International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 6, June - 2013

Effect Of Grinding Variables On Surface Finish Of Ceramics

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Abstract

Surface finish is one the most critical quality measures in ceramics components. As competition among industries grows rapidly, customers are more inclined for quality. Creating components and eventually products with good surface finish have become a main competitive demand in ceramic industries. Nowadays, grinding is one the most popular method of machining hard materials. Resin boned diamond grinding wheel is used to grind the external surface finish of ceramic workpieces in hydraulic cylinder grinding machine. Design of Experiment (DOE) approach is used to study the effect of grinding variables on the surface finish of ground ceramic surfaces. In the present work, experiments are carried out to investigate the effect of depth of cut, feed rate and coolant flow rate on surface finish. Average surface roughness (Ra) value is measured using portable surface roughness tester (Mitutoyo SJ-201P). Analysis of variances is used for examining the impact of grinding factor and factor interactions on surface finish. A surface roughness model is developed using the experimental data considering only the significant factors.

1. Introduction

Glass, silicon, porcelain, advanced ceramics such as aluminum oxide, silicon carbide, zirconium oxide and aluminum based metal matrix composites reinforced with ceramic materials are becoming more significant in engineering applications. This is due to the fact that ceramics has higher hardness, temperature resistant property etc. These materials come into the category of difficult to machine materials. Grinding, lapping and polishing are the methods for machining hard materials. The process, time, cost are required high for these materials. Among all these methods, grinding with diamond wheel is the most popular and cost effective method for machining hard materials [1]. The effective use of ceramics in industrial applications demands the machining of ceramics with good surface finish [2]. The importance of a surface finish of a product depends upon its functional requirements [3]. Ceramic coated components used in industrial applications require post treatment for surface finish by precision machining [4, 5]. The coarse diamond grains creates rough surface. In order to improve the surface finish, finer diamond grains should be used in grinding wheel [6]. Grinding fluids are used to cool the workpiece and the grinding wheel, to transport debris away from the grinding zone, and to provide lubrication at the contact between the wheel and the workpiece [7]. Previous researches have shown that increase in cutting speed increases surface finish [8]. In high speed grinding of ceramics, a great amount of coolant has to be applied to the grinding zone to remove heat at the ceramic-wheel interface [9]. Surface finish in grinding depends on number of parameters such as material, depth of cut, feed rate, cutting speed, wheel type, machine characteristic, etc. There are number of parameters to describe surface finish but the commonly used parameter is average surface roughness (Ra). This study establishes the model for process optimization for improving the surface finish. The objective of this study is to evaluate the effect of grinding variables on the surface finish obtained on ground ceramic workpieces. A surface roughness model is developed to optimize the grinding conditions, viz. depth of cut, feed rate and coolant flow rate.

2. Experimental work

Experiments are performed on the hydraulic cylindrical grinding machine (HMT - K130-500). The workpiece selected for the experimentation is made of porcelain material. A resin bonded diamond grinding wheel with a grit size of 400# (with 100% diamond concentration) is used to grind the ceramic workpieces for external surface finish. The reason for this is that previous researches have shown that metal bonded diamond grinding wheel gives poor surface finish compared with resin bonded diamond grinding wheel [10]. After completing each experiment; the grinding wheel is dressed with silicon carbide dressing stick. Fig. 1 shows experimental setup for grinding operation. As per machine specification, the RPM of grinding wheel is 15200. The RPM given to the workpiece is 80. The cutting speed of grinding wheel obtained is 23.8 m/s. An emulsion of 10% concentration of soluble oil (Gulf Emulsil NA) in water is used as coolant. Average surface roughness (Ra) of workpiece is measured with portable surface roughness tester (Mitutoyo SJ-201P). The cutoff filter length is set at 0.8 mm and number of sampling length is taken as 3. Minitab 16 statistical software is used to conduct ANOVA and to develop surface roughness model.

Fig. 1 Experimental setup

3. Design of Experiments

The mathematical modelling of surface roughness involves lots of factors but to facilitate the experimental data collection, only three actors are considered in the planning of experiments. 3^3 full factorial design is used to plan the experiments. The three factors are depth of cut, feed rate and coolant flow rate. The response measured is surface roughness (Ra). The range of value of each factor has been set at three levels namely low, medium and high are shown in Table 1. Based on this setting, a total of 27 experiments, each having a combination of different levels of factors and their results are shown in Table 2. Experiments are randomised to remove any extraneous factor error [11].

