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# Application of MCDM/MADM Approach Entropy-TOPSIS in Turning of AA6061

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**ABSTRACT**

*In the present work, an experimental investigation has been conducted to optimize the cutting parameters during turning of AA6061-T6 on Lathe in dry conditions. CVD made coated carbide inserts (WEDIA CNMG 120404, CNMG 120408) are used as cutting tools. Cutting speed (1000, 2000, 3000, 4000 RPM), feed (0.05, 0.1, 0.15, 0.2 mm/rev), depth of cut (0.5, 1, 1.5, 2 mm) and Nose radius (0.4, 0.8 mm) were considered as fixed parameters. A mixed level orthogonal array (L16) from taguchi has been adopted for the experiments. The multiple performances of Material Removal rate (MRR) and Roughness characteristics (Ra and Rz) were optimized by a hybrid Entropy-TOPSIS approach. The results revealed that the nose radius has the most predominant effect on the multiple responses.*

***Keywords:*** *AA6061-T6; Material removal rate (MRR); Roughness characteristics (Ra and Rz); Entropy-TOPSIS approach.*

## 1.0 Introduction

Nowadays, the manufacturing industries are focusing their attention on dimensional accuracy and surface finish of machined objects. In addition to the surface finish quality, the material removal rate (MRR) is also an important characteristic in turning operation and high MRR is always desirable. Hence, there is a need to optimize the process parameters in a systematic way to achieve the output characteristics/responses by using experimental methods and statistical models. For getting better responses it is necessary to employ various optimizing techniques to get the optimal cutting parameters and the theoretical models to do the predictions. The optimization of multi-response characteristics is more complex in comparison to single response. The multi-response optimization principle is different from single response optimization. There is more than one objective function in multi-response optimization, each of which may have a different solution. Among many MCDM techniques avail, TOPSIS is most trending one. TOPSIS stands for technique for order preference by similarity to ideal solution. This method was developed by Hwang and Yoon in the year 1995. It is based on the idea that the chosen alternative should have the shortest distance from the positive ideal solution and on the other side the farthest distance of the negative ideal solution. The ideal solution is a hypothetical solution for which all attribute values correspond to the minimum attribute values in the data base. TOPSIS thus gives a solution that is not only closest to the hypothetically best but also farthest from the hypothetically worst.

In the present work, TOPSIS method has been employed to convert the multi-responses to an equivalent single response. Taguchi approach is used to analyse the effect of turning parameters such as speed, feed, depth of cut and nose radius. Regression analysis was employed along with analysis of variance (ANOVA) to judge the significance of factor for responses.

## 2.0 Experimentation Details

The work material selected for the present study is AA6161-T6.It is taken in cylindrical form of 25 mm diameter each. It has wide range applications in aircraft fittings, couplings, marine fittings, pistons,

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magneto parts, hinge pins and bike frames etc. The chemical composition and properties were given in tables 1 and 2. A number of experiments were carried outon the work piece as per the taguchi's L16 orthogonal array for the selected process parameters (Table 3) as given in table 4.

**Table 1: Chemical Composition of AA6061**

| | |
|---|---|
| Al | 95.8-98.6 |
| Cr | 0.04-0.35 |
| Cu | 0.15-0.4 |
| Fe | 0.7 max |
| Mg | 0.8-1.2 |
| Mn | 0.15 max |
| Si | 0.4-0.8 |
| Ti | 0.15 max |
| Zn | 0.25 max |
| Others | 0.15 max |

**Table 2: Mechanical Properties of AA6061**

| | |
|---|---|
| Density (gm/cm$^3$) | 2.7 |
| Tensile (MPa) | 310 |
| Yield (MPa) | 276 |
| Elongation (%) | 12-17 |
| Poisson's ratio | 0.33 |
| Hardness (BHN) | 95 |

**Table 3:Process Parameters and their Levels**

| Parameter | Level-1 | Level-2 | Level-3 | Level-4 |
|---|---|---|---|---|
| Speed, N | 1000 | 2000 | 3000 | 4000 |
| Feed, f | 0.05 | 0.1 | 0.15 | 0.2 |
| Depth of cut, d | 0.5 | 1 | 1.5 | 2 |
| Nose Radius, r | 0.4 | 0.8 | - | - |

