"PARAMETRIC OPTIMIZATION OF MACHINING PARAMETER DURING TURNING OF INCONEL-625"

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ABSTRACT

In this thesis the results of an experimental investigation about the effect on Inconel-625 during hard turning using cubic boron nitride (CBN) based ceramic cutting tool. Turning experiments were carried out at different cutting speeds, feed rates and depth of cut .Tool performance was evaluated with respect to temperature, cutting forces, surface roughness and material removal rate generated during turning. The effect of cutting speed, depth of cut and feed rate on temperature, cutting forces, surface roughness and material removal rate during hard turning of Inconel-625 was experimented and analyzed by using taguchi method. The orthogonal array used for optimization. Than optimize the temperature, cutting forces, surface roughness and material removal rate using analysis of variance (ANOVA) Regression and Grey Relational Analysis (GRA) method.

Keyword: *-Hard Turning, Surface roughness, MRR, Temperature, cutting force, Optimization.*

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1. INTRODUCTION

Turning is a very important machining process in which a single-point cutting tool removes material from the surface of a rotating cylindrical work-piece. The cutting tool is fed linearly in a direction parallel to the axis of rotation. The turning is carried out on a lathe that provides the power to turn the work-piece at a given rotational speed and to feed the cutting tool at a specified rate and depth of cut. Therefore, three cutting parameters are listed below Cutting speed (v), Feed rate (f), Depth of cut (d).

Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece to a specified dimension and to produce a smooth finish on the work-piece. Often the work piece will be turned so that adjacent sections have different diameters.

1.1 TEMPERATURE

Heat phenomena that occur in the narrow and in the broad area of the cutting zone are directly related to wear rate of tool, to the machinability rate of workpiece material, to the tool stability and related to many other characteristics of the machining process. Generated heat goes from the cutting zone into the chips, tool, and workpiece into the environment though thermal energy. The decrease of the hardness of tool's cutting elements, cutting wedge deformations, the loss of the tool cutting ability and its bluntness occur. Generated heat distribution in workpiece in tool and in chips that is, the temperature level at working elements of the tool, at processed surface and at chips depends on: workpiece material (its mechanical and chemical characteristics) cutting speed, feed rate, depth of cut, tool geometry, lubricants type and many other relevant parameters.

1.2 SURFACE ROUGHNESS

The surface quality is an important performance criterion to ass's machinability of any material with dimensional accuracy and surface finish. Surface roughness is used as the critical quality indicator for the machined surface. Formation of a rough surface is a complicated mechanism involving many parameters. The quality of the work piece (either roughness or dimension) are greatly influenced by the cutting conditions, tool geometry, tool material, machining process, chip formation, work piece material, tool wear and vibration during cutting. Every machining process leaves its impact on the machined surface in the form of finely spaced irregularities. Each cutting tool leaves its own individual pattern on the surface. Surface Roughness may be considered as being superposed on a wavy surface. The CLA (Centre Line Average) value of surface roughness (Ra) is the arithmetical average of the departure of the whole of the profile both above and below its centerline throughout the prescribed meter cut-off in a plane substantially normal to the surface.

$$Ra = 1/L \int_0^L Y(x)dx$$

Where,
L is the sampling length
Y is the profile curve
X is the profile direction

1.3 MATERIAL REMOVAL RATE

The Investigation presents the use of Taguchi method for optimizing the material removal rate in turning medium inconel-625 which is extensively used as a main engineering material in various industries such as Rollers, Supporting shafts, and Structural column etc. These materials are considered as easy to machining and possess superior machinability. Taguchi's orthogonal arrays are highly fractional designs used to estimate main effects using only few experimental runs. These designs are not only applicable to two level factorial experiments, but also can investigate main effects when factors have more than two levels.

2. LITERATURE REVIEW

[1]" Effect of cutting parameters on cutting force and surface roughness during finish hard turning AISI52100 grade steel", Gaurav Bartarya1, S.K.Choudhury2, Procedia CIRP 1 (2012) 651 – 656.

