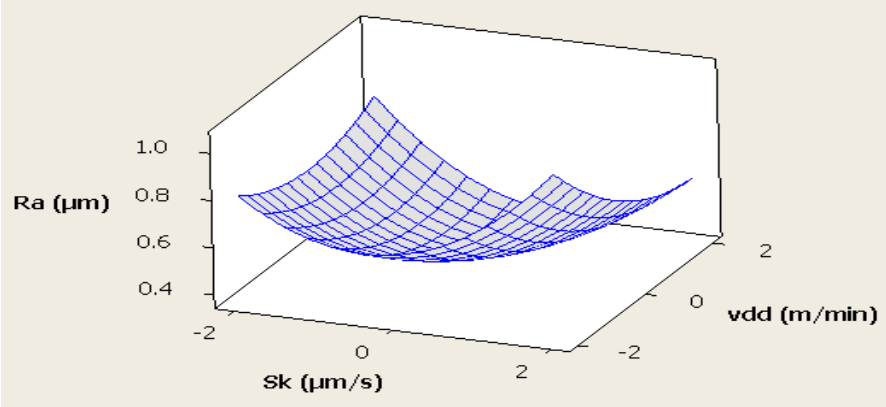

Fig 10: Interaction effect of S_k and v_{dd} on Ra

3.2. Effect of input parameters on roundness error

Fig 11 depicts the main effect on roundness error. The interaction effect of input parameters on surface roughness are shown in Figs 12-17. In each of these graphs, two input parameters are varied while the third and fourth parameters are the help as its mid value. The graphs show that all of the input parameters have a significant effect on the roundness error.