**Table 4: L16 OA of Process Parameters**

| S.No. | Speed (RPM) | Feed (mm/rev) | Depth of Cut (mm) | Nose Radius (mm) |
|---|---|---|---|---|
| 1 | 1000 | 0.05 | 0.5 | 0.4 |
| 2 | 1000 | 0.1 | 1 | 0.4 |
| 3 | 1000 | 0.15 | 1.5 | 0.8 |
| 4 | 1000 | 0.2 | 2 | 0.8 |
| 5 | 2000 | 0.05 | 1 | 0.8 |
| 6 | 2000 | 0.1 | 0.5 | 0.8 |
| 7 | 2000 | 0.15 | 2 | 0.4 |
| 8 | 2000 | 0.2 | 1.5 | 0.4 |
| 9 | 3000 | 0.05 | 1.5 | 0.4 |
| 10 | 3000 | 0.1 | 2 | 0.4 |
| 11 | 3000 | 0.15 | 0.5 | 0.8 |
| 12 | 3000 | 0.2 | 1 | 0.8 |
| 13 | 4000 | 0.05 | 2 | 0.8 |
| 14 | 4000 | 0.1 | 1.5 | 0.8 |
| 15 | 4000 | 0.15 | 1 | 0.4 |
| 16 | 4000 | 0.2 | 0.5 | 0.4 |

**3.0 Results and Discussions**

The measured experimental results of Material Removal Rate (MRR) and Surface Roughness characteristics ($R_a$and $R_z$) are optimized using Entropy-TOPSIS approach. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a popular MCDM/MADM method involving simple mathematical model calculations. The calculations Step by step procedure is given below.

Step 1: Make an evaluation matrix comprising of 'm' alternatives (16) and 'n'criterias (3), with the intersection of each alternative and criteria given as $x_{ij}$, as given in Table 5.

**Table 5: Experimental Results of Responses**

| S.No. | MRR (Cm$^3$/min) | $R_a$ (μm) | $R_z$ (μm) |
|---|---|---|---|
| 1 | 2.5133 | 0.18 | 1.23 |
| 2 | 10.0530 | 0.33 | 1.80 |
| 3 | 22.6193 | 1.31 | 5.90 |
| 4 | 40.2120 | 1.39 | 6.06 |
| 5 | 10.0530 | 0.47 | 3.14 |
| 6 | 10.0530 | 0.40 | 2.54 |
| 7 | 60.3180 | 0.54 | 2.85 |
| 8 | 60.3180 | 0.57 | 3.06 |
| 9 | 22.6193 | 0.31 | 1.65 |
| 10 | 60.3180 | 0.35 | 1.94 |
| 11 | 22.6193 | 0.95 | 3.84 |
| 12 | 60.3180 | 1.26 | 5.11 |
| 13 | 40.2120 | 0.50 | 2.69 |
| 14 | 60.3180 | 1.79 | 8.24 |
| 15 | 60.3180 | 0.59 | 2.92 |
| 16 | 40.2120 | 0.95 | 4.68 |

Step 2:The criteria values with different measuring units are need to be normalized to form the matrix R = $(r_{ij})_{mxn}$ using the normalization method using Equation 1. The matrix formed is given in table 6.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad \text{Eq. (1)}$$

Where i = 1,2,…,m and j = 1,2,…, n.

Step 3: In the present work, the individual weights for the responses ar e assigned from entropy method and the values are obtained as $W_{MRR}$ = 0.3955, $W_{Ra}$ = 0.3570and $W_{Rz}$ = 0.2475 respectively. Now, a weighted matrix is to be created by using equation 2. The matrix would be given as in the table 7.

$$a_{ij} = w_j r_{ij} = w_i \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad \text{Eq.(2)}$$

Where i = 1, 2…m and j = 1, 2…n.

