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MCDM BASED MULTI OBJECTIVE OPTIMISATION DURING TURNING OF AISI D3 STEEL WITH CASTER OIL AS CUTTING FLUID USING DNMG STYLED COATED INSERT

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ABSTRACT:

Turning with minimum quantity lubrication is one such technique which can alleviate the pollution problems associated with cutting fluids. The continued application of conservative fluids is being confronted by the need to minimize health risks and bio-contamination. Cutting fluids of various types are usually enrolled to control the heat generated in machining. Bio-oils assisted machining is an environmental bio-compatible technology for desirable control of temperature. Hence in this work the castor oil is used as cutting fluid in substitution of mineral based oil during turning of AISI D3 steel. Experimentation is intended as per Taguchi design of orthogonal array which is carried out on a TURNMASTER 35 Conventional lathe in combination with DNMG styled PVD tools. The input parameters considered are cutting speed, feed and depth of cut and quality targets are Material removal rate, Surface roughness and Power consumed. MCDM technique of Deng's similarity based approach is implemented to find optimal process parameter combinations for higher the Material Removal Rate, lower the Surface Roughness and lower power consumption. Finally, the optimal parameter combination for multi objective optimization is obtained by using MCDM Technique which is significantly improved the objective results as compared to initial setting values.

Keywords: *Minimum quantity lubrication, Turn master 35 conventional lathe, DNMG, castor oil, PVD, and Deng's similarity based approach.*

1. INTRODUCTION

During the recent years, green manufacturing gaining popularity in manufacturing industry because of challenges faced due to the increased environmental issues and occupational safety. The important goal in the modern industries is to manufacture the product with lower cost and with high quality in short span of time. There are two main practical problems that engineers face in a manufacturing process, the first is to determine the product quality (meet technical specifications) and the second is to maximize manufacturing system performance using the available resources. The challenge of modern machining industry is mainly focused on achievement of high quality ,in terms of work piece dimensional accuracy, surface finish ,high production rate, less wear on the cutting tools ,economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact. The above said problems in metal cutting industry are related to use and disposal of cutting fluids.

The use of cutting fluids provides numerous advantages in machining but suffers from serious drawbacks of operator health hazard as well as environmental and economic problems. When cutting fluids comes into contact with skin of the operator will cause skin related problems and also suffers from serious respiratory problems. All the above said problems can be stunned by the use of vegetable oil based cutting fluids and that too in minimum quantity.

Hence in the present work castor oil is used as cutting fluid and lubrication employed here is minimum quantity lubrication. Cutting fluids are applied to the cutting zone to improve cutting performance. 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, desirability function analysis 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 power consumed

The objective of the present work is to find out the set of optimum conditions for the selected control factors in order to reduce surface roughness, Increase Material removal rate and reduce power consumption. By using DENG'S similarity based approach.

2. LITERATURE SURVEY

This work reviews in details the literature for a better understanding of the problem discussed in this area.

Kirby et al. [1] presented an application of the Taguchi parameter design method to optimize the surface finish in a turning operation. The control parameters for this operation included: spindle speed, feed rate, depth of cut and tool nose radius. A confirmation run was used to verify the results, which indicated that this method was both efficient and effective in determining the best turning parameters for the optimal surface roughness

M.Y Wang & T.S. Lan[3] presents Orthogonal array of Taguchi experiment where in four parameters like cutting speed, feed rate, tool nose run off with three levels in optimizing the multi-objective such as surface roughness, tool wear and material removal rate in precision turning on CNC lathe. For the purpose of multi response optimization, Grey relational analysis was employed.

N. Tosum & l. Ozler[5] presented an investigation in optimization and effect of cutting parameters on multiple performance characteristics(the tool life and work piece surface roughness) obtained by hot turning operation. A plan of experiments based on Taguchi method was designed M20 sintered carbide as tool and high manganese steel as work material were used in the experiments. The results showed that the cutting speed, feed rate were dominant variables on multi cutting performance characteristics. An optimal parameter combination was obtained by using statistical Analysis

Papiya Bhowmik etal [4] focused on an experimental investigation into the role of green machining on surface Roughness (Ra), in the machining of aluminium AA1050. A comparative study of turning experiments, between VBCFs and MBCFs under various cutting conditions, using neat or straight Sunflower oil and Coconut oil, was conducted using the same machining parameter set-up. Vegetable oils used on the principle of Minimum Quantity Lubrication (MQL) that is oil dropped between the cutting tool and workpiece interface directly. The results show that vegetable oil performance is comparable to that of mineral oil machining. The results show that Vegetable oils have potential to replace the mineral oils