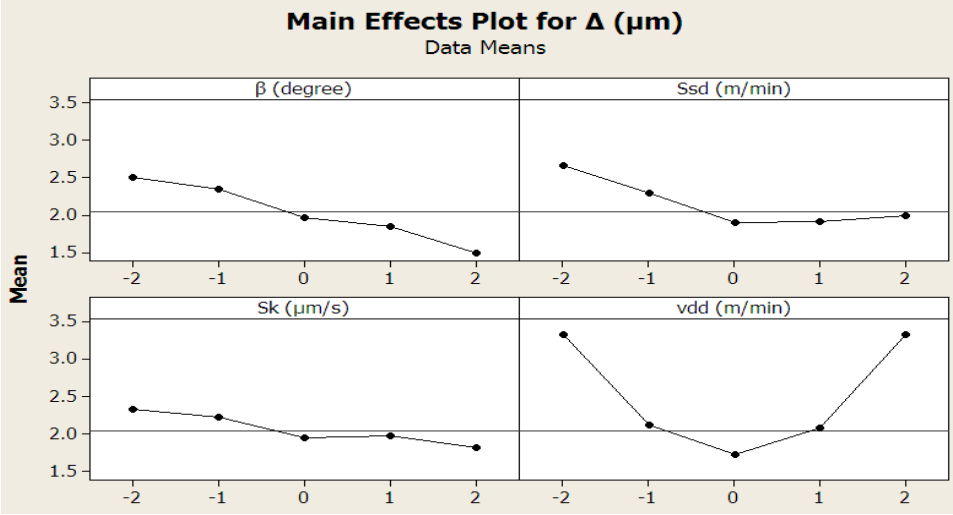

Fig 11: Main effect of input parameters on Δ

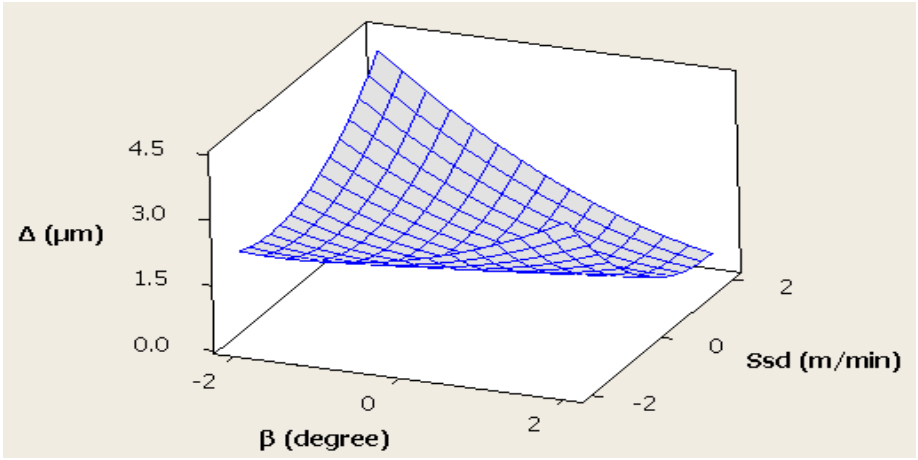

Fig 12: Interaction effect of β and S_{sd} on Δ

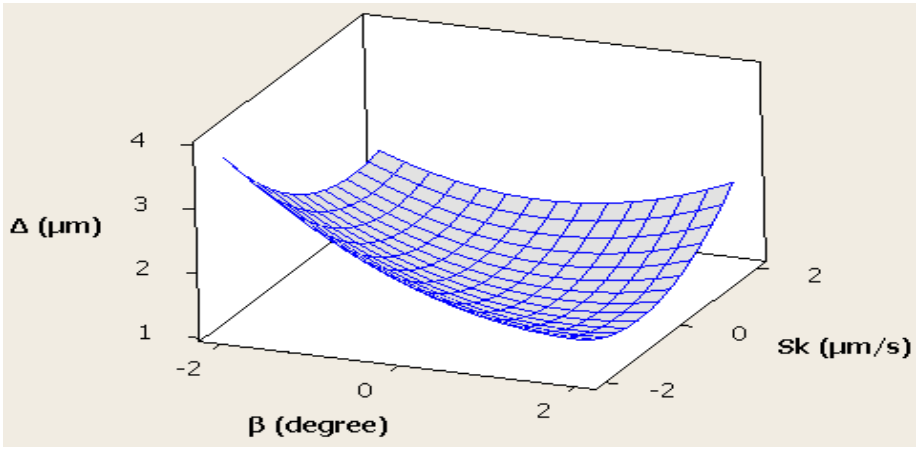

Fig 13: Interaction effect of β and S_k on Δ

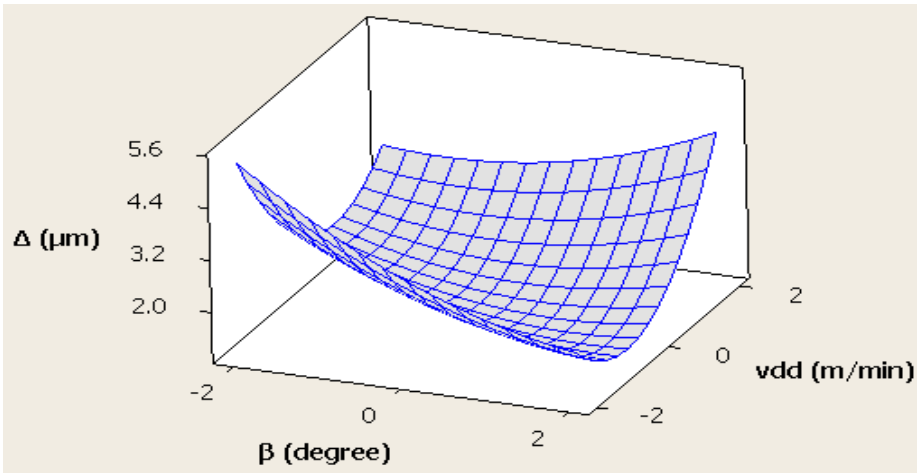

Fig 14: Interaction effect of β and v_{dd} on Δ

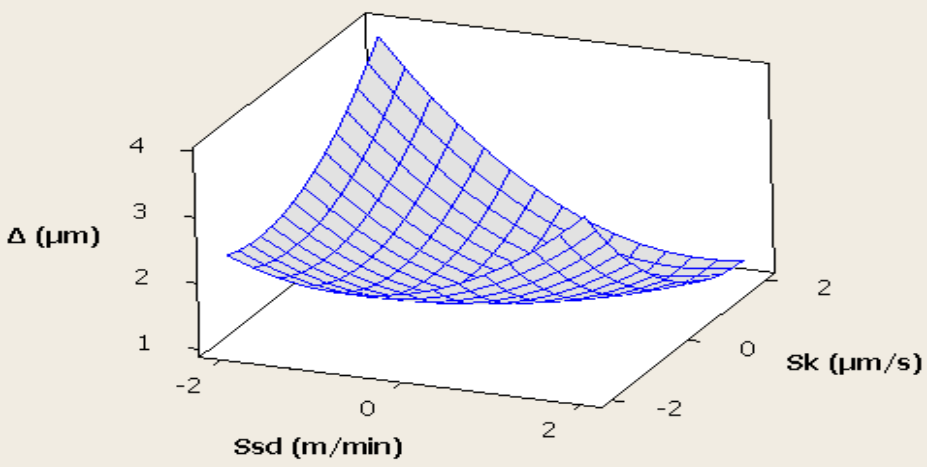

Fig 15: Interaction effect of S_{sd} and S_k on Δ

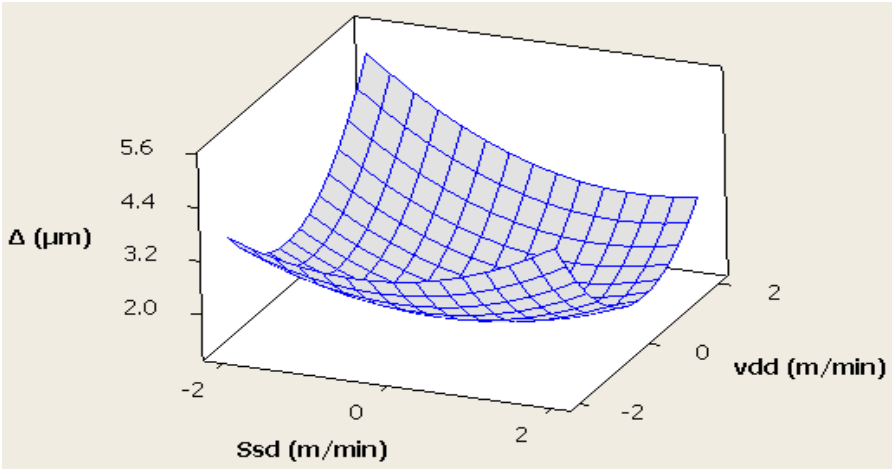

Fig 16: Interaction effect of S_{sd} and v_{dd} on Δ

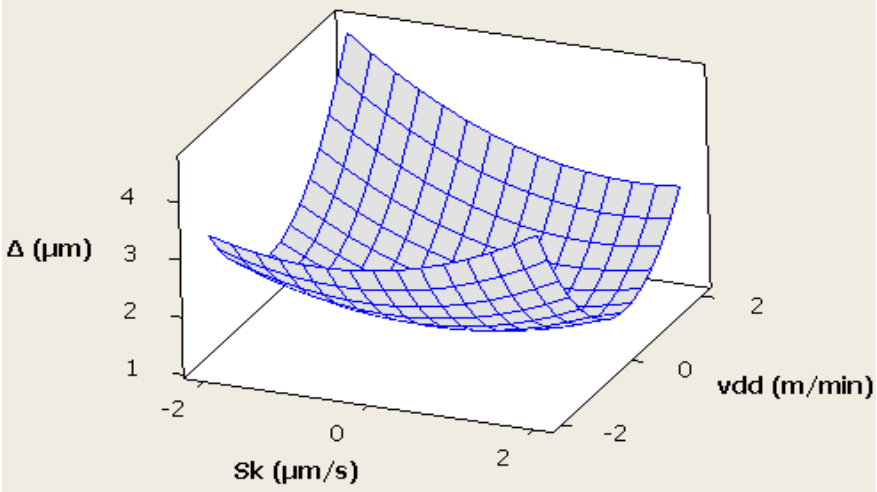

Fig 17: Interaction effect of S_k and v_{dd} on Δ

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5. REGRESSION MODELS

The statistical analysis software Minitab 16 was used to determine the regression coefficients. The analysis for estimated regression coefficients for Ra and Δ quadratic models is shown in Tables 4 and 5 respectively. The surface roughness and roundness error models was developed in the form of non-reduced final equation in terms of coded parameters.

Table 4: Estimated regression coefficients for Ra quadratic model

Estimated Regression Coefficients for Ra

Term	Coef	SE Coef	T	P
Constant	0.414000	0.007695	53.801	0.000
β	-0.065833	0.003512	-18.744	0.000
Ssd	0.227500	0.003512	64.772	0.000
Sk	0.008333	0.003512	2.373	0.033
vdd	-0.057500	0.003512	-16.371	0.000
β*β	0.088792	0.003378	26.285	0.000
Ssd*Ssd	0.113792	0.003378	33.686	0.000
Sk*Sk	0.073792	0.003378	21.845	0.000
vdd*vdd	0.026292	0.003378	7.783	0.000
β*Ssd	-0.038750	0.004302	-9.008	0.000
β*Sk	0.065000	0.004302	15.110	0.000
β*vdd	0.016250	0.004302	3.778	0.002
Ssd*Sk	-0.035000	0.004302	-8.136	0.000
Ssd*vdd	-0.078750	0.004302	-18.307	0.000
Sk*vdd	-0.027500	0.004302	-6.393	0.000

