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# A Utility based Approach towards the Multi Objective Optimization during Turning of AISI D3 Steel using Various Bio Degradable Cutting Fluids

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***Abstract: Green manufacturing in combination with minimum quantity lubrication is a method where in products are manufacture by consuming less natural resources and being safe to operators, environment and society as the cutting fluid used is bio-degradable. This paper envisages an experimental investigation that compares the machining characteristics when castor oil, palm oil and ground nut oil are used as cutting fluids during turning of AISI D3 steel by using DNMG, TNMG and CNMG styled CVD coated inserts. The result of the study compares the responses such as surface roughness, material removal rate and specific energy by considering single response as well as multi responses (Utility concept) and provides the basis for the adequacy for the utility approach***
***Keywords: Minimum quantity lubrication, cutting fluids, AISI D3 steel, CVD inserts, surface roughness, material removal rate, specific energy***

## I. INTRODUCTION

Quality and productivity are two important, but contradictory parameters which prevails in manufacturing. Quality mainly concerns with dimensional accuracy where as productivity is a direct measure of material removal rate during machining. Minimizing cutting force is also important which affects tool wear. Also power consumed is directly related to cutting force. Specific energy is the ratio of power consumed to material removal rate. For a effective machining specific energy need to be at lowest level. Hence it becomes essential to evaluate the optimum cutting parameters setting in order to satisfy the requirements of quality and productivity. The proper application of cutting fluid provides higher cutting speeds and higher feed rates possible. The selection of cutting fluid not only improves cutting performance but also fulfils a number of requirements which are non-harmful to health for operators, not a fire hazard, no smoke (or) for and cost is less. Cutting fluids are applied at the cutting zone to improve cutting performance. The primary function of cutting fluid is to reduce interface temperature between tools and work thus tool lip will be extended. Secondary cutting fluid acts as good lubricant by which heat generated due to friction will be reduced. To conclude with high lubricant capacity are suitable in low speed machining such as screw cutting, broaching, gear cutting and difficult to cut materials whereas cutting fluids with high cooling ability are generally employed in high speed machining. In the present work, AISI D3 steel was selected as work material which finds applications in the manufacture of Blanking & Forming dies, press tools, punches, bushes, forming rolls and many more. For the purpose of experimentation, factorial design experiments are considered as per Taguchi DOE. By advocating Taguchi design, a clear understanding of the nature of variation and economic consequences of quality engineering in the world of manufacturing can be clearly got through. In the present study, Taguchi based utility approach was performed to combine the multiple performance characteristics in to one numerical score which is an indicative of the optimal process parameter setting. Analysis of variance (ANOVA) is also performed to investigate the most influencing parameters on the surface roughness, material removal rate and specific energy.