Ujjwal Kumar etal [6] focuses on an experimental investigation into the role of green machining on surface Roughness (Ra), in the machining of aluminium AA1050. A comparative study of turning experiments, between VBCFs and MBCFs under various cutting conditions, using neat or straight Coconut oil and Castor oil, was conducted using the same machining parameter set-up. Vegetable oils used on the principle of Minimum Quantity Lubrication (MQL) that is oil dropped between the cutting tool and workpiece interface directly. The vegetable oil performance is comparable to that of mineral oil machining. The results show that Vegetable oils have potential to replace the Mineral oils

M.P. Jenarthanan & R. Jeyapaul[7] presents a new approach for optimizing machining arameters on milling glass-fibre reinforced plastic(GFRP) composites. Optimization of parameters was done by an analysis called desirability function analysis(DFA) which is a useful tool for optimizing multi response problems. A composite desirability value is obtained for multi- responses viz., surface roughness. Delamination factor and machining force using individual desirability values from DFA. Based on composite desirability value, the optimum levels of parameters have been identified and significant contribution of parameters is determined by analysis of variance.

T.Saravanan & R. Udaykumar [8] presents the machining of hybrid metal matrix using a medium duty lathe. The optimum machining parameters have been identified by a composite desirability value obtained from desirability function analysis as the performance index and significant contribution of parameters can then be determined by analysis of variance.

3. EXPERIMENTAL SETUP AND DESIGN

In the present study, three turning parameters were selected with three levels as shown in Table.3.2. The experimentation was carried out using L9 orthogonal array based on Taguchi design of experiments. The work material selected for this experiment is AISI D3 steel of 45 mm diameter, length 100 mm. The chemical composition of AISI D3 steel has been done by Chemical Analyser and is reported as below in table3.1 and experimental conditions are shown in table 3.3

Table3.1 Chemical Analysis report

Element	C	Si	Mn	P	S	Cr	V	W
Specified values	2.00 to 2.35	0.10 to 0.60	0.10 to 0.60	0.03 max	0.03 max	11.0 to 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 3.2 Process parameters and their levels

Cutting parameters	Level 1	Level 2	Level 3
Cutting speed (m/min)	100	150	200
Feed, F(mm/rev)	0.05	0.07	0.09
Depth of cut, D(mm)	1.0	1.5	2.0

Table 3.3 Experimental condition

Machine used	Turn master 35 conventional lathe, power: 5 HP
Work material	AISI D3 steel
Size of work piece	Diameter 45 mm x 70 mm
Cutting tool holder	PCLNR2525M12
Cutting inserts employed	DNMG 150608 EN-TM CTP 2135
MQL supply	Castor oil (300 ml/ hour)
Cutting parameters	Cutting velocity 100-200 m/min Feed 0.05-0.09 mm/rev Depth of cut 1.0-2.0 mm
Response variable	measured Surface roughness, SR(μm), Material removal rate, MRR(mm3/sec) and Power consumed(watts)

3.4 Surface Roughness Tester

Surface roughness measurement is measured using a portable stylus type Profilometer. The Profilometer is portable self-controlled instrument for the measurement of surface texture (Ra). The surface roughness tester SJ – 201Pis used to measure the surface roughness of the machined work piece. The measured profile has been digitized. Surface roughness measurement with the help of stylus is shown in the Figure No 3.1.

Figure No. 3.1: Profilometer Measuring Surface Roughness

3.2 Material Removal Rate (MRR):

The rate at which material is removed from the workpiece by turning process is termed as material removal rate. And it is expressed in mm^3/sec. It is calculated by using the equation shown in equation 3.1

MRR = [π/4(D12-D22) L]/t mm3/sec (3.1)

Where,

D1 = Diameter of the work piece before turning mm

D2 = Diameter of the work piece after turning.mm

L = Length of turning, mm

t = Machining time, sec

Power consumed is measured by using Watt meter

4. METHODS USED:

4.1 Taguchi Method

The objective of the robust design is to find the controllable process parameters setting for which Noise or variation as a minimal effect on the product or process functional characteristics. It is to be noted that the aim is not to find the parameter setting for the uncontrollable noise variables but the controllable design variables. To attain this objective, the control parameter also known as inner array variables, are systematically varied as stipulated by the inner orthogonal array. For the each experiment of inner array, a series of new experiments is conducted by varying the level settings of the uncontrollable noise variables. The level combinations of noise variables are done using the outer orthogonal array. The interference of noise on the performance characteristics can be found using the ratio where S is the standard derivation of the performance parameters of the each inner array experiment and N is the total number of experiment in the outer orthogonal array. This ratio indicates the functional variation due to noise. Using this result, it is possible to predict which control parameter settings will make the process in sensitive to noise. Taguchi method focus on robust design through use of Signal to noise ratio and orthogonal array.