In this paper researcher had worked on effect of cutting parameters on cutting force and surface roughness during finish hard turning AISI52100 grade steel. The present work is an attempt to develop a force prediction model during finish machining of EN19 steel (equivalent to AISI 52100 steel) hardened to 60±2 HRC using hone edge uncoated CBN tool and to analyze the combination of the machining parameters for better performance within a selected range of machining parameters. A full factorial design of experiments procedure was used to develop the force and surface roughness regression models, within the range of parameters selected. The regression models developed show that the dependence of the cutting forces i.e. cutting, radial and axial forces and surface roughness on machining parameters are significant; hence they could be used for making predictions for the forces and surface roughness. The predictions from the developed models were compared with the measured force and surface roughness values. To test the quality of fit of data, the ANOVA analysis was undertaken. The favorable range of the machining parameter values is proposed for energy efficient machining

[2] "Analysis of surface roughness and cutting force components in hard turning with CBN tool: Prediction model and cutting conditions optimization", HamdiAouici1, Mohamed AthmaneYallese2, KamelChaoui3, TarekMabrouki4, Jean- François Rigal5, Measurement 45 (2012) 344–353.

This paper is related to analysis of surface roughness and cutting force components in hard turning with CBN tool: prediction model and cutting conditions optimization. In this study, the effects of cutting speed, feed rate, work piece hardness and depth of cut on surface roughness and cutting force components in the hard turning were experimentally investigated. AISI H11 steel was hardened to (40; 45 and 50) HRC, machined using cubic boron nitride (CBN 7020 from Sandvik Company) which is essentially made of 57% CBN and 35% Ti-CN. Four-factor (cutting speed, feed rate, hardness and depth of cut) and three-level fractional experiment designs completed with a statistical analysis of variance (ANOVA) were performed. Mathematical models for surface roughness and cutting force components were developed using the response surface methodology (RSM). Results show that the cutting force components are influenced principally by the depth of cut and work piece hardness.

[3] "Machinability investigations in hard turning of AISI D2 cold work tool steel with conventional and wiper ceramic inserts." V.N. Gaitonde[et al] (2009) 754-763

In this paper researcher have done an investigative study on machinability aspect. During hard turning of high chromium AISI D2 cold work tool steel, the machining force, power, specific cutting force, surface roughness and tool wear has been measured with different CC650, CC650WG and GC6050WH ceramic inserts with linear increasing depth of cut. The response surface methodology (RSM) used for development of mathematical model and analyze effects of depth of cut (0.2, 0.4 and 0.6 mm) and machining time (5, 10 and 15 min) with machinability of constant 80 m/min and 0.10 mm/rev. The experiments have been done as per full factorial design (FFD) and the sufficiency of the model has been tested through the analysis of variance (ANOVA) based on the experimental results and parametric analysis. It have been found that CC650WG wiper ceramic insert is perform better in for low surface roughness and tool wear while CC650 is better in minimizing of power, machining force and specific cutting force.

[4] "Tool wear and machining performance of CBN–TIN coated carbide inserts and PCBN compact inserts in turning AISI 4340 hardened steel" Abhijit S. More[et al](2006) 253-262

This paper reported on Hard turning experiments based on full factorial design of experiments over hardened AISI 4340 steel using CBN–TIN coated inserts and commercially available PCBN (poly crystalline cubic boron nitride) inserts with vary cutting speed (100, 125 and 150 m/min) and a feed rate (0.10, 0.15 and 0.20 mm/rev) corresponding to a fixed depth of cut of 0.25 mm. It has been found that effect of above parameter on tool wear, surface roughness, and cutting forces was analyzed using ANOVA techniques.

