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PARAMETRIC OPTIMIZATION OF MACHINING PARAMETER DURING HARD TURNING OF INCONEL 625

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Abstract — *In this thesis an experimental investigation done 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. Than optimize the temperature, cutting forces, surface roughness and material removal rate using analysis of variance (ANOVA) technique, Regression analysis and Grey Relational Analysis (GRA) method.

Keywords *- Inconel 625, CBN cutting tool, Tagichi, Regression analysis, Grey relational analysis.*

I INTRODUCTION

TURNING PROCESS

Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal. Often the work piece will be turned so that adjacent sections have different diameters. Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface:

- With the work piece rotating.
- With a single-point cutting tool, and
- With the cutting tool feeding parallel to the axis of the work piece and at a distance that will remove the outer surface of the work.

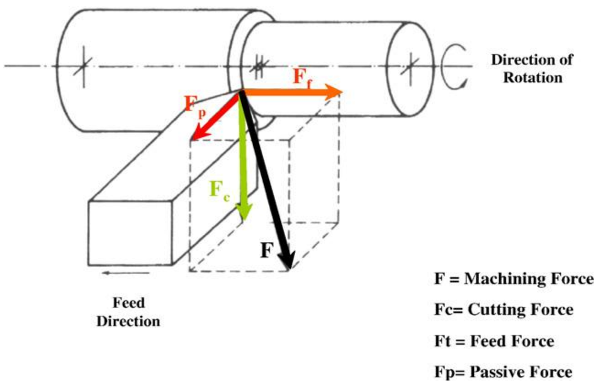

Figure 1. Schematic draw of the machining forces components in a turning operation

Taper turning is practically the same, except that the cutter path is at an angle to the work axis. Similarly, in contour turning, the distance of the cutter from the work axis is varied to produce the desired shape. Even though a single-point tool is specified, this does not exclude multiple-tool setups, which are often employed in turning. In such setups, each tool operates independently as a single-point cutter.

II LITERATURE REVIEW

J.Hu, Y.K. Chou et all determined the Nanocrystalline diamond coatings were produced using a microwave plasma-assisted CVD (chemical vapour deposition) process and deposited on common tungsten carbide tools. The NCD (nanocrystalline) tools were investigated in machining high-Si Al alloy at a range of machining conditions with tool wear and cutting forces examined and analyzed by varying speed (3 and 10 m/s) and feed (0.2 and 0.8 mm/rev) and constant depth of cut 1 mm at two stage with different tool MCD,PCD,NCD. In addition, commercial CVD diamond coating and PCD (poly crystalline) tools were also tested and compared against the NCD tool performance. Moreover, an FE model was developed to study the stress modifications in diamond coating tools after the depositions and during machining at different conditions.

V. Bedekar et all conducting experiment on Nanostructural characterization of hard turned surface layers of carburized steels done to study the effect of tool design, tool wear and turning parameters on the near surface material

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transformations. They had been working for to quantify subsurface evolution, numerical predictions correlated with the measured structural and hardness parameters. They showed that the process design space can be partitioned into three regions based on thermal phase transformations, plastic grain refinement, and where both mechanisms were active.

J. Paulo Davim et all determined characterization of the machinability evaluation in hard turning of cold tool work steel (D2) using ceramic tools. they showed that the tool wear is highly influenced by the cutting velocity (57.4%) and, in a smaller degree, by cutting time (13.4%). They revealed that the excessive flank tool wear existent in the ceramic tools, which works with high cutting velocity has a correspondent reduction on surface roughness. They conclude from the experiment that the specific cutting pressure is strongly influenced by the feed rate (64.1%) and surface roughness is influenced by feed rate (29.6%) and cutting time.

J.V.C. Souza et all done investigation about the effect of cutting forces on gray cast iron turning using silicon nitride (Si3N4) based ceramic tool. It have been carried out experiments with five different cutting speeds(180, 240, 300, 360 and 420 m/min) and feed rates(0.12, 0.23, 0.33, 0.40 and 0.50 mm/rev) while constant depth of cut 1.0 mm. Tool performance was evaluated cutting forces, tool wear, temperature and surface finish produced during turning. It have been show that the cutting forces is reduced after cutting speed of 300 m/min and the low tool wear of the inserts suggests that Si3N4 is best for machining gray cast iron average temperature is reduced at same speed and higher the feed rates.