Hari singh and Pradeep kumar [1] used utility concept coupled with Taguchi method for optimizing multiple quality characteristics during turning of En 24 steel. Surinder et al [2] presents a case study for optimizing multi-response in turning using Taguchi design approach in conjunction with utility concept for GFRP composite material with the help of carbide(K10) cutting tool. Yogendra kumar and Hari singh [3] used Taguchi design of approach and utility concept to optimize multiple performance characteristics namely axial force, radial force, main cutting force and material removal rate during dry turning of En- 47 steel. The optimal values obtained using multi characteristics optimization model is validated by confirmation experiments. Sunil Hansda and Simul Banerjee [4] used utility concept with Taguchi approach in optimizing multi characteristics in drilling of CFRP composite. Experiments were conducted based on Taguchi L9 orthogonal array. Analysis was performed based on utility method varying the importance of quality characteristics in drilling process. Antony [5] proposed a methodology to develop a simple and practical step by step approach for tackling multi responses or effects and also for determining the optimal condition of the process. Kaladhar et al [6] in his work applied a multi characteristics response optimization model based on Taguchi and utility concept to optimize process parameters such as speed, feed, depth of cut and nose radius on multiple performance characteristics namely surface roughness and material removal rate during turning of AISI 202 austenitic stainless steel using CVD coated cemented carbide tool. Taguchi L18 AO is selected for planning. The experimental results analysis showed that the combination of higher levels of cutting speed, depth of cut and nose radius and lower level of feed is essential to achieve simultaneous maximization of material removal rate and minimization of surface roughness. ANOVA and F-test are conducted and results are found to be with in confidence interval. Singaravel et al [7] estimated optimal machining parameters using Taguchi based utility concept coupled with principle component analysis(PCA) on turning of En 25 steel with CVD and PVD coated carbide tools. PC is adopted to find weight factors involved for all objectives,. Finally, ANOVA concept is employed on multi SN ratios to find relative significance of machining parameters in term of percentage contribution. Waghmare et al [8] presents utility concept along with the Taguchi methodology to optimize the RSW machine setting for multiple quality characteristics. Taguchi's modified L19 OA is used for experimentation along with using logarithmic scale for getting performance value and weightages is provided to each quality characteristics as per customer requirement to determine overall utility. Ajay Mishra and Anshul Gangela [9] investigated the multi objective optimization for the turning process of AISI 1045 steel cylindrical bar to yield the minimum tool flank wear width, surface roughness and roundness through the combination of Taguchi method and utility concept. Finally confirmation tests were conducted for validation purpose. Papiya Bhowmik et al [10] focused on the experimental investigation in to the role of green manufacturing on surface roughness in the machining of Aluminium AA 1050. A comparison is made under various cutting conditions using mineral oil, sun flower oil and coconut oil using the principle of minimum quantity lubrication. The results shown that vegetable oil performance is comparable to that of mineral oil machining and has potential to mineral oil with vegetable oil. With the consideration of all the view points from the literature survey, the present work employs utility concept along with Taguchi methodology to optimize multi quality characteristics during turning of AISI D3 steel in combination with CVD coated tool inserts with different styles using castor oil, palm oil and ground nut oil as cutting fluids.

## II. EXPERIMENTATION

In the present study, five turning parameters were selected with three levels as shown in Table.1. The experimentation was carried out using L27 orthogonal array based on Taguchi design of experiments. The work material selected for this experiment is AISI D3 steel of 40 mm diameter, length 100 mm. The chemical composition of AISI D3 steel has been done by chemical Analyzer and is reported as below in Table1and process parameters and its levels is shown in Table 2 and experiment data in Table 3

TABLE1 Chemical Analysis report

| Element | C | Si | Mn | P | S | Cr | V | W |
|---|---|---|---|---|---|---|---|---|
| Specified values | 2.00-2.35 | 0.10-0.60 | 0.10-0.60 | 0.03 max | 0.03 max | 11.00-13.50 | 1.00 max | 1.00 max |
| Observed values | 2.07 | 0.406 | 0.457 | 0.02 | 0.029 | 11.28 | 0.037 | <0.003 |

TABLE 2 Process parameters and its levels

| Process parameters | Designation | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Insert style | A | DNMG | TNMG | CNMG |
| Cutting fluid | B | Castor oil | Palm oil | Ground nut oil |
| Cutting speed (m/min) | C | 100 | 150 | 200 |
| Feed(mm/rev) | D | 0.05 | 0.07 | 0.09 |
| Depth of cut(mm) | E | 0.10 | 0.15 | 0.20 |

TABLE 3 Experimental data and results for 3 parameters, corresponding Ra, MRR and Specific energy for CVD tool