Table 1 Experiment factors and their levels

Factors		**Values of different levels**		
Designation	**Description**	**Low (-)**	**Medium(0)**	**High(+)**
d	Depth of cut (µm)	2.5	5	7.5
f	Feed rate(mm/s)	3	6	9
c	Coolant flow rate (liter/s)	0.01250	0.03065	0.0488

Table 2 Experimental data and result

Exp. Run No.	**Depth of cut (µm)**	**Feed rate (mm/s)**	**Coolant flow rate (l/s)**	**Surface Roughness, Ra (µm)**
1	2.5	6	0.03065	0.84
2	7.5	9	0.03065	1.67
3	5	3	0.0125	1.03
4	5	9	0.0488	1.16
5	7.5	3	0.0125	1.33
6	7.5	9	0.0125	1.7
7	2.5	6	0.0488	0.82
8	5	9	0.0125	1.2
9	2.5	9	0.0488	0.9
10	7.5	6	0.0488	1.42
11	5	9	0.03065	1.19
12	5	6	0.0125	1.12
13	2.5	6	0.0125	0.88
14	7.5	3	0.0488	1.25
15	2.5	3	0.0125	0.76
16	2.5	9	0.03065	0.92

17	5	3	0.0488	0.98
18	5	6	0.03065	1.08
19	2.5	3	0.0488	0.72
20	7.5	9	0.0488	1.61
21	7.5	6	0.0125	1.52
22	5	6	0.0488	1.05
23	7.5	3	0.03065	1.28
24	5	3	0.03065	1
25	2.5	3	0.03065	0.75
26	7.5	6	0.03065	1.46
27	2.5	9	0.0125	0.97

Table 3 ANOVA for surface roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
d	2	1.81814	1.81814	0.90907	9817.96	0.000
f	2	0.27383	0.27383	0.13691	1478.68	0.000
c	2	0.02003	0.02003	0.01001	108.16	0.000
d*f	4	0.03659	0.03659	0.00915	98.80	0.000
d*c	4	0.00126	0.00126	0.00031	3.40	0.066
f*c	4	0.00044	0.00044	0.00011	1.18	0.389
Error	8	0.00074	0.00074	0.00009		
Total	26	2.15103				

4. Result and Discussion

ANOVA is performed to find the effect of factor and their interactions on the responses. The result of ANOVA for surface roughness is shown in Table 3. From Table 3, the main variables d, f & c and two way interactions; d & f are significant at 95% confident level and remaining interactions are not significant at 95% confident level.

It is found from Table 2 that the highest average surface roughness obtained is 1.7 µm at level of d = 7.5 µm, f = 9 mm/s, c = 0.01250 l/s and the lowest average surface roughness obtained is 0.72 µm at level of d = 2.5 µm, f = 3 mm/s, c = 0.0488 l/s. Fig. 3 & 4 shows the graphs of surface roughness profile which is taken from Mitutoyo (SJ-201P).

From Fig. 2, it can be seen that increase in depth of cut from 2.5 µm to 7.5 µm decreases surface finish to a great extent; increase in feed rate from 3 mm/s to 9 mm/s decreases surface finish; increase in coolant flow rate from 0.01250 l/s to 0.0488 l/s increases surface finish. It could be related that increase in depth of cut and feed rate increases grinding force which causes decrease in surface finish.

5. Surface Roughness model

The results of ANOVA for surface roughness (Ra) indicate that the main factors depth of cut, feed rate, coolant flow rate and two way interaction effect between depth of cut and feed rate are significant at 95% confident level and remaining interactions are not significant at 95% confident level. Thus these parameters are considered to develop surface roughness model (Ra) and it is given below:

Surface roughness model

$$\mathbf{Ra = 0.693 - 0.01*d + 0.008*f - 1.056*c + 0.01*d^2 + 0.006*f*d} \quad (1)$$

The proposed model is evaluated by comparing the predictions with the measured surface roughness (Ra) value obtained through grinding experiments. The results showed that predictions are consistent with the measured value with maximum error of 4.71%.

6. Conclusion

The investigations indicate that the factors depth of cut, feed rate and coolant flow rate are the factors which affect surface finish during grinding. High surface finish can be achieved with decrease in depth of cut & feed rate and increase in coolant flow rate. The most significant factor which affects surface finish is depth of cut followed by feed rate followed by coolant flow rate. It also reveals that the interaction between depth of cut and feed are significant. The predictive empirical model could serve as a basis for selection of process parameters to attain the required surface finish to meet the functional requirements of the ceramic components. The approach presented in this paper provides a means to develop mathematical models, based on the experimental results, to predict the surface roughness value in terms of the significant factors taken under consideration.