The performance of the CBN–TIN coated carbides inserts and commercially available PCBN inserts was compared in terms of cutting forces, surface roughness, and tool wear at cutting conditions of F = 0.15 mm/rev, V = 125 m/min, and DOC = 0.25 mm. At these conditions, the CBN–TIN coated carbide inserts tool life of approximately 17–20 min per cutting edge, whereas PCBN cutting tools produced a tool life of 31 min. The surface roughness for CBN–TIN coated inserts was below 1.3μm and while the PCBN tool gave a constant surface roughness value. The cutting forces are slightly different between them. Based on cost analysis, it shows that CBN–TIN coated carbide tools are capable of reducing machining costs so it's suitable for hard turning.

[5]"Determination of optimum cutting parameters during machining of AISI 304 austenitic stainless steel", IhsanKorkut[1], Mustafa Kasap[2], Ibrahim Ciftci[3], UlviSeker[4], Materials and Design 25 (2004) 303–305.

This paper determination of optimum cutting parameters during machining of AISI304 austenitic stainless steel High strength, low thermal conductivity, high ductility and high work hardening tendency of austenitic stainless steels are the main factors that make their machinability difficult. The optimum cutting speed has been aimed when turning an AISI 304 austenitic stainless steel using cemented carbide cutting tools. The influence of cutting speed on tool wear and surface roughness was investigated. A decrease in tool wear was observed with increasing the cutting speed up to 180 m/min. Surface roughness (Ra) was also decreased with increasing the cutting speed. Correlation was made between the tool wear/surface roughness and the chips obtained at the three cutting speeds of 120, 150 and 180 m/min

2. Process parameter and their level

Table -2.1: Process parameter

Parameter	Unit	Level		
		1	2	3
Cutting speed (v)	RPM	1000	1500	
Feed rate (f)	mm/rev	0.05	0.10	0.15
Depth of cut (d)	Mm	0.5	0.75	1.00

The three primary factors in turning operation are speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right at the machine.

The working levels of the input parameters are based on literature survey. Taguchi's L18 (2^1x3^2) Orthogonal Array (OA) has been selected. In the present experimental study, cutting velocity feed and depth of cut will be considered as input parameters. To conduct the experiment different level of parameter has been chosen cutting speed has two level while feed and depth of cut has three level

3. S/N Ratio calculation for Material Removal Rate, Surface Roughness, Temperature and Cutting force

In this the observe value of Temperature, material removal rate, surface roughness and cutting force are transform in S/N ratio values to find out the optimum combination of parameters for response variable. In Temperature and surface roughness response "smaller is better" is objective characteristics, where as in material removal rate response should be "higher is the better".

3.1 Main Effects Plot of Material Removal Rate

The main effects plot for S/N ratio of material removal rate versus feed, speed and DOC are shown in fig.

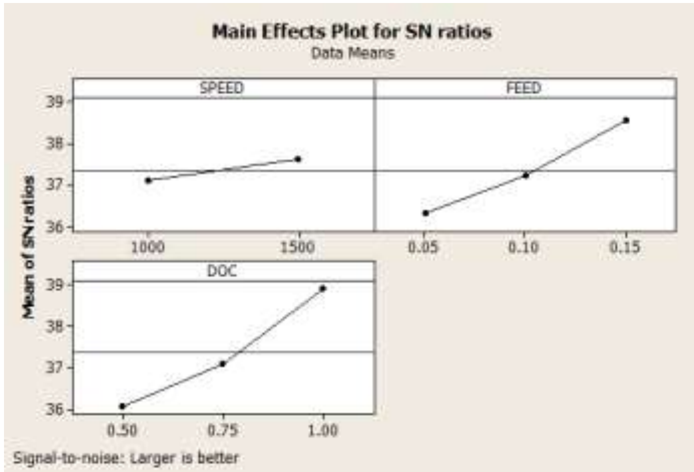

Figure 3.1 Effect of control factor on material removal rate

Fig.2 shows that higher material removal rate will meet at feed 0.15 mm/rev, speed 100 RPM and depth of cut 0.75 mm. The graph generate by use of minitab-16 statistical software for material removal rate.
It has been conclude that the optimum combination of each process parameter for higher material removal rate is meeting at high Feed [B3], low speed [A1] and high DOC [C3].