| Expt No | Insert Style | Cutting fluid | Cutting speed(m/min) | Feed (mm/rev) | Doc(mm) | Surface roughness(µm) | Material removal rate($mm^3$/sec) | Specific Energy (J/$mm^3$) |
|---|---|---|---|---|---|---|---|---|
| 1 | DNMG | CO | 100 | 0.05 | 0.10 | 0.268 | 55.190 | 36.445 |
| 2 | DNMG | CO | 100 | 0.05 | 0.15 | 0.738 | 80.909 | 26.675 |
| 3 | DNMG | CO | 100 | 0.05 | 0.20 | 1.113 | 116.664 | 19.441 |
| 4 | DNMG | PO | 150 | 0.07 | 0.10 | 0.336 | 73.896 | 32.177 |
| 5 | DNMG | PO | 150 | 0.07 | 0.15 | 0.680 | 138.459 | 18.229 |
| 6 | DNMG | PO | 150 | 0.07 | 0.20 | 0.854 | 177.686 | 14.823 |
| 7 | DNMG | GO | 200 | 0.09 | 0.10 | 0.184 | 206.897 | 14.145 |
| 8 | DNMG | GO | 200 | 0.09 | 0.15 | 0.452 | 263.404 | 1.666 |
| 9 | DNMG | GO | 200 | 0.09 | 0.20 | 0.596 | 349.252 | 9.112 |
| 10 | TNMG | CO | 150 | 0.09 | 0.10 | 0.232 | 126.373 | 19.394 |
| 11 | TNMG | CO | 150 | 0.09 | 0.15 | 0.582 | 180.543 | 14.791 |
| 12 | TNMG | CO | 150 | 0.09 | 0.20 | 0.682 | 260.220 | 10.824 |
| 13 | TNMG | PO | 200 | 0.05 | 0.10 | 0.432 | 114.151 | 24.035 |
| 14 | TNMG | PO | 200 | 0.05 | 0.15 | 0.648 | 158.305 | 18.024 |
| 15 | TNMG | PO | 200 | 0.05 | 0.20 | 0.878 | 194.311 | 15.249 |
| 16 | TNMG | GO | 100 | 0.07 | 0.10 | 0.322 | 44.159 | 42.248 |
| 17 | TNMG | GO | 100 | 0.07 | 0.15 | 0.510 | 60.537 | 32.631 |
| 18 | TNMG | GO | 100 | 0.07 | 0.20 | 0.568 | 88.332 | 24.848 |
| 19 | CNMG | CO | 200 | 0.07 | 0.10 | 0.567 | 146.216 | 19.765 |
| 20 | CNMG | CO | 200 | 0.07 | 0.15 | 0.728 | 216.592 | 14.018 |
| 21 | CNMG | CO | 200 | 0.07 | 0.20 | 1.047 | 282.822 | 11.123 |
| 22 | CNMG | PO | 100 | 0.09 | 0.10 | 0.334 | 76.273 | 25.419 |
| 23 | CNMG | PO | 100 | 0.09 | 0.15 | 0.438 | 111.533 | 19.023 |
| 24 | CNMG | PO | 100 | 0.09 | 0.20 | 0.690 | 140.177 | 15.926 |
| 25 | CNMG | GO | 150 | 0.05 | 0.10 | 0.448 | 61.848 | 37.854 |
| 26 | CNMG | GO | 150 | 0.05 | 0.15 | 0.526 | 105.896 | 23.489 |
| 27 | CNMG | GO | 150 | 0.05 | 0.20 | 0.700 | 135.025 | 19.235 |

``The turning tests were carried out on Kirloskar model centre lathe machine to determine the responses characteristics for various runs of experiment. Surface roughness is measured using “SJ 201-P” surface roughness measuring instrument.

The material removal rate ($mm^3$/sec) is calculated using formula:

$$MRR = [\pi/4(D_1^2-D_2^2)\ L]/t \qquad mm^3/sec \qquad (1)$$

Where, $D_1$ = Diameter of the work piece before turning.mm

$D_2$ = Diameter of the work piece after turning.mm

L = Length of turning, mm

t = Machining time, sec

Specific energy is obtained by considering the ratio between Power consumed and material removal rate. Power consumed is measured by using Watt meter fitted to lathe machine.

## III. METHODOLOGY

### *A. Entropy approach for weight determination*

Entropy method is one of the well-known and widely used methods to calculate the criteria of decision weights [11]. Decision weights increases the importance of criteria and is usually categorized into two types. One is subjective weight which is determined by the knowledge and experience of experts or individuals, and the other is objective weight which is determined mathematically by analyzing the collected data. Here, it is an objective weighting method.

