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RESPONSE SURFACE ANALYSIS OF CYLINDRICAL GRINDING FOR MATERIAL REMOVAL RATE OF ALLOY STEEL EN9

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Abstract - Grinding is a term that describes machining with high-speed abrasive wheels, pads, and belts in contemporary production. Grinding wheels are available in many forms, sizes and types of abrasives. The next chapters will go over some of the most common types of wheels and abrasives. For single optimization the analysis of variance (ANOVA) results based on the estimated MRR values are provided, which show that depth of cut has the highest contribution of 92.06% and then the minimum influence due to cutting speed by 4.65% and feed rate by 0.94% in determining the MRR values, thus validating the above-obtained conclusion. The optimum combination for input control parameters is A2B3C1 and calculated grey relational grade by equation (7) is 0.4413. Table 5.9 shows the confirmation experiment for response parameters. It can be noted that the experimental value of Cutting Speed (V_C) in rpm, Depth of cut mm and Feed Rate mm/rev. are considerably enhanced by response surface methodology.
Index Terms: Cylindrical grinding Taguchi method Alloy steel EN9 Material removal rate.

1 INTRODUCTION

Contact with the work surface. [3] Most of the manufacturing processes are incomplete without the grinding process. Grinding is a major manufacturing process, which accounts for more than twenty percent of the total expenditure on machining operations [1–4]. Grinding machines are used to process and manufacture almost all technical components [5]. Turning, milling, drilling, boring, broaching, shaping, slotting, grinding, and other machining processes are examples. Grinding is one of these finishing processes, and it is used to provide a smooth surface finish with high dimensional and form accuracy [6]. Grinding process used to bring workpiece dimensions within very close tolerance after all the rough finishing and heat treatment operations have been carried out and also used for sharpening the carbide tool. Grinding machines are used to finish items that are cylindrical, flat, or have an internal surface.

The kind of surface finish largely depends on the type of grinding machine; according to the quality of surface finish classified as rough grinder and precision grinder. The main purpose of rough grinder is to remove stock without any references to the accuracy of the results. Precision grinders produce good surface finish with high degree of accuracy. The metal removal rate of the grinding process is much lower compared to other machining processes. Since it is a finishing operation, the utmost care has to be taken to achieve the desired responses without affecting surface integrity [7].

The grinding wheel is made of abrasive grains held together in a binder. These abrasive grains act as cutting tool, removing tiny chips of material from the work. As these abrasive grains wear and become dull, the increased resistance leads to fracture of the grains or weakening of their bond. The dull pieces break away, revealing sharp grains that continue cutting. The requirement for efficient grinding includes:

- Abrasive component which are harder than the work
- Shock and heat resistant abrasive wheels
- Abrasives that is friable

This chapter introduces basic material removal in grinding, starting with the rules for rubbing, ploughing and chipping, and progressing to the parameters governing material removal. The removal of material depends not only on the basic removal parameters, but also on the abrasive material and the hardness of the grinding machine. Basic parameters for removal rate include depth of cut, grinding strength, machine deflection, grinding width and feed rate. The actual depth of cut and the required spark-out period depend on the hardness of the grinding machine and the width of the grinding contact. Deflections are shown to affect size and shape errors. A hardness factor can be employed to calculate the required spark-out period and reduce size errors. Specific removal rate, removal energy and specific energy are related to the ease of grinding the particular material.

1.1 Element Characteristics

A system specification includes the following details.

- Work piece material: Shape, hardness, stiffness, thermal and chemical properties.
- Grinding machine: Type, control system, accuracy, stiffness, temperature stability and vibrations

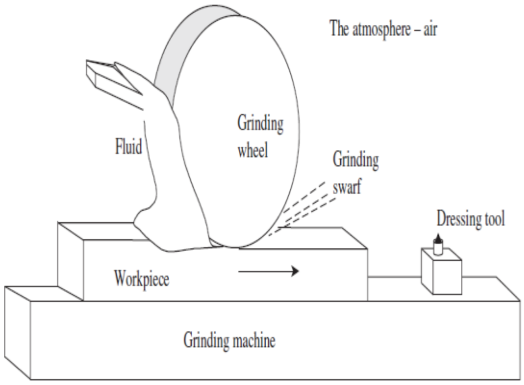

Figure 1.1 Elements of a basic grinding system[17]

Kinematics: The geometry and motions governing the engagement between the grinding wheel and the workpiece. Speeds and feeds of the workpiece and the wheel.

- Grinding wheel: Abrasive, grain size, bond, structure, hardness, speed, and stiffness, thermal and chemical properties.
- Dressing conditions: Type of tool, speeds and feeds, cooling, lubrication and maintenance.
- Grinding fluid: Flow rate, velocity, pressure, physical, chemical and thermal properties.
- Atmospheric environment: Temperature, humidity and effect on environment.
- Health and safety: Risks to the machine operators and the public.
- Waste disposal.
- Costs.