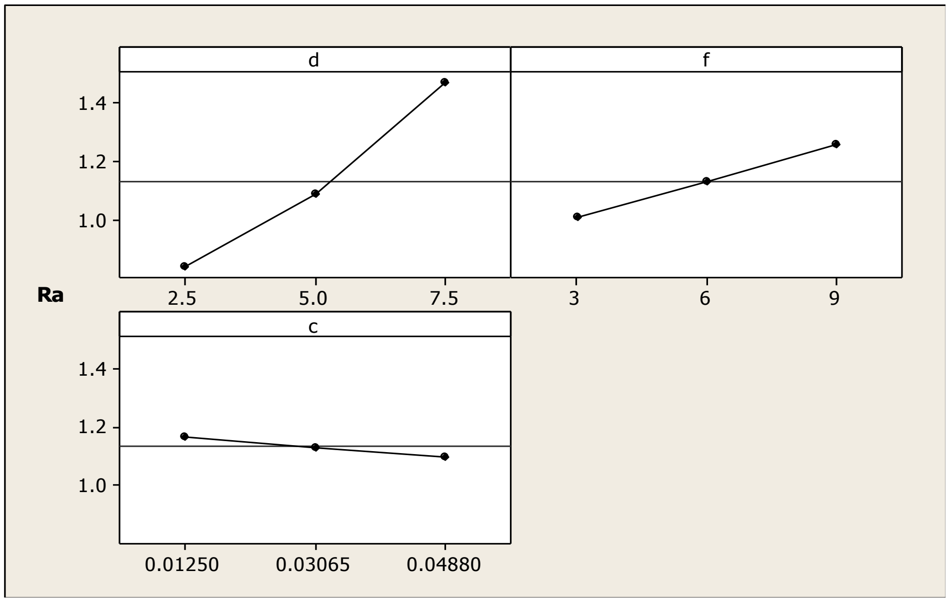

Fig. 2 Main Effects plot of Ra vs. d, f and c

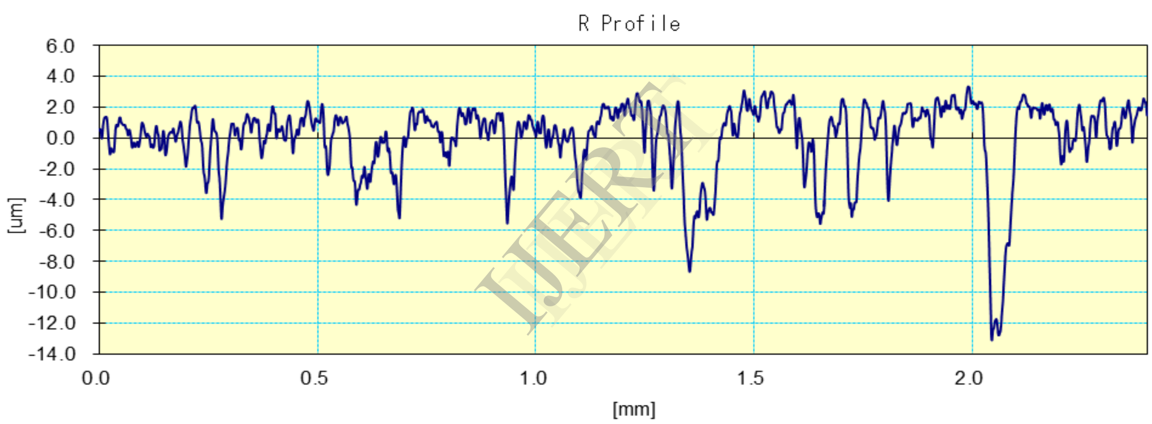

Fig. 3 Ra = 1.7 µm

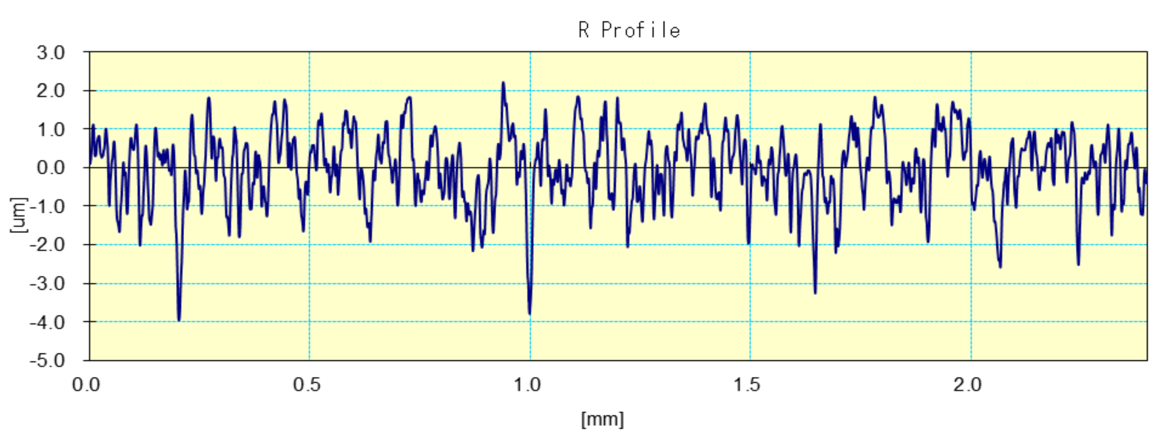

Fig. 4 Ra = 0.72 µm

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