$$\begin{aligned} Ra = {} & 0{,}4140 - 0{,}065833\beta + 0{,}22750S_{sd} + 0{,}0083333S_k \\ & - 0{,}0575v_{dd} + 0{,}088792\beta^2 + 0{,}113792S_{sd}^2 + 0{,}073792S_k^2 \\ & + 0{,}026292v_{dd}^2 - 0{,}03875\beta.S_{sd} + 0{,}065\beta.S_k + 0{,}01625\beta.v_{dd} \\ & - 0{,}035S_{sd}.S_k - 0{,}07875S_{sd}.v_{dd} - 0{,}0275S_k.v_{dd} \end{aligned} \quad (2)$$

Table 5. Estimated regression coefficients for Δ quadratic model

Estimated Regression Coefficients for Δ

Term	Coef	SE Coef	T	P
Constant	1.23200	0.10776	11.432	0.000
β	-0.25000	0.04919	-5.083	0.000
Ssd	-0.18083	0.04919	-3.676	0.002
Sk	-0.12500	0.04919	-2.541	0.024
vdd	-0.01417	0.04919	-0.288	0.778
β*β	0.13658	0.04731	2.887	0.012
Ssd*Ssd	0.22033	0.04731	4.657	0.000
Sk*Sk	0.15658	0.04731	3.310	0.005
vdd*vdd	0.46908	0.04731	9.916	0.000
β*Ssd	-0.33375	0.06024	-5.540	0.000
β*Sk	0.14625	0.06024	2.428	0.029
β*vdd	0.29250	0.06024	4.855	0.000
Ssd*Sk	-0.24875	0.06024	-4.129	0.001
Ssd*vdd	-0.18750	0.06024	-3.112	0.008
Sk*vdd	-0.16750	0.06024	-2.780	0.015

$$\begin{aligned}\Delta &= 1{,}232 - 0{,}25\beta - 0{,}18083 S_{sd} - 0{,}125 S_k - 0{,}014167 v_{dd} \\ &+ 0{,}13658\beta^2 + 0{,}22033 S_{sd}^2 + 0{,}15658 S_k^2 + 0{,}46908 v_{dd}^2 \\ &- 0{,}33375\beta.S_{sd} + 0{,}14625\beta.S_k + 0{,}2925\beta.v_{dd} - 0{,}24875 S_{sd} S_k \\ &- 0{,}1875 S_{sd} v_{dd} - 0{,}1675 S_k v_{dd}\end{aligned} \quad (3)$$

The upper models can be used to predict surface roughness and roundness error at particular design points. The numerical values of predicted responses R_a^* and Δ^* are also summarized in Table 3. The differences between the measured and predicted responses are shown in Figs 18 and 19.