2 PROBLEM DESCRIPTION

Under the machining process, there are several factors which exert influence on material removal rates, including cutting condition, tool variables, machine status and workpiece variables. In the cylindrical grinding process (CGP), it is not easy to consider all process parameters that device material removal rate (MRR) because it needs much experimentation which consumes time, human resources and money. Henceforth, selection of the optimised cutting parameters with optimal cutting conditions for the given equipment and set up is an important process. The selection of the optimised machining parameter is not an easy process. Likewise, to increase the quality of MRR at the same time, the optimal cost of equipment CGP requires a systematic approach. Currently, there are many studies related to the optimisation of cylindrical grinding conditions when grinding different steels. Many of the summarised studies in Table 1 optimised different kinds of steel. However, through an extensive literature survey, we did not find machining parameters regarding EN9 steel material. Therefore, this study mainly dealt with EN9.

2.1 Material removal rate (MRR)

MRR was explained by Patel and Deshpande [18] as "the material or metal that is removed per unit time in mm3/sec. For each revolution of the workpiece, a ring-shaped layer of material is removed". Eq. (1) can be used to compute MRR [18].

$$MRR = v \times f \times d$$

Where by v ="cutting speed (mm/s)"; f = "feed (mm/rev)"; d = "depth of cut (mm)" [15]; and MRR = mm3/s.

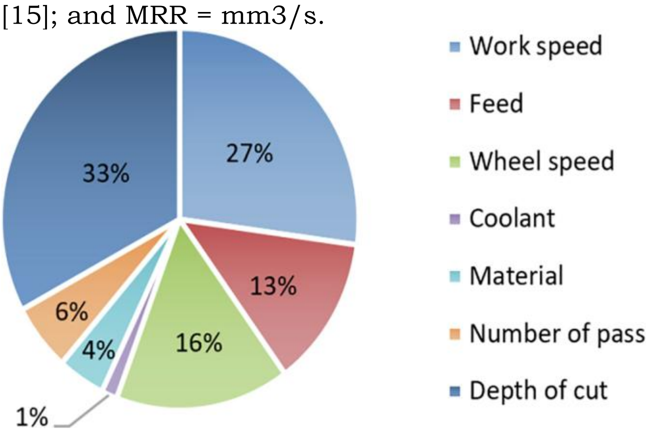

Fig. 2.1 The frequency occurrence of the used process parameters.[19]

3 METHODOLOGY

3.1 Design of Experiment

Design of experiment is technique developed to understand the behavior of the mechanical system. Data are collecting from the sets of the variable, and it can qualitatively explain the undergoing phenomenon. Hence it is well known that aim of any research is design the experiment with minimum number of the experiment and with this experiment collects maximum information as much as possible. Every experiment focuses on the major number of the factor which can directly affect the results of the experiment. And such types of factor can be detected by quantities which have major effect on the experiments outcomes. One of the most important concepts for identified such factor is to look after the experiment performed later or by theories.

Example if one can know about the process undergoing is affected by the material removal rate during the experiment, hence by knowing one can identified the minimum and the maximum value of the MRR presented in the experiment, so one can run an experiment by considering that values. In the Design of experiment can be design by the sets of factors and their levels, the value of factor and the level is decided by the operators. So many times with particular factor and the levels same experiment were repeated, these types of repeated experiment were known as replicate experiments.

Table 3.1 L27 orthogonal array and results.

Experiment No.	Cutting Speed	DOC	Feed Rate	MRR
1	1700	0.02	0.04	1.242
2	1700	0.02	0.04	1.268
3	1700	0.02	0.04	1.204
4	1700	0.04	0.06	1.603
5	1700	0.04	0.06	1.601
6	1700	0.04	0.06	1.719
7	1700	0.06	0.08	2.317
8	1700	0.06	0.08	2.429
9	1700	0.06	0.08	2.43
10	1900	0.02	0.06	1.4
11	1900	0.02	0.06	1.52
12	1900	0.02	0.06	1.768
13	1900	0.04	0.08	1.872
14	1900	0.04	0.08	1.875
15	1900	0.04	0.08	1.941
16	1900	0.06	0.04	2.675
17	1900	0.06	0.04	2.56
18	1900	0.06	0.04	2.51
19	2200	0.02	0.08	1.392
20	2200	0.02	0.08	1.457
21	2200	0.02	0.08	1.468
22	2200	0.04	0.04	1.567
23	2200	0.04	0.04	1.6
24	2200	0.04	0.04	1.771
25	2200	0.06	0.06	2.52
26	2200	0.06	0.06	2.601
27	2200	0.06	0.06	2.643

Table 3.2 Control Parameters and their levels

Parameter	Factor	Level 1	Level 2	Level 3
Cutting Speed (Vc) in rpm	A	1700	1900	2200
Depth of cut mm	B	0.02	0.04	0.06
Feed Rate mm/rev	C	0.04	0.06	0.08

Replicate presents in the experiment is depend upon the number of the factors and the levels decided for the sets of variable, as the number of experiment were increases than the number of replicates will also be increases within the experiment. There are different method are used on the design of experiment, like Full factorial method, Taguchi Method, Response surface method , Mixture Design etc. Each experiment having their own importance it depends upon the situation or depends upon the types of factors and their levels that which method is best suitable for their experiment.