### *B. Utility concept*

Quality is the key attribute which dictates customer satisfaction. Hence manufacturer attempts to produce a product by considering number of quality characteristics in to consideration. To able to make a rational choice, these performance evaluation on different characteristics are combined to give a composite index. Such a composite index shows the utility of the product. In this paper it is assumed that the over- all utility of a product is the total sum of utilities of each particular quality characteristics of a product. Proper weightages need to be given to each response characteristics and sum of the weighted response characteristics will signifies the overall utility. Thus if xi is the measure of effectiveness of $i^{th}$ process response characteristic and n represents number of responses, then the overall utility function can be written as[12]:

$$U(x1, x2, x3 \ldots\ldots\ldots\ldots\ldots, xn) = f[U_1(x_1), U_2(x_2), \ldots\ldots\ldots\ldots\ldots\ldots, U_n(x_n)]$$

Where $Ui(xi)$ is the utility of the $i^{th}$attribute

The overall utility function is the sum of individual utilities. If the attributes are independent. Then,

$$U(x_1, x_2, x_3 \ldots\ldots\ldots\ldots., x_n) = \sum_{i=1}^{n} Wi\ Ui(xi)$$

Where $W_i$is the weight assigned to the attribute $i$ and the total sum of the weights for all the attributes is equal to one

$$\sum_{i=1}^{n} Wi = 1$$

## IV. RESULTS AND ANALYSIS

The objective of the present work is to minimize surface roughness & specific energy and maximize material removal rate. In the present work, a multi response methodology based on Taguchi technique and utility concept is used for optimizing the multi-response characteristics Taguchi proposed many different possible S/N ratios to obtain the optimum parameter setting [13]. Two of them are selected for the present work. Those are

Smaller the better S/N ratios for $R_a$ (surface roughness) and SE (specific energy)

$[\eta_1] = -10\log_{10}(R_a{}^2)$

$[\eta_2] = -10\log_{10}(SE^2)$

Larger the better S/N ratio for MRR (material removal rate)

$[\eta_3] = -10\log_{10}(1/MRR^2)$

From the utility concept, the multi-response S/N ratios of the overall utility value is given by

$\eta_{abs} = \eta_1 W_1 + \eta_2 W_2 + \eta_3 W_3$

where $W_1$, $W_2$ and $W_3$are weights assigned to the Ra, MRR and SE, The weights are evaluated by using Entropy method, Therefore $W_1$ = 0.278, $W_2$= 0.447 & $W_3$= 0.275

A Determination of optimal range for surface roughness, material removal rate and specific energy at single response From mean table for surface roughness, the optimal setting is found at insert style at level 2, cutting fluid at level 3, cutting speed at level 1, feed at level 3 & depth of cut at level 1

$\mu_{SR}$ = 0.1757

Hence predicted value of experimental data for surface roughness is 0.0757 µm

Confidence interval for predicted optimum experimental data on a confirmation run can be calculated using

$$C.I = \sqrt{F\alpha(1,fe)Ve[\frac{1}{\eta eff}+\frac{1}{R}]} \quad (1)$$

Where $F\alpha(1,fe)$ = F ratio required for α, α = risk, $fe$ = residual error, $Ve$ = error variance, $\eta eff$ = effective number of replications $=N(1 + total\ DOF\ associated\ in\ the\ estimated\ of\ mean)$

R = number of repetitions for confirmation experiment, N = total number of experiments

The specific values are required in (1) are: $fe$ = 16, $Ve$ = 0.01004, $N$ = 27, $R$ = 1,

$F0.05(1,16)$ = 4.49, $C.I$ = ± 0.25188

The predicted optimal range (for a confirmation run) of surface roughness is:

$$-0.17618 < \mu SR < 0.32758$$

From mean table for material removal rate, the optimal setting is found at insert style at level 1, cutting fluid at level1, cutting speed at level 3, feed at level 3 & depth of cut at level 3