**Table 6: Normalized Values of Responses**

| S.No. | Normalized values ($r_{ij}$) | | |
|---|---|---|---|
| | **MRR** | **$R_a$** | **$R_z$** |
| 1 | 0.0149 | 0.0515 | 0.0758 |
| 2 | 0.0595 | 0.0945 | 0.1110 |
| 3 | 0.1339 | 0.3750 | 0.3638 |
| 4 | 0.2381 | 0.3980 | 0.3737 |
| 5 | 0.0595 | 0.1346 | 0.1936 |
| 6 | 0.0595 | 0.1145 | 0.1566 |
| 7 | 0.3571 | 0.1546 | 0.1757 |
| 8 | 0.3571 | 0.1632 | 0.1887 |
| 9 | 0.1339 | 0.0888 | 0.1017 |
| 10 | 0.3571 | 0.1002 | 0.1196 |
| 11 | 0.1339 | 0.2720 | 0.2368 |
| 12 | 0.3571 | 0.3607 | 0.3151 |
| 13 | 0.2381 | 0.1431 | 0.1659 |
| 14 | 0.3571 | 0.5125 | 0.5081 |
| 15 | 0.3571 | 0.1689 | 0.1801 |
| 16 | 0.2381 | 0.2720 | 0.2886 |

**Table 7: Weighted Normalized Values of Responses**

| S.No. | Weighted Normalized Values ($w_j r_{ij}$) | | |
|---|---|---|---|
| | **MRR** | **$R_a$** | **$R_z$** |
| 1 | 0.0059 | 0.0184 | 0.0188 |
| 2 | 0.0235 | 0.0337 | 0.0275 |
| 3 | 0.0530 | 0.1339 | 0.0900 |
| 4 | 0.0942 | 0.1421 | 0.0925 |
| 5 | 0.0235 | 0.0480 | 0.0479 |
| 6 | 0.0235 | 0.0409 | 0.0388 |
| 7 | 0.1412 | 0.0552 | 0.0435 |
| 8 | 0.1412 | 0.0583 | 0.0467 |
| 9 | 0.0530 | 0.0317 | 0.0252 |
| 10 | 0.1412 | 0.0358 | 0.0296 |
| 11 | 0.0530 | 0.0971 | 0.0586 |
| 12 | 0.1412 | 0.1288 | 0.0780 |
| 13 | 0.0942 | 0.0511 | 0.0411 |
| 14 | 0.1412 | 0.1830 | 0.1258 |
| 15 | 0.1412 | 0.0603 | 0.0446 |
| 16 | 0.0942 | 0.0971 | 0.0714 |

Step 4: Determine the Positive Ideal Solution ($A_j^+$) and the Negative Ideal Solution ($A_j^-$) for the alternative by using equations 3 and 4. The obtained results are given in the table 8.

$$A_j^+ = \begin{cases} \max a_{ij} \; for \; j = 1, \dots k \\ \min a_{ij} \; for \; j = k+1, \dots . n \end{cases} \quad \text{Eq.(3)}$$

$$A_j^- = \begin{cases} \min a_{ij} \; for \; j = 1, \dots k \\ \max a_{ij} \; for \; j = k+1, \dots . n \end{cases} \quad \text{Eq.(4)}$$

**Table 8: PIS and NIS Values of Responses**

| | MRR | $R_a$ | Rz |
|---|---|---|---|
| PIS | 0.1412 | 0.0184 | 0.0188 |
| NIS | 0.0059 | 0.1830 | 0.1258 |

Step 5: Calculate the distance between the target alternative i from the negative and positive ideal solutions of responses by using equations 5 and 6. The measured distances values are given in table 9.

$$S^- = \sqrt{\sum_{J=1}^{n} \left(a_{ij} - A_j^-\right)^2} \quad \text{Eq.(5)}$$

$$S^+ = \sqrt{\sum_{J=1}^{n} \left(a_{ij} - A_j^+\right)^2} \quad \text{Eq.(6)}$$

Step 6: Calculate the relative distance of the points from the ideal solution using the equation 7.