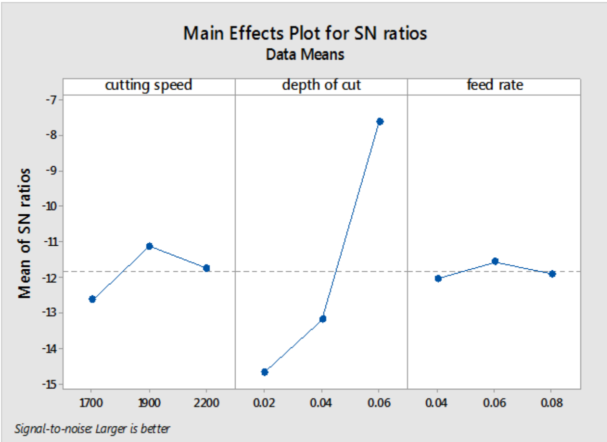

Fig. 3.1 Main Effects Plot for SN ratios of MRR

Table 3.3 Response Table for Signal to Noise Ratios Larger is better

Level	Cutting Speed	DOC	Feed Rate
1	4.568	2.920	4.790
2	5.846	4.711	5.433
3	5.233	8.017	5.425
Delta	1.278	5.097	0.643
Rank	2	1	3

As MRR is the larger-the-better type quality characteristic, it can be seen from the main effect plot (Figure 3.1) that the second level of cutting speed (A2), first level of depth of cut (B1) third level of feed (C3) provides maximum value of MRR. As the feed rate and cutting speed increase, the MRR also increases but with very small amount. On the other hand, with increase in 0.02 mm in depth of cut, the MRR increases significantly.

3.2 Analysis of Variance

Anova analysis is the method in stats use to differentiate between two or more mean, as the name from the definition is different it name should be Analysis of means rather than analysis of the variance, but the analyze variance inference the mean. There are different methods are used of Analysis the means but why Anova analysis is best because of only one reason there are more and more complex types of problem were solved or analysis by the Anova analysis. Second thing is the Anova analysis the most commonly used method for comparing the mean. And with the help of Anova analysis it is very easy to understand the research. Anova analysis is also use to make relationship between the response and the predict variable or it is use to investigate the relation between the different independent variable in corresponding to their response. Since in some aspect Anova analysis is different from the regression analysis hence it can predict the qualitative variable (categorical factor), but in moist of the cases of the Minitab Anova analysis is done for both qualitative and quantitative variables.

The table below is the table for Anova analysis as it is clear that three different method were used in these table one is linear and second one is square and the final one is 2 way interaction, in the linear model one can show the relationship between the output variable with individual input hence in our case the output is material removal rate. For single optimization, so in the linear model the relationship between the Cutting Speed, DOC, Feed Rateand the material removal rate.

Table 3.4 Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Cutting Speed	2	0.29614	4.65%	0.29614	0.14807	19.75	0.000
DOC	2	5.86121	92.06%	5.86121	2.93060	390.81	0.000
Feed Rate	2	0.05958	0.94%	0.05958	0.02979	3.97	0.035
Error	20	0.14997	2.36%	0.14997	0.00750		
Lack-of-Fit	2	0.00736	0.12%	0.00736	0.00368	0.46	0.636
Pure Error	18	0.14261	2.24%	0.14261	0.00792		
Total	26	6.36690	100.00%				

Model Summary: Finally the regression equation is shown give the exact model equation or it will show the relationship between the input and the output variables.

Table 3.5 Model Summary

S	R-sq	R-sq (adj)	PRESS	R-sq (pred)
0.0865951	97.64%	96.94%	0.273328	95.71%

P Value : P value in the Anova analysis is the most important part and the term, P value shows the effect of the individual variable on the output , As from the American standard of the mechanical engineering P value must be less than 0.05 , if the P value for any factor is less than 0.05 than this the factor which having the more effect on the output , or this is the most responsible factor for producing the output, or the quality of the product or the value of the response is being deflected or differentiate by changing the value of the individual variable. Hence for the belter quality of the product or producing the better response the P value must be below 0.05.