III METHODOLOGY

Taguchi method

A scientific approach to plan the experiments is a necessity for efficient conduct of experiments. By the statistical design of experiments the process of planning the experiment is carried out, so that appropriate data will be collected and analysed by statistical methods resulting in valid and objective conclusions. When the problem involves data that are subjected to experimental error, statistical methodology is the only objective approach to analysis. Thus, there are two aspects of an experimental problem: the design of the experiments and the statistical analysis of the data. These two points are closely related since the method of analysis depends directly on the design of experiments employed.

A. Selection of process parameter

The four process cutting parameters in wire cut operation are speed, feed and depth of cut.

Table .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	0.50	0.75	1

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.

B. 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

$$Y= b_0 + b_1x_1+b_2x_2+\ldots+b_kx$$

Where:

- Response (Y) is the value of the response.
- Constant (b_0) 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 (b_1, b_2… b_k) 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.

C. Grey Relational Analysis

Through the grey relational analysis, a grey relational grade can be obtained to evaluate the multiple performance characteristic. As a result, optimization of the complicated multiple performance characteristic can be

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converted into the optimization of a single grey relation grade. For multiple performance characteristic optimizations using GRA, following steps are followed:

1. Normalization of experimental result for all performance characteristics.
2. Performance of grey relational generating and calculation of grey relational coefficient (GRC).
3. Calculation of grey relation grade (GRG) using, weighing factor for performance characteristics.
4. Analysis of experimental results using GRG and statistical analysis of variance (ANOVA).
5. Selection of optimal levels of process parameters

IV EXPERIMENTAL RESULT AND DISCUSSION

The experiment was conducted in company to measures the value of material removal rate, surface roughness, cutting force, temperature for the various combination of input parameter.

Table .2 L18(2^1x3^2) orthogonal array with Experimental Readings

Ex. No.	SPEED	FEED	DOC	MRR (gm/min)	Ra (µm)	Fc (N)	TEMP. (°C)
1	1000	0.05	0.50	55.6	1.58	146	63
2	1000	0.05	0.75	61.5	1.68	162	72
3	1000	0.05	1.00	74.5	1.89	165	74
4	1000	0.10	0.50	59.8	1.72	152	58
5	1000	0.10	0.75	68.7	1.79	159	59
6	1000	0.10	1.00	85.6	1.98	162	61
7	1000	0.15	0.50	69.8	1.78	158	53
8	1000	0.15	0.75	79.8	1.81	165	59
9	1000	0.15	1.00	98.8	1.99	172	61
10	1500	0.05	0.50	62.5	1.35	138	64
11	1500	0.05	0.75	64.6	1.41	142	78
12	1500	0.05	1.00	76.8	1.59	151	74
13	1500	0.10	0.50	62.5	1.45	141	60
14	1500	0.10	0.75	73.5	1.52	148	64
15	1500	0.10	1.00	90.4	1.72	159	68
16	1500	0.15	0.50	72.9	1.48	145	58
17	1500	0.15	0.75	84.9	1.58	153	63
18	1500	0.15	1.00	108.5	1.69	163	67

A. **Main Effects Plot of material removal rate**

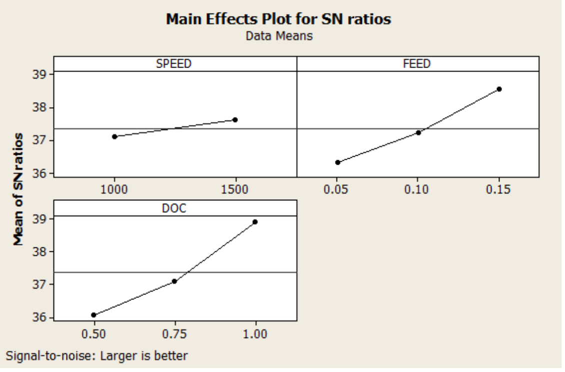

Figure 2. Effect of control factor on material removal rate

Fig.2 shows that higher material removal rate will meet at feed 0.15 mm /rev, speed 1500 RPM and depth of cut 1 mm. From the fig., it has been conclude that the optimum combination of each process parameter for higher material removal rate is meeting at high speed [A2], high Feed [B3] and high DOC [C3].