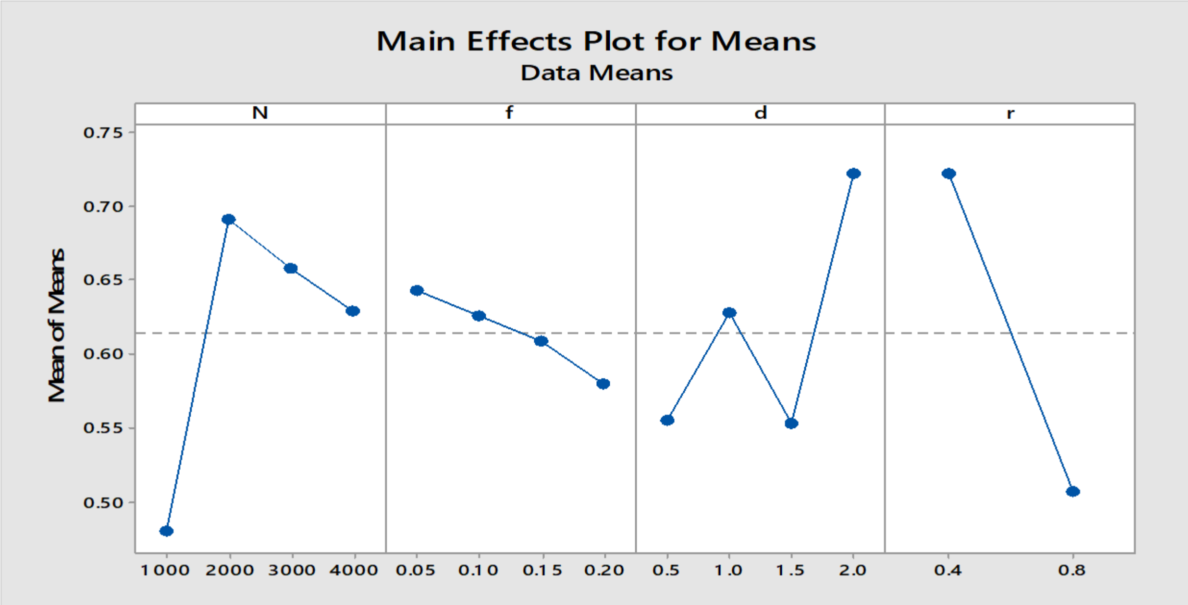
$$C_i^+ = \frac{S^-}{S^+ + S^-} \quad \text{Eq.(7)}$$

Step 7: Rank the $C_i^+$ in the descending order with the highest valued criteria /alternative being an ideal one.

**Table 9: Distance Measures and Composite Relative Distance Values**

| **S.No.** | **$S_i^+$** | **$S_i^-$** | **$C_i^+$** |
|---|---|---|---|
| 1 | 0.1353 | 0.1963 | 0.5920 |
| 2 | 0.1190 | 0.1796 | 0.6015 |
| 3 | 0.1618 | 0.0769 | 0.3221 |
| 4 | 0.1515 | 0.1029 | 0.4044 |
| 5 | 0.1248 | 0.1569 | 0.5569 |
| 6 | 0.1215 | 0.1675 | 0.5797 |
| 7 | 0.0443 | 0.2035 | 0.8212 |
| 8 | 0.0487 | 0.2003 | 0.8044 |
| 9 | 0.0894 | 0.1877 | 0.6773 |
| 10 | 0.0205 | 0.2219 | 0.9155 |
| 11 | 0.1247 | 0.1188 | 0.4878 |
| 12 | 0.1253 | 0.1534 | 0.5505 |
| 13 | 0.0614 | 0.1799 | 0.7454 |
| 14 | 0.1963 | 0.1353 | 0.4080 |
| 15 | 0.0492 | 0.1999 | 0.8025 |
| 16 | 0.1057 | 0.1347 | 0.5603 |

**Figure 1: Main Effect Plots for Means of Composite Relative Distance**




ow the multi objective problem is turned into a single objective in the name of compositerelative distance ($C_i^+$). Taguchi Larger-the-Better characteristic has been employed on the single objective obtained and the results are given in the table 10. The main effect plot is drawn and shown in figure 1 and it shows that the optimal combination of process parameters is obtained at speed:2000 RPM, feed:0.05 mm/rev, depth of cut:2 mm and nose radius:0.4 mm respectively.