$\mu_{MRR}$ = 336.823

Hence predicted value of experimental data for material removal rate is 336.823 $mm3/sec$ -

Confidence interval for predicted optimum experimental data on a confirmation run can be calculated using

$$C.I = \sqrt{F\alpha(1,fe)Ve[\frac{1}{\eta eff}+\frac{1}{R}]} \quad (1)$$

Where $F\alpha(1,fe)$ = F ratio required for α, α = risk, $fe$ = residual error, $Ve$ = error variance, $\eta eff$ = effective number of replications = $N/(1 + total\ DOF\ associated\ in\ the\ estimated\ of\ mean)$

R = number of repetitions for confirmation experiment, N = total number of experiments

The specific values are required in (1) are: $fe$ = 16, $Ve$ = 369.0151, $N$ = 27, $R$ = 1,

$F0.05(1.16)$ = 4.49, $C.I$ = ± 48.2899

The predicted optimal range ( for a confirmation run) of material removal rate is:

$$288.533 < \mu MRR < 385.113$$

From mean table for specific energy the optimal setting is found at insert style at level 1, cutting fluid at level1, cutting speed at level3, feed at level 3 & depth of cut at level 3

$\mu_{SE}$ = 1.578

Hence predicted value of experimental data for specific energy is 1.578 $J/mm3$

Confidence interval for predicted optimum experimental data on a confirmation run can be calculated using

$$C.I = \sqrt{F\alpha(1,fe)Ve[\frac{1}{\eta eff}+\frac{1}{R}]} \quad (1)$$

Where $F\alpha(1, fe)$ = F ratio required for α, α = risk, $fe$ = residual error, $Ve$ = error variance, $\eta eff$ = effective number of replications = $N/(1 + total\ DOF\ associated\ in\ the\ estimated\ of\ mean)$

R = number of repetitions for confirmation experiment, N = total number of experiments

The specific values are required in (1) are: $fe$ = 16, $Ve$ = 7.9061, $N$ = 27, $R$ = 1,

$F0.05(1.16)$ = 4.49, $C.I$ = ± 7.068

The predicted optimal range (for a confirmation run) of specific energy is:

$$-5.49 < \mu SE < 8.646$$

### A. *Analysis of single response characteristic*

The optimal setting for surface roughness, material removal rate and specific energy are determined individually by Taguchi's approach. Table 4 shows the individual optimal values and corresponding setting of the process parameters. Further the ANOVA is used to determine the percentage contribution made by each process parameters on the individual target. Tables 5, 6 & 7 reveal the results of ANOVA

TABLE 4 Individual optimal values and its corresponding settings of the process parameters

| Performance characteristics | Optimum parameter level | Predicted optimum level |
|---|---|---|
| Surface roughness | A2B3C1D3E1 | 0.1757µm |
| Material removal rate | A1B1C3D3E3 | 336.823 $mm^3/sec$ |
| Specific energy | A1B1C3D3E3 | 1.578 $J/mm^3$ |

Table 5 ANOVA results for surface roughness

| Source | DOF | Sum of squares | Mean sum of squares | F-ratio | Percent contribution |
|---|---|---|---|---|---|
| A | 2 | 0.02604 | 0.01302 | 1.2967 | 1.8579 |
| B | 2 | 0.14424 | 0.07212 | 7.1826 | 10.2915 |
| C | 2 | 0.02229 | 0.01114 | 1.1095 | 1.5904 |
| D | 2 | 0.17801 | 0.08900 | 8.8636 | 12.7005 |
| E | 2 | 0.87031 | 0.43516 | 43.338 | 62.0968 |
| Error | 16 | 0.16066 | 0.01004 | | 11.4628 |
| Total | 26 | | | | 100.000 |