B. Main Effects Plot of Surface roughness

Fig.3 shows that lower Surface roughness will meet at cutting speed 1500 RPM, feed 0.05 mm/rev and depth of cut 0.50 mm. From the fig., 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].

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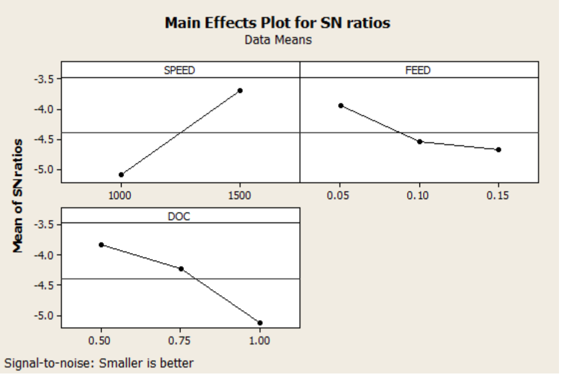

Figure 3. Effect of control factor on Surface roughness

C. Main Effects Plot of Cutting Force

Fig.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. From the fig., it has been conclude that the optimum combination of each process parameter for high speed [A2], low feed [B1], and low DOC [C1] gives optimum result.

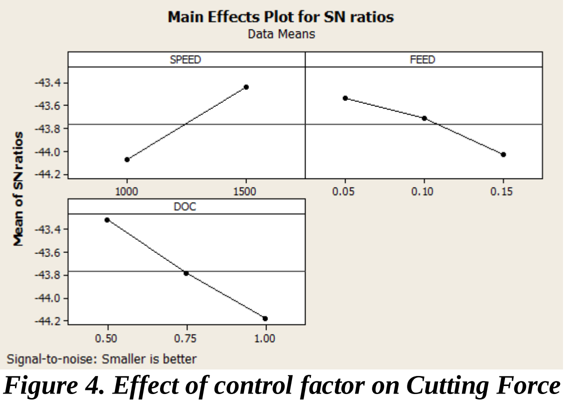

Figure 4. Effect of control factor on Cutting Force

D. Main Effects Plot of Temperature

Fig.5 shows that Lower Temperature meet at higher feed 0.15 mm/rev, lower speed 1000 RPM and lower depth of cut 0.50 mm. From the fig., it has been conclude that the optimum combination of each process parameter for low speed [A1], high feed [B3], and low DOC [C1] gives optimum result.

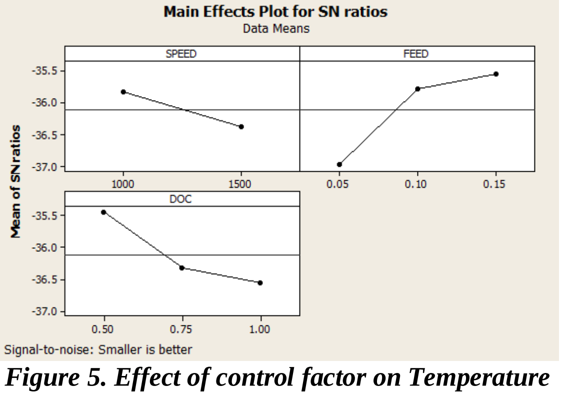

Figure 5. Effect of control factor on Temperature

E. Analysis of Variance for material removal rate

Table 3. 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%		

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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.

F. 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. ANOVA table for Surface roughness

Source	DF	Seq ss	Adj ss	Adj ms	F	P
Speed	1	0.32805	0.32805	0.32805	676.13	0.000
Feed	2	0.06521	0.06521	0.06521	67.20	0.000
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%		

G. 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 5. ANOVA table for Cutting Force

Source	DF	Seq ss	Adj ss	Adj ms	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%		

H. 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 6. ANOVA table for Temperature

Source	DF	Seq ss	Adj ss	Adj ms	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%		

V REGRESSION ANALYSIS

The Regression model for predicting the response parameters in turning can be derived using methods like Regression analysis.