**Table 10: Response Table for Means of $C_i^+$**

| Level | N | f | d | r |
|---|---|---|---|---|
| 1 | 0.4800 | 0.6429 | 0.5550 | 0.7218 |
| 2 | 0.6906 | 0.6262 | 0.6279 | 0.5069 |
| 3 | 0.6578 | 0.6084 | 0.5530 | |
| 4 | 0.6291 | 0.5799 | 0.7216 | |
| Delta | 0.2106 | 0.0630 | 0.1687 | 0.2150 |
| Rank | 2 | 4 | 3 | 1 |

### 3.1 RSM results

Response surface methodology has been employed on the composite response and a second order regression model has been prepared and given in equation 8. ANOVA results of the responses were given in table 11. From the results, it is found that there are no interaction effects for r*r and d*r.

$$C_i^+ = 0.554 + 0.000235\,N + 2.75\,f - 0.689\,d + 0.277\,r - 0.000000\,N{*}N - 1.2\,f{*}f + 0.096\,d{*}d - 0.00013\,N{*}f + 0.000187\,N{*}d - 0.000188\,N{*}r + 0.45\,f{*}d - 2.88\,f{*}r \quad \text{Eq.(8)}$$

The model developed is tested for adequacy, the residual plots shown in figure 3, predicts that the model is accurate, adequate and can be used for the best predictions of future responses as the residuals are following the normality and does not showing any regular patterns. Contour plots are drawn for finding the optimal region for the multi responses and shown in figures 4, 5 and 6.

**Table 11: Analysis of Variance**

| Source | DF | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|
| Moderl | 12 | 0.383820 | 0.031985 | 2.25 | 0.274 |
| Linear | 4 | 0.245350 | 0.061337 | 4.32 | 0.129 |
| N | 1 | 0.010858 | 0.010858 | 0.77 | 0.446 |
| f | 1 | 0.013417 | 0.013417 | 0.95 | 0.403 |
| d | 1 | 0.006113 | 0.006113 | 0.43 | 0.558 |
| r | 1 | 0.107134 | 0.107134 | 7.55 | 0.071 |
| Square | 3 | 0.066564 | 0.022188 | 1.56 | 0.361 |
| N*N | 1 | 0.057253 | 0.057253 | 4.04 | 0.138 |
| f*f | 1 | 0.000139 | 0.000139 | 0.01 | 0.927 |
| d*d | 1 | 0.009173 | 0.009173 | 0.65 | 0.480 |
| 2-Way Interaction | 5 | 0.053338 | 0.010668 | 0.75 | 0.637 |
| N*f | 1 | 0.000209 | 0.000209 | 0.01 | 0.911 |
| N*d | 1 | 0.036471 | 0.036471 | 2.57 | 0.207 |
| N*r | 1 | 0.011348 | 0.011348 | 0.80 | 0.437 |
| f*d | 1 | 0.001122 | 0.001122 | 0.08 | 0.797 |
| f*r | 1 | 0.013884 | 0.013884 | 0.98 | 0.395 |
| Error | 3 | 0.042563 | 0.014188 | | |
| Total | 15 | 0.426383 | | | |