3.2 Main Effects Plot of Surface Roughness

Fig.3 shows that lower Surface roughness will meet at cutting speed 200 RPM, feed 0.15 mm/rev and depth of cut 0.50 mm. It has been conclude that the optimum combination of each process parameter for lower Surface Roughness is meeting at high Feed [B3], low Speed [A3] and nominal DOC [C2].

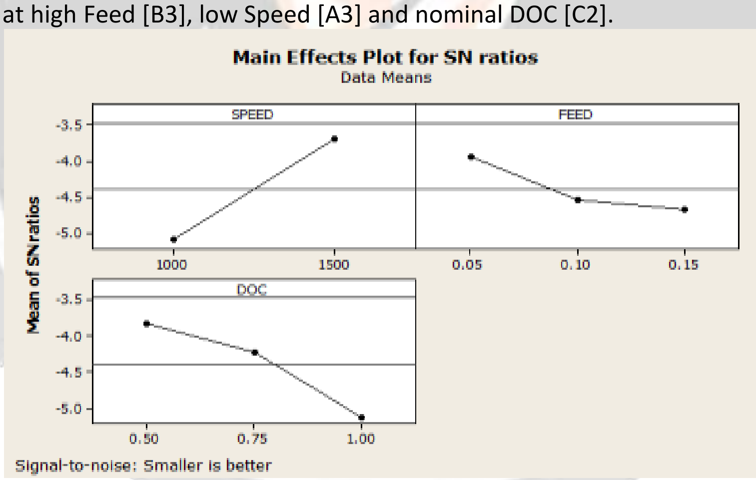

Figure 3.2: Effect of control factor on Surface roughness

3.3 Main Effects Plot of Temperature

It has been conclude that the optimum combination of each process parameter for lower feed force is meeting at high Speed [A2], low Feed [B1] and low DOC [C1].

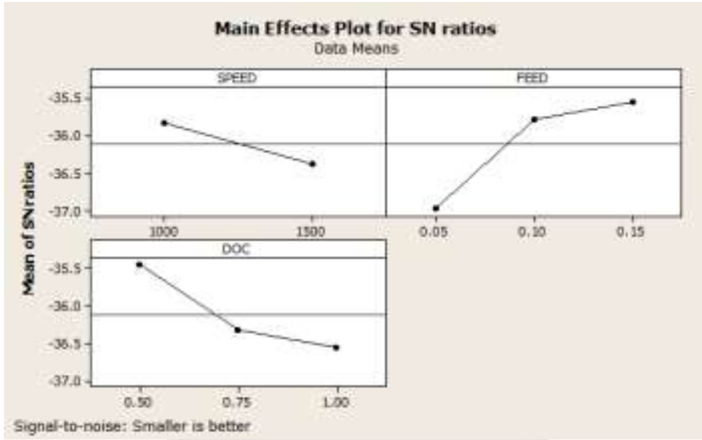

Figure 3.3: Effect of control factor on Temperature

3.4 Main Effects Plot of Cutting Force

Fig.5.4 shows that Lower Cutting Force meet at lower Feed 0.05mm/rev, higher speed 1500 RPM and lower depth of cut 0.50 mm. so that the high speed [A2],low feed [B1], and low DOC [C1] gives optimum result