A. Regression Equation for MRR

The regression equation is

MRR = 5.49 + 0.00944 SPEED + 199 FEED + 50.5 DOC

Table 7. Regression Coefficient for Cutting Force

Predictor	Coefficient	SE Coef	T	P
Constant	5.492	6.710	0.82	0.427
Speed	0.009444	0.003979	2.37	0.032
Feed	198.67	24.37	8.15	0.000
DOC	50.500	4.873	10.36	0.000

S = 4.22014 R-Sq = 92.8% R-Sq(adj) = 91.2%

The co-efficient of determination (R-Sq) indicates the goodness of fit for model. The R-Sq value is 92.8 % which is indicates that model is fit for prediction

B. Regression Equation for Surface roughness

The regression equation is

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

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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.

Table 8. Regression Coefficient for Surface roughness

Predictor	Coefficient	SE Coef	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%

C. Regression Equation for Cutting force

The regression equation is

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

Table 9. Regression Coefficient for Feed 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.

D. Regression Equation for Temperature

The regression equation is

TEMP. = 52.6 + 0.00800 SPEED - 107 FEED + 16.3 DOC

Table 10. Regression Coefficient for Feed Force

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.

VI GREY RELATIONAL ANALYSIS

Table 11. Normalization, GRC and GRG of experimental data

Sr. No.	Normalized S/N Ratios				GRC				GRG
	MRR	RA	Fc	TEMP	MRR	RA	Fc	TEMP.	
1	0.0000	0.4054	0.2559	0.4473	0.3333	0.4568	0.4019	0.4750	0.4167
2	0.1508	0.5636	0.7280	0.7928	0.3706	0.5340	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	0.7270	0.6431	0.2775	0.4225	0.6469	0.5835	0.4090	0.5155
6	0.6454	0.9870	0.7280	0.3638	0.5851	0.9747	0.6477	0.4401	0.6619
7	0.3402	0.7126	0.6145	0.0000	0.4311	0.6350	0.5646	0.3333	0.4910
8	0.5405	0.7557	0.8113	0.2775	0.5211	0.6717	0.7261	0.4090	0.5820
9	0.8599	1.0000	1.0000	0.3638	0.7811	1.0000	1.0000	0.4401	0.8053
10	0.1750	0.0000	0.0000	0.4881	0.3774	0.3333	0.3333	0.4941	0.3845
11	0.2244	0.1121	0.1297	1.0000	0.3920	0.3602	0.3649	1.0000	0.5293
12	0.4831	0.4217	0.4087	0.8638	0.4917	0.4637	0.4582	0.7859	0.5499
13	0.1750	0.1842	0.0976	0.3210	0.3774	0.3800	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	0.7270	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	0.4750	0.4983
18	1.0000	0.5789	0.7560	0.6066	1.0000	0.5428	0.6720	0.5597	0.6936

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The higher grey relational grade reveals that the corresponding experimental result is closer to the ideally normalized value. Experiment 9 has the best multiple performance characteristic among 18 experiments, because it has the highest grey relational grade shown in table 11. 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.

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

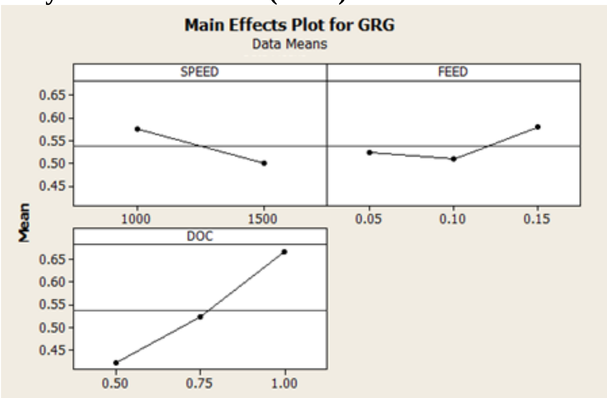

Figure.6. Effect of control factors plot of SNR of GRG

For the combined response maximization or minimization, fig.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 12. 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.

VII CONFIRMATION TEST

The confirmation test is the final step of this experimentation. The purpose of conformation test is to validate the conclusion drawn during the analysis phase. In addition, the conformation test needs to be carried out in order to ensure that the theoretical predicted model for optimum results using the software is accepted and in order to verify adequacy of the models that are developed.

In our research study, material removal rate, surface roughness, cutting force and temperature has optimal combination are [A2, B3, C3], [A2, B1, C1], [A2, B1, C1] and [A1, B3, C1] respectively. All responses optimal combination is match in orthogonal array. So there are not required to confirmation for material removal rate, surface roughness and temperature.

VIII 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.

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