F value: F value is the most important term to be considered during the data analysis, f value is taken into the consideration when there is more than one variable have the value of p is less than 0.05, hence the confidence interval of 95%.

Then question is which is the most responsible factor for effecting the response, or among all the variable having the value of p is less than 0.05, then there is the relationship between the value of p and the value of f, less or minimum is the value of and correspondence to which higher is the value of F, and the among all the variable, the variable having minimum value of P and the maximum value of F is the factor responsible for the effecting the response

4 NUMERICAL OPTIMIZATION

The purpose of this research is to find the best parametric settings to achieve maximum Material Removal Rate of grinding process at the same time, which is ideal for good grinding efficiency. The desirability analysis is used to determine the best parametric setting to obtain the absolute Material Removal Rate of the grinding process. The grinding process is optimized using the Minitab18 program. The common steps and procedures that are followed in the Minitab software are described in detail here. The results of multi-objective optimization for Material Removal Rate are shown in fig. 4.1. Optimal Material Removal Rate 2.816(Gm./Min) has been obtained at(a) Cutting Speed(V_C) in rpm A2 1900 rpm (b) Depth of cut (mm), B30.06 mm. (c) Feed Rate 0.04 (mm/rev)C1 The mixed desirability factor D has a value of 0.93650.

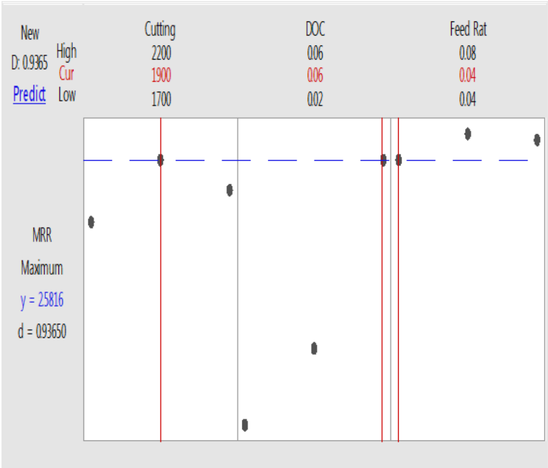

Fig. 4.1 Optimization results of Material Removal Rate by RSM

4.1 Confirmation Test

The optimization results obtained have been validated by performing confirmatory experiments. Table 4.1 represents the results of confirmatory tests that are conducted in optimal conditions. It is seen from the table that the error in terms of percentage between the estimated and experimental results is very small and is less than 1%. This indicates for single optimization, good agreement with experimental Alloy steel EN9 for cylindrical grinding. Parameters. Three fresh experiments are conducted for confirmation of models Eqs. (3) And (4), with achieved optimal values of Material Removal Rate. The average of measured values for Optimal Material Removal Rate 2.816 (Gm./Min) has been obtained at(a) Cutting Speed(V_C) in rpm A2 1900 rpm (b) Depth of cut (mm), B3 0.06 mm. (c) Feed Rate 0.04 (mm/rev) C1.

The accuracy of the models is analyzed on the basis percentage error. . Since the error is less than10%, it is evidently proved that there is a good agreement between experimental and predicted values [38].Finally, an attempt has been made for estimation of optimum cylindrical machining condition to produce the best desirable response within the experimental constraint.

Table 4.1 Multi-objective optimization results

Optimal Control Parameters	Level	Optimal Level	Experimental	Predicted (RSM)	Error (%)
Cutting Speed(V_C) in rpm	A	A_2 B_3 C_1	2.675	2.816	1.4
Depth of cut mm	B				
Feed Rate mm/rev	C				

5. CONCLUSION AND FUTURE SCOPE

Experiments were conducted for various combinations of tool rotational speed and welding speed at three levels in Taguchi's orthogonal array. The strength of the joints was analyzed by hardness test.

The following observations were made from the studies:

1. Taguchi's orthogonal array has been successfully used to find the optimum level setting of process parameters.
2. As MRR is the larger-the-better type quality characteristic, it can be seen from the main effect plot (Figure 3.1) that the second level of cutting speed (A2), first level of depth of cut (B1) third level of feed (C3) provides maximum value of MRR.
3. For single optimization the analysis of variance (ANOVA) results based on the estimated MRR values are provided in Table 3.3, which show that depth of cut has the highest contribution of 92.06% and then the minimum influence due to cutting speed by 4.65% and feed rate by 0.94% in determining the MRR values, thus validating the above-obtained conclusion.
4. R-sq: According to the research methodology the value for the R-sq is must be above 40% for predicting the good agreement between the input and the output values. From the table

below the value for the R-sq is 97.64% which reflects the good agreement between the input and the output variables. Hence there is strong relationship between the input and the output variables.

5. Response surface methodology (RSM) is found to be very helpful in the process of optimization carried out in the present study. Here the predicted value obtained from the models is very near to the experimental value.

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