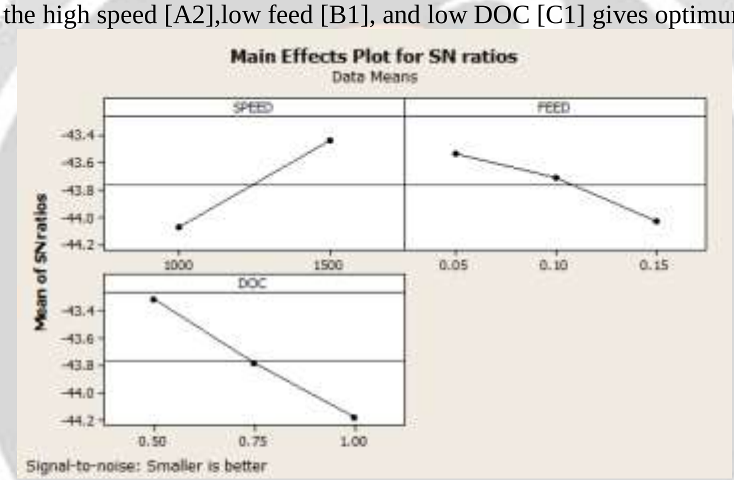

Figure 3.4: Effect of control factor on Cutting force

4. ANALYSIS OF VARIANCE

Analysis of variance (ANOVA) is a statistical model which can be used for find out effect of independent parameter on single dependent parameter and also it can be use full to find out the significant machining parameters and the percentage contribution of each parameter. This table concludes all information of analysis of variance and case statistics for further interpretation.

4.1 Analysis of Variance for material removal rate

According to the analysis done by the MINITAB16 software, if the values of probability are less than 0.05, it indicated that the factors are significant to the response parameters. Comparing the p-value to a commonly used α- level = 0.05, it is found that if the p- value is less than or equal to α, it can be concluded that the effect is significant, otherwise it is not significant

Table 4.1 -ANOVA table of material removal rate

Source	DF	Seq ss	Adj ss	Adj ms	F	P
Speed	1	100.3	100.3	100.3	7.95	0.015
Feed	2	1207.74	1207.74	603.87	47.86	0.000

DOC	2	1986.93	1986.93	993.47	78.74	0.000
Error	12	151.40	151.40	12.62		
total	17					
	R-Sq = 95.61%			R-Sq(adj) = 93.78%		

From ANOVA result it is observed that the feed, speed and depth of cut are influencing parameter for material removal rate, because the value of p is less than 0.05 p values.

4.2 Analysis of variance for Surface Roughness

From ANOVA result it is observed that the feed, speed and depth of cut are influencing parameter for Surface roughness, because the value of p is less than 0.05 p values.

Table 4.2 ANOVA table for Surface roughness

Source	DF	Seqss	Adjss	Adjms	F	P
Speed	1	0.32805	0.32805	0.32805	676.13	0.000
Feed	2	0.06521	0.06521	0.06521	67.20	0.007
DOC	2	0.19888	0.19888	0.09944	204.95	0.000
Error	12	0.00582	0.00582	0.00049		
total	17	0.59796				
	R-Sq = 99.03%			R-Sq(adj) = 98.62%		

4.3 Analysis of variance for Cutting Force

From ANOVA result it is observed that the feed, speed and depth of cut are influencing parameter for Cutting Force, because the value of p is less than 0.05 p values.

Table 4.3 ANOVA table for Cutting Force

Source	DF	Seqss	Adjss	Adjms	F	P
Speed	1	566.72	566.72	566.72	73.04	0.000
Feed	2	234.33	234.33	117.17	15.10	0.001
DOC	2	706.33	706.33	353.17	45.52	0.000
Error	12	93.11	93.11	7.76		
Total	17	1600.50				
	R-Sq = 94.18%			R-Sq(adj) = 91.76%		

4.4 Analysis of variance for Temperature

From ANOVA result it is observed that the feed, speed and depth of cut are influencing parameter for Temperature, because the value of p is less than 0.05 p values.