TABLE 6 ANOVA results for Material removal rate

| Source | DOF | Sum of squares | Mean sum of squares | F-ratio | Percent contribution |
|---|---|---|---|---|---|
| A | 2 | 3424.939 | 1712.4695 | 4.6406 | 2.1939 |
| B | 2 | 4387.500 | 2193.750 | 5.9448 | 2.8105 |
| C | 2 | 75167.44 | 37583.720 | 101.848 | 48.1502 |
| D | 2 | 28074.300 | 14037.15 | 38.039 | 17.9836 |
| E | 2 | 39151.840 | 19575.920 | 53.0491 | 25.07961 |
| Error | 16 | 5904.241 | 369.0151 | | 3.7821 |
| Total | 26 | | | | 100.0000 |

TABLE 7 ANOVA results for Specific energy

| Source | DOF | Sum of squares | Mean sum of squares | F-ratio | Percent contribution |
|---|---|---|---|---|---|
| A | 2 | 23.9156 | 11.9578 | 1.5125 | 1.1918 |
| B | 2 | 110.4176 | 55.2088 | 6.9831 | 5.5025 |
| C | 2 | 618.6326 | 309.3163 | 39.1238 | 30.8289 |
| D | 2 | 421.2761 | 210.6381 | 26.6425 | 20.9938 |
| E | 2 | 705.9272 | 352.9636 | 44.6445 | 35.1791 |
| Error | 16 | 126.4973 | 7.9061 | | 6.3039 |
| Total | 26 | | | | 100.0000 |

*B. Determination of optimal range for all the response characteristics when considered simultaneously by considering utility concept*

From mean response graphs for multi response utility value, the optimal setting is found at insert style at level 1, cutting fluid at level1, cutting speed at level3, feed at level 3 & depth of cut at level 3

$\mu_{SR} = 0.7373$

Hence predicted value of experimental data for surface roughness is 0.7373 µm

Confidence interval for predicted optimum experimental data on a confirmation run can be calculated using

$$C.I = \sqrt{F\alpha(1,fe)Ve[\frac{1}{\eta eff} + \frac{1}{R}]}$$

Where $F\alpha(1,fe)$ = F ratio required for α, α = risk, $fe$ = residual error, $Ve$ = error variance, $\eta eff$ = effective number of replications $= N(1 + total\ DOF\ associated\ in\ the\ estimated\ of\ mean)$

R = number of repetitions for confirmation experiment, N = total number of experiments

The specific values are required in (1) are: $fe = 16$, $Ve = 0.01004$, $N = 27$, $R = 1$,

$F0.05(1.16) = 4.49$, $C.I = \pm\ 0.25188$

The predicted optimal range ( for a confirmation run) of surface roughness is:

$$0.4854 < \mu SR < 0.9892$$

From mean response graphs for multi response utility value, the optimal setting is found at insert style at level 1, cutting fluid at level1, cutting speed at level3, feed at level 3 & depth of cut at level 3

$\mu_{MRR} = 336.823$

Hence predicted value of experimental data for material removal rate is 336.823 $mm3/sec$

Confidence interval for predicted optimum experimental data on a confirmation run can be calculated using

$$C.I = \sqrt{F\alpha(1,fe)Ve[\frac{1}{\eta eff} + \frac{1}{R}]}$$

Where $F\alpha(1,fe)$ = F ratio required for α, α = risk, $fe$ = residual error, $Ve$ = error variance, $\eta eff$ = effective number of replications $= N(1 + total\ DOF\ associated\ in\ the\ estimated\ of\ mean)$

R = number of repetitions for confirmation experiment, N = total number of experiments

The specific values are required in (1) are: $fe = 16$, $Ve = 369.051$, $N = 27$, $R = 1$,

$F0.05(1.16) = 4.49$, $C.I = \pm\ 48.2899$

The predicted optimal range ( for a confirmation run) of material removal rate is:

$$288.533 < \mu MRR < 385.113$$

From mean response graphs for multi response utility value, the optimal setting is found at insert style at level 1, cutting fluid at level1, cutting speed at level3, feed at level 3 & depth of cut at level 3

$\mu_{SE} = 1.578$

Hence predicted value of experimental data for material removal rate is 1.578 $J/mm3$

Confidence interval for predicted optimum experimental data on a confirmation run can be calculated using