**Figure 2: Residual Plots for $C_i^+$**

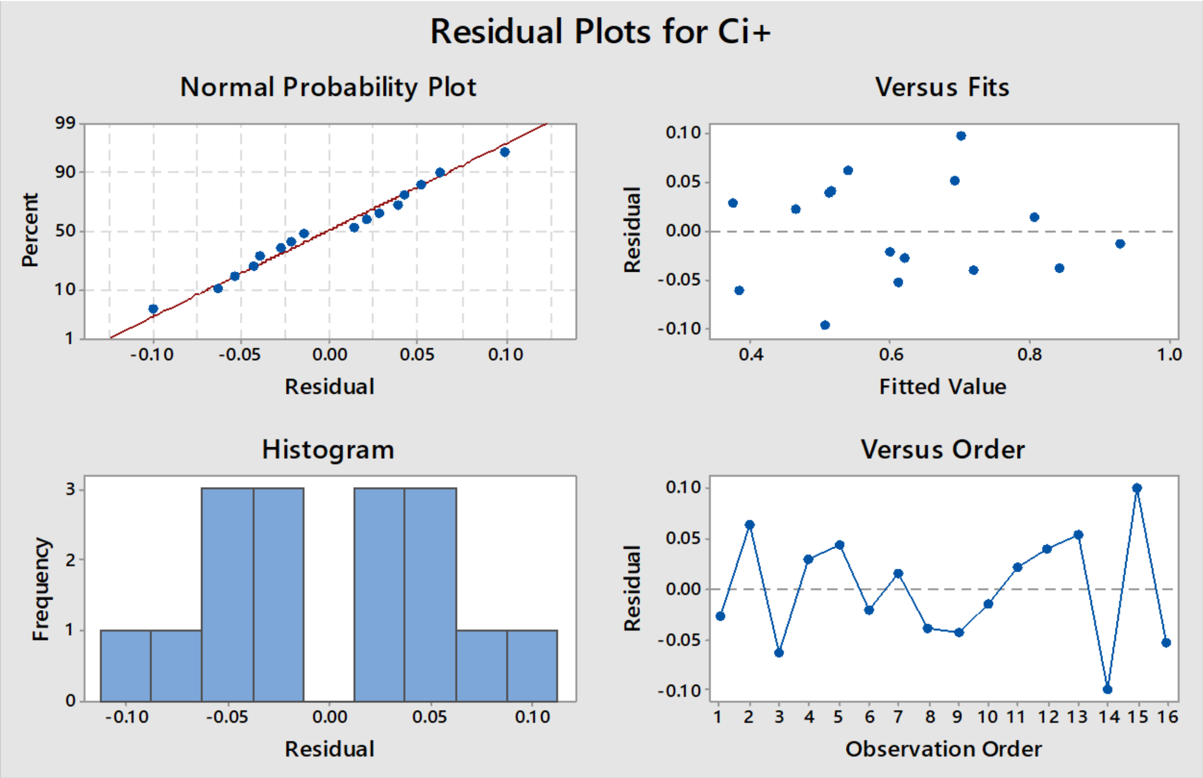



**Figure 3: Contour Plot of $C_i^+$Vs N. f**

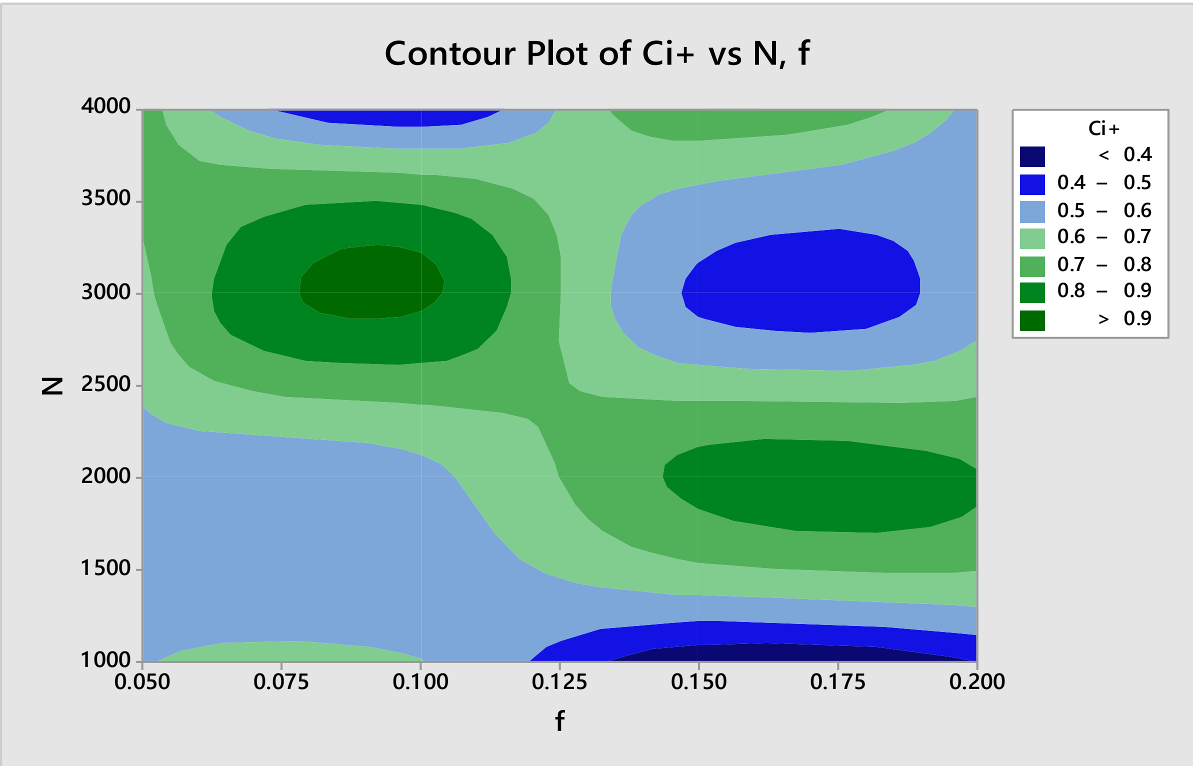


**Figure 4: Contour Plot of $C_i^+$Vs N, d**

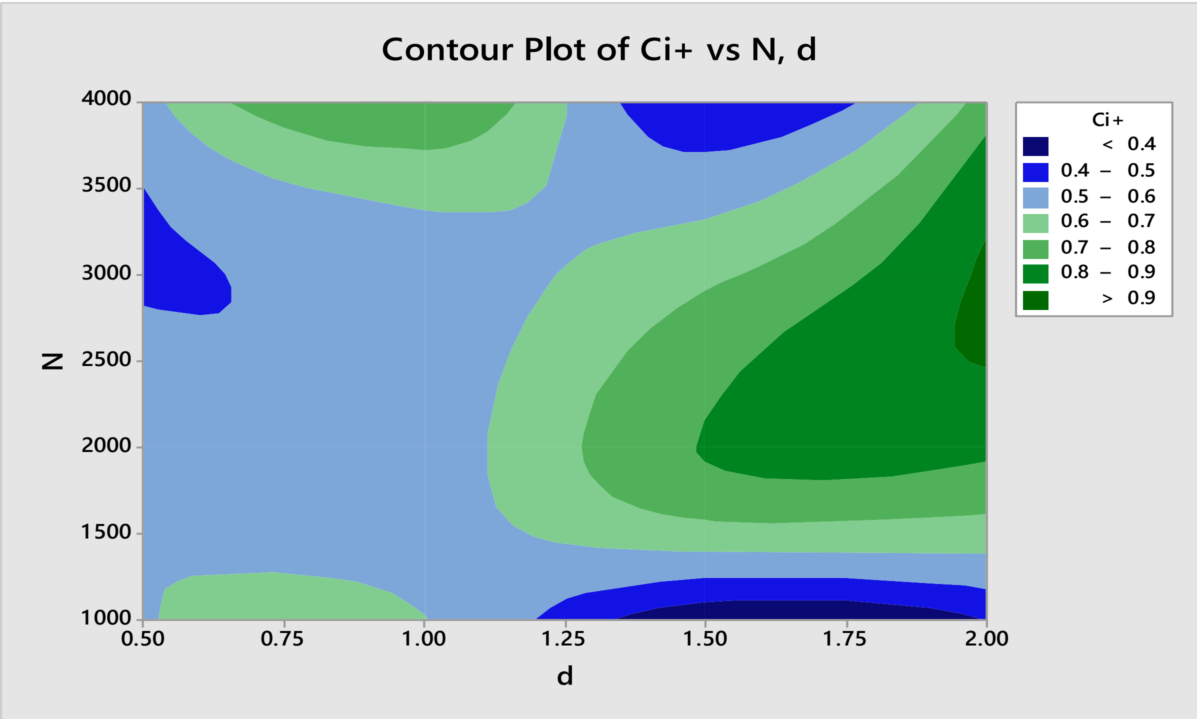