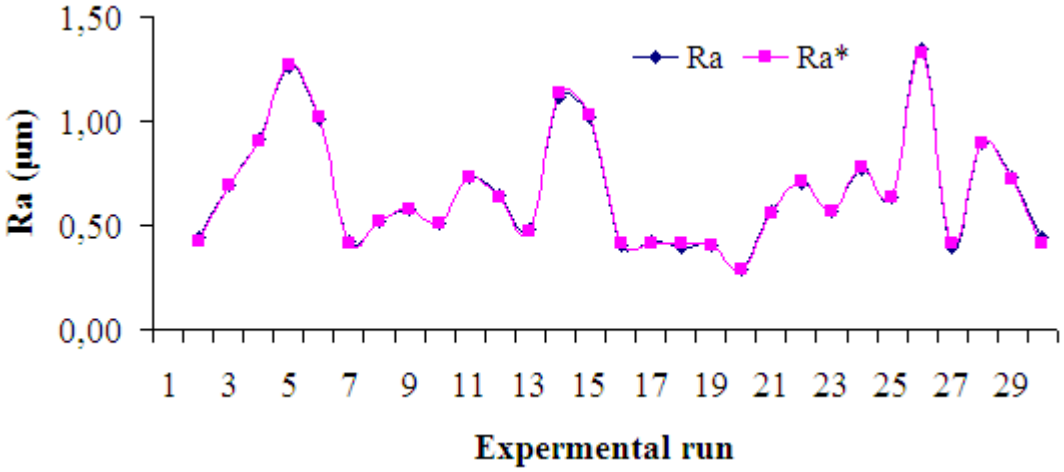

Fig 18: Measured and predicted surface roughness

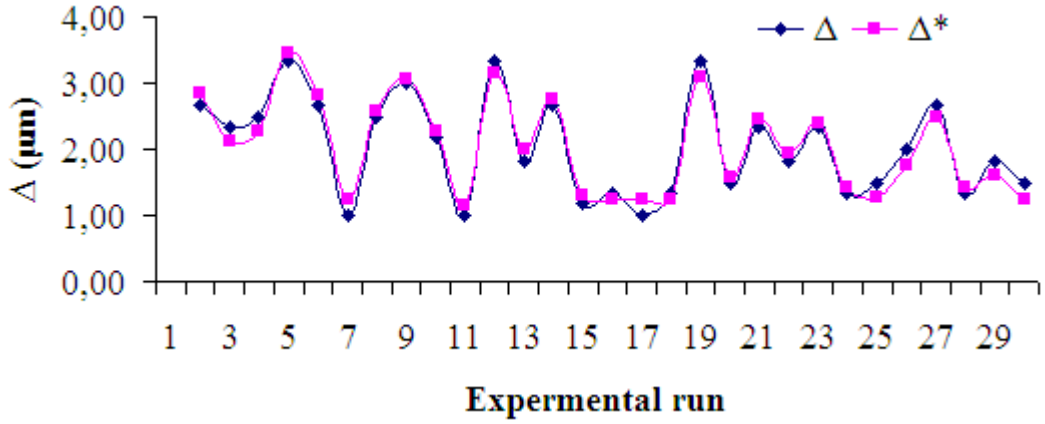

Fig 19: Measured and predicted roundness error

6. OPTIMIZATION

In the process of optimization, the goal is to minimize the surface roughness (Ra) and the roundness error (Δ), which form the multi objective optimizatio problem. Minitab 16 software is used to optimize these objectives. The optimization graph and numerical values are shown in Figure 20 and Table 6 respectively.

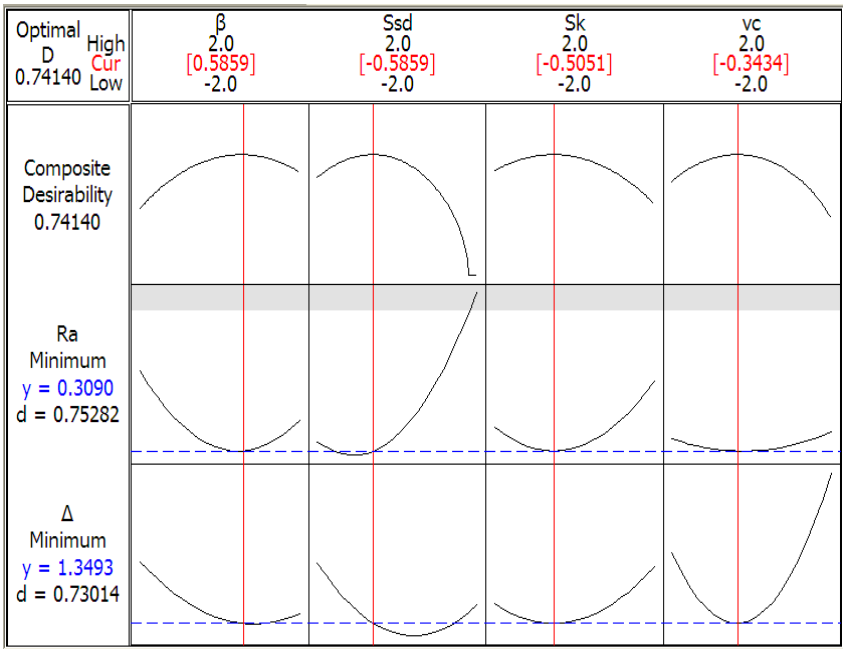

Fig 20: Optimization graph

Table 6: Optimization result

Output parameters	Objective function	Optimal input parameters				Predicted response
		β (^{0})	S_{sd} (mm/min)	S_k (μm/s)	v_{dd} (m/min)	
Ra (μm)	Min	7,90	241,41	7,98	27,76	0,3090
Δ (μm)	Min					1,3493

7. CONCLUSION

For the work material 20X-carbon infiltration steel, all of four input parameters (β, S_{sd}, S_k, v_{dd}) have a significant effect on both output parameters, surface roughness and roundness error. Thus, to achieve the minimum surface roughness and roundness error of the 20X-carbon infiltration steel, the numerical values of β, S_{sd}, S_k and v_{dd} are $7,9^0$; 241,41mm/min; 7,98μm/s and 27,76m/min respectively.

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