Table 4.4 ANOVA table for Temperature

Source	DF	Seqss	Adjss	Adjms	F	P
Speed	1	72.00	72.00	72.00	12.79	0.004

Feed	2	400.11	400.11	200.06	35.54	0.000
DOC	2	223.44	223.44	111.72	19.85	0.000
Error	12	67.56	67.56	5.63		
total	17	67.56				
	R-Sq = 91.15%			R-Sq(adj) = 87.46%		

5. REGRESSION MODEL

The Regression model for predicting the response parameters in turning can be derived using methods like Regression analysis. Regression analysis is often used to: Determine how the response variable changes as particular predictor variable changes. Predict the value of the response variable for any value of the predictor variable, or combination of values of the predictor variables. The regression equation takes the form of: Response= constant + coefficient (predictor) +… + coefficient (predictor) OR Y= b0 + b1x1+b2x2+…+bkx Where; Response (Y) is the value of the response. Constant (b0) is the value of the response variable when the predictor variable(s) is zero. The constant is also called the intercept because it determines where the regression line intercepts (meets) the Y-axis. Predictor (X) is the value of the predictor variable. Coefficients (b1, b2… bk) represent the estimated change in mean response for each unit change in predictor value. In other words, it is the change in Y that occurs when X increase by one unit. The mathematical model using regression analysis is derived with the help of MINITAB software.

5.1 Regression Equation for Surface roughness

The regression equation is

Ra = 1.83 - 0.000540 SPEED + 1.38 FEED + 0.500 DOC

Table 5.1 Regression Coefficient for Surface roughness

Predictor	Coefficient	SE Coeff	T	P
Constant	1.82889	0.06719	27.22	0.000
Speed	-0.00054	0.00003984	-13.55	0.000
Feed	1.3833	0.2440	5.67	0.000
DOC	0.50000	0.04880	10.25	0.000

S = 0.0422601 R-Sq = 95.8% R-Sq(adj) = 94.9%

The co-efficient of determination (R-Sq) indicates the goodness of fit for model. The R-Sq value is 95.08 % which is indicates that model is fit for prediction with high accuracy.

5.2 Regression Equation for Cutting force

The regression equation is

Fc = 151 - 0.0224 SPEED + 86.7 FEED + 30.7 DOC

Table 5.2Regression Coefficient for cutting Force

Predictor	Coefficient	SE Coef	T	P
Constant	150.889	4.315	34.97	0.000
Speed	-0.022444	0.002559	-8.77	0.000
Feed	86.67	15.67	5.53	0.000
DOC	30.667	3.134	9.79	0.000

S = 2.71387 R-Sq = 93.6% R-Sq(adj) = 92.2%
The co-efficient of determination (R-Sq) indicates the goodness of fit for model. The R-Sq value is 93.6%, which is quiet high; therefore model is suitable for result prediction.

5.3 Regression Equation for Temperature

The regression equation is
TEMP. = 52.6 + 0.00800 SPEEDS - 107 FEED + 16.3 DOC

Table 5.3 Regression Coefficient for Temperature

Predictor	Coefficient	SE Coef	T	P
Constant	52.639	5.199	10.13	0.000
Speed	0.008000	0.003083	2.59	0.021
Feed	-106.67	18.88	-5.65	0.000
DOC	16.333	3.776	4.33	0.001

S = 3.26993 R-Sq = 80.4% R-Sq(adj) = 76.2%
The co-efficient of determination (R-Sq) indicates the goodness of fit for model. The R-Sq value is 80.4%, which is quiet high; therefore model is suitable for result prediction

5.4 Regression Equation for Cutting force

The regression equation is
Fc = 151 - 0.0224 SPEED + 86.7 FEED + 30.7 DOC

Table 5.4Regression Coefficient for cutting Force

Predictor	Coefficient	SE Coef	T	P
Constant	150.889	4.315	34.97	0.000
Speed	-0.022444	0.002559	-8.77	0.000
Feed	86.67	15.67	5.53	0.000
DOC	30.667	3.134	9.79	0.000

S = 2.71387 R-Sq = 93.6% R-Sq(adj) = 92.2%

The co-efficient of determination (R-Sq) indicates the goodness of fit for model. The R-Sq value is 93.6%, which is quiet high; therefore model is suitable for result prediction.