C.I = $\sqrt{F\alpha(1, fe)Ve[\frac{1}{\eta eff} + \frac{1}{R}]}$

Where $F\alpha(1, fe)$ = F ratio required for α, α = risk, $fe$ = residual error, $Ve$ = error variance, $\eta eff$ = effective number of replications =$N(1 + total\ DOF\ associated\ in\ the\ estimated\ of\ mean)$

R = number of repetitions for confirmation experiment, N = total number of experiments

The specific values are required in (1) are: $fe$ = 16, $Ve$ = 7.9061, $N$ = 27, $R$ = 1,

$F0.05(1.16)$ = 4.49, $C.I$ = ± 7.0680

The predicted optimal range ( for a confirmation run) of surface roughness is:

$$-5.691 < \mu SE < 7.068$$

TABLE 8 ANOVA results for multi response considering utility value

| Source | DOF | Sum of squares | Mean sum of squares | F-ratio | Percent contribution |
|---|---|---|---|---|---|
| A | 2 | 3.6304 | 1.8152 | 3.8045 | 1.7688 |
| B | 2 | 2.4736 | 1.2368 | 2.5922 | 1.2052 |
| C | 2 | 98.9167 | 49.4584 | 103.659 | 48.1925 |
| D | 2 | 75.0103 | 37.5052 | 78.607 | 36.5452 |
| E | 2 | 17.5884 | 8.7942 | 18.432 | 8.5691 |
| Error | 16 | 7.6339 | 0.47712 | | 3.7193 |
| Total | 26 | | | | 100.0000 |

*C. Confirmation experiment*

The confirmation experiment is performed at the optimal setting of turning process parameters of utility data. The following values were obtained at condition $A1 - B1 - C3 - D3 - E3$

Surface roughness = 0.7044 µm
Material removal rate = 353.323 $mm^3/sec$
Specific energy = 2.367 $J/mm^3$

Comparison of results between single and multi objective optimization

The summary of results and comparison are reported in Table 9

TABLE 9 Summary and comparison of results

| Method | Characteristics | Optimal condition | optimal predicted value |
|---|---|---|---|
| Single characteristics | Surface roughness | A2B3CID3E1 | 0.1757 µm |
| Optimization | Material removal rate | A1B1C3D3E3 | 336.823 $mm^3$/sec |
| | Specific energy | A1B1C3D3E3 | 1.578 $J/mm^3$ |
| Multi objective | Surface roughness, | | 0.7373 µm |
| Optimization | Material removal rate | A1B1C3D3E3 | 336.823 $mm^3$/sec |
| (utility method) | & Specific energy | | 1.578 $J/mm^3$ |

## V. CONCLUSIONS

*A.* For a single objective optimization using Taguchi analysis, optimality condition has been found by considering mean values. The optimal predicted values for surface roughness is 0.1757µm, material removal rate 336.823 $mm^3$/min and specific energy 1.578 J/$mm^3$ . And all these values are well with- in optimal range.

*B.* In single objective optimization, from ANOVA results it is found that depth of cut signifies most (62.09%) followed by feed (12.70%) for surface roughness. For material removal rate, cutting speed has got greater contribution (48.15%) followed by depth of cut (25.08%) and for specific energy, depth of cut signifies most (35.18%) followed by cutting speed (30. 83%)

*C.* For multi objective optimization using utility concept, an optimality condition has been found and optimal predicted values are: Surface roughness 0.7373 µm, material removal rate 336.823$mm^3$/sec, Specific energy 1.578 J/$mm^3$. Also confirmatory experimental values are found at Surface roughness 0.7044 µm, material removal rate 353.323 $mm^3$/sec, Specific energy 2.367 J/$mm^3$. Also it is found that the deviation percentage between optimal predicted value and confirmatory experimental values are well with-in 5%. Hence the utility model is checked and validated

*D.* In multi objective optimization, from ANOVA results it is found that cutting speed signifies most(48.19%) followed by feed(36.54%) , depth of cut(8.57%)

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