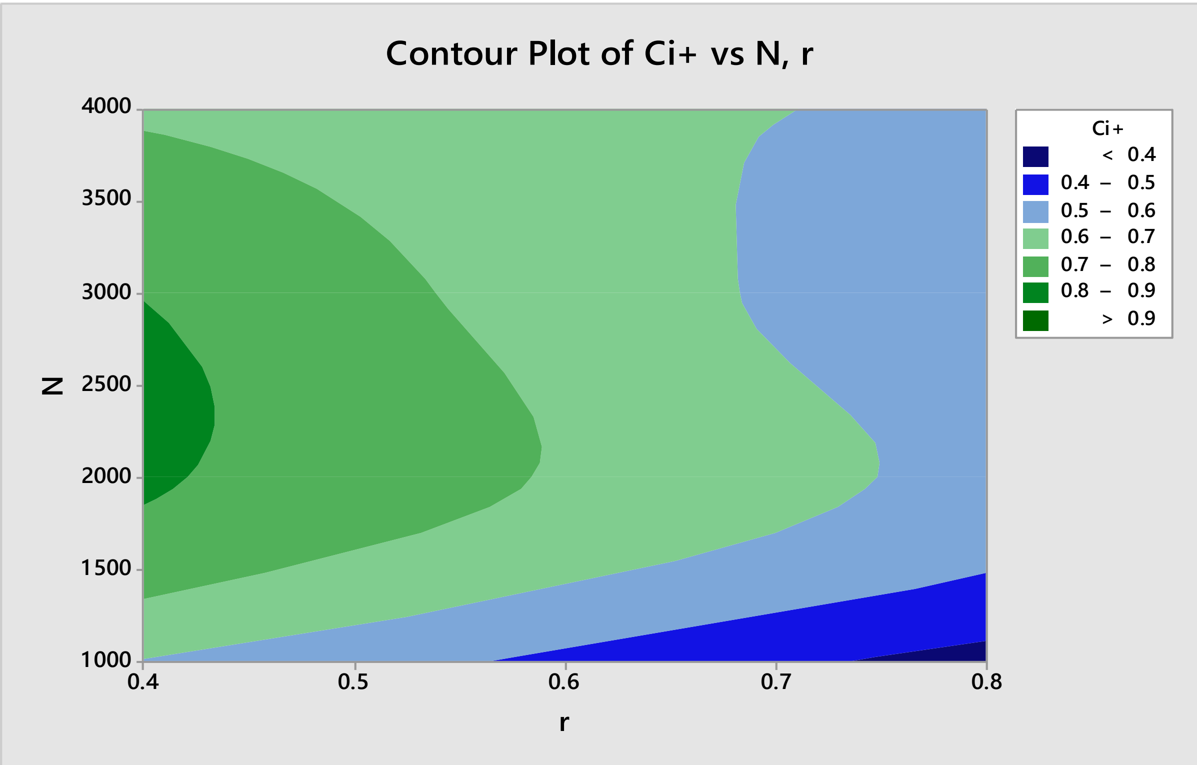



**Figure 5: Contour Plot of $C_i^+$Vs N, r**



### 4.0 Conclusions

The present work involves in finding the optimal combination of process parameters for achieving desired multiple responses simultaneously. From the results of Entropy-TOPSIS approach the optimal combination is found at speed:2000 RPM, feed:0.05 mm/rev, depth of cut:2 mm and nose radius:0.4 mm. ANOVA results showed that Nose radius has the highest influence and feed has the lowest influence on the multiple response.

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