6. GREY RELATIONAL ANALYSIS CALCULATION

The higher grey relational grade reveals that the corresponding experimental result is closer to the ideally normalized value. Experiment 14 has the best multiple performance characteristic among 27 experiments, because it has the highest grey relational grade shown in table 5.5. The higher the value of the grey relational grade, the closer the corresponding factor combination is, to optimal. A higher grey relational grade implies better product quality, therefore, on the basis of the grey relational grade, the factor effect can be estimated and the optimal level for each controllable factor can also be determined.

Table 6.1- Normalize experiment data, gray relation coefficient, and Gray relation grade of experiment

Sr. No.	Normalized S/N Ratios				GRC				GRG
	MRR	Ra	Fc	Temp.	MRR	Ra	Fc	Temp.	
1	0	0.4054	0.2559	0.4473	0.3333	0.4568	0.4019	0.475	0.4167
2	0.1508	0.5636	0.728	0.7928	0.3706	0.534	0.6477	0.7071	0.5648
3	0.4377	0.8671	0.8113	0.8638	0.4707	0.7901	0.7261	0.7859	0.6932
4	0.1089	0.6242	0.4387	0.2333	0.3594	0.5709	0.4711	0.3947	0.4491

5	0.3164	0.727	0.6431	0.2775	0.4225	0.6469	0.5835	0.409	0.5155
6	0.6454	0.987	0.728	0.3638	0.5851	0.9747	0.6477	0.4401	0.6619
7	0.3402	0.7126	0.6145	0	0.4311	0.635	0.5646	0.3333	0.491
8	0.5405	0.7557	0.8113	0.2775	0.5211	0.6717	0.7261	0.409	0.582
9	**0.8599**	**1**	**1**	**0.3638**	**0.7811**	**1**	**1**	**0.4401**	**0.8053**
10	0.175	0	0	0.4881	0.3774	0.3333	0.3333	0.4941	0.3845
11	0.2244	0.1121	0.1297	1	0.392	0.3602	0.3649	1	0.5293
12	0.4831	0.4217	0.4087	0.8638	0.4917	0.4637	0.4582	0.7859	0.5499
13	0.175	0.1842	0.0976	0.321	0.3774	0.38	0.3565	0.4241	0.3845
14	0.4175	0.3057	0.3176	0.4881	0.4619	0.4186	0.4229	0.4941	0.4494
15	0.727	0.6242	0.6431	0.6449	0.6469	0.5709	0.5835	0.5848	0.5965
16	0.4052	0.2369	0.2247	0.2333	0.4567	0.3959	0.3921	0.3947	0.4098
17	0.6331	0.4054	0.4685	0.4473	0.5768	0.4568	0.4847	0.475	0.4983
18	1	0.5789	0.756	0.6066	1	0.5428	0.672	0.5597	0.6936

7. Main Effect of Factors on Grey Relational Grade (GRG)

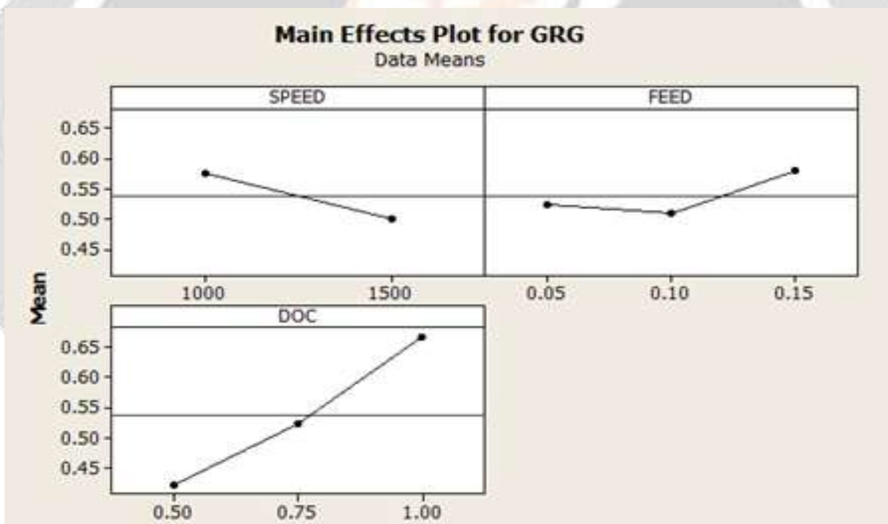

Figure 7.1 Effect of control factors plot of SNR of GRG

For the combined response maximization or minimization, fig.5.6 gives optimum value of each control factor. It interprets that level A1, B3, and C3 gives optimum result. The mean of grey relational grade for each level of the other machining parameters can be computed in similar manner. The mean of grey relational grade for each level of the machining parameters is summarized and shown in following table.

Table 7.1 Main effect of factors on Grey Relational Grade

Symbol	Control Factor	Level-1	Level-2	Level-3
A	**Speed**	**0.5755**	0.4995	

B	**Feed**	0.5231	0.5095	**0.58**
C	**DOC**	0.4226	0.5232	**0.6667**

As we know that higher grey relational grade value will give optimum value of MRR, cutting forces, Temperature and surface roughness. So from above table 5.6, it is concluded that level-1 is higher for cutting speed and level-3 is higher than for feed and as well as depth of cut. Thus it is revealed that response will be optimum at cutting speed 1000 RPM, feed 0.15 mm/rev and depth of cut 1.00 mm.

7.1Analysis of Variance of Grey Relational Grade

Analysis of variance is applied to analyze grey relational grade for find out effect of each parameter on multi objective optimization. By use of MINITAB16 statistical software used to analyze the ANOVA analysis for multi objective optimization is shown in table 5.7

Table 7.2 ANOVA of Grey Relational Grade

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	1	0.025969	0.025969	0.025969	19.12	0.001
Feed	2	0.016797	0.016797	0.008399	6.18	0.014
DOC	2	0.180644	0.180644	0.090322	66.51	0.000
Error	12	0.016297	0.016297	0.001358		
Total	17	0.239706				
R-Sq = 93.20%				R-Sq = 90.37%		

From ANOVA result it is observed that the speed, feed rate and cutting speed are influencing parameter for multi objective optimization, which is lower than 0.05 p values. So, it is not influencing parameter for multi objective optimization. The confidence level (CL) used for investigation is taken 95% for this investigation. The parameter R-Sq described the amount of variation observed in grey relational grade is explained by the input factors. R-Sq = 93.20% which indicate that the model is able to predicate the response with high accuracy.

8. CONCLUSION

1. While studying the effect of the cutting parameters on the material removal rate, it was observed that the higher material removal rate will meet at feed 0.15 mm /rev, speed 1500 RPM and depth of cut 1 mm. The optimum condition for machining to reduce material removal rate would be A2 B3 C3.
2. The lower Surface roughness will meet at cutting speed 1500 RPM, feed 0.05 mm/rev and depth of cut 0.50 mm. The optimum condition for machining to reduce material removal rate would be A2 B1 C1.
3. It was observed that the Lower Cutting Force meet at lower Feed 0.05mm/rev, higher speed 1500 RPM and lower depth of cut 0.50 mm. The optimum condition for machining to reduce material removal rate would be A2 B1 C1.
4. The Lower Temperature meet at higher feed 0.15 mm/rev, lower speed 1000 RPM and lower depth of cut 0.50 mm. The optimum condition for machining to reduce material removal rate would be A1 B3 C3.
5. From grey relational analysis, we came to know that the all this Reponses maximum material removal rate, minimum surface roughness and minimum temperature will obtain at optimum at cutting speed 1000 RPM, feed 0.15 mm/rev and depth of cut 1 mm

6. REFERENCES

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