4. Deng's Similarity Measure Approach

Hepu Deng (2007) proposed a new approach to find out the best alternative of the multi-criteria decision problem. In some cases, TOPSIS was found inefficient, because, comparing the distance between two alternatives was not sufficient. Deng discovered that, the comparison would be more effective, if magnitude and conflict between the alternative and ideal solution are taken in to consideration. Gradients of the variables indicate the conflicts and from the rank of conflict index, the best alternative can be identified. Steps involved in Deng's similarity based approach are given below:

Step1: The first step is to formulate decision matrix with 'm' alternatives and 'n' attributes Duckstein, L and Opricovic. S [9] and then the Decision matrix is normalized by using the equation 4.1. The Normalization matrix is formed in order to transform the various attribute dimensions into non-dimensional attributes, which allows comparison across the attributes Duckstein, L and Opricovic. S, U, P. L., Deng, H, Yeh, C.H., Willis, R.J [7, 41, 6].

$$D = \begin{bmatrix} X_{11} & X_{12} \ldots \ldots & X_{1n} \\ X_{21} & X_{22} \ldots \ldots & X_{2n} \\ X_{m1} & X_{m2} & X_{mn} \end{bmatrix}$$

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad (4.1)$$

Where,

i = 1……m and j = 1……n, a_{ij} represents the actual value of the i^{th} value of j^{th} experimental run and r_{ij} represents the corresponding normalized value.

Step 2: Weight for each response is calculated. Here these weightages are obtained from AHP priority values for each out responses.

Step 3: The weighted normalized decision matrix is then calculated by using equation 4.2. This weighted normalized matrix is formed by multiplying the normalized decision matrix by its associated weights.

$$Y_{ij} = W_i \times r_{ij} \quad (4.2)$$

Where,

i = 1……m and j = 1……n.

w_j represents the weight of the j^{th} attribute or criteria.

Step 4: Positive ideal solution (PIS) and negative ideal solution (NIS) are determined in this step. The positive ideal and negative ideal solutions can be expressed as:

(a) Positive ideal solution (PIS):

$Y^+ = \{(\max Y_{ij}/j \in J), (\min Y_{ij}/j \in \mathbf{J}), (\min Y_{ij}/j \in \mathbf{J})\ i = 1, 2, 3 \ldots.m\}$ (4.3)

i.e. $Y^+ = (y_1^+, y_2^+ \ldots.. y_n^+)$ maximum values

(b)Negative ideal solution (NIS):

$Y^- = \{(\min Y_{ij}/j \in J), (\max Y_{ij}/j \in \mathbf{J}) (\max V_{ij}/j \in \mathbf{J})\ i = 1, 2, 3 \ldots.m\}$ (4.4)

i.e. $Y^- = (y_1^-, y_2^- \ldots\ldots y_n^-)$ minimum values

Where;

J = {j = 1, 2, 3 …n; j associated with benefit criteria}

J = {j = 1, 2, 3 …n; j associated with cost criteria}

Step5: Degree of conflict between each alternative and positive ideal solution and negative ideal solution can calculated as follows Conflict between the alternative and positive ideal solution can be obtained as:

$$\cos\theta_i^+ = \frac{\sum_{j=1}^{m} y_{ij}\, y_j^+}{\left(\sum_{j=1}^{m} y_{ij}^2\right)^{0.5} \left(\sum_{j=1}^{m} y_{ij}^{+2}\right)^{0.5}} \quad (4.5)$$

Conflict between the alternative and negative ideal solution can be obtained as:

$$\cos\theta_i^- = \frac{\sum_{j=1}^{m} y_{ij}\, y_j^-}{\left(\sum_{j=1}^{m} y_{ij}^2\right)^{0.5} \left(\sum_{j=1}^{m} y_j^{-2}\right)^{0.5}} \quad (4.6)$$

Here, the value of θ lies between 0° and 90°.

Step 6: The degree of similarity and conflict between the alternatives and positive and negative ideal solution is calculated as:

Degree of conflict:

$$|C_i| = \cos\theta_i^{-+} \times |A_i| \quad (4.7)$$

Degree of similarity:

$$S_i^{-+} = \frac{|C_i|}{|A^{-+}|} = \frac{\cos\theta^{-+} \times |A_i|}{|A^{-+}|} = \frac{\cos\theta^{-+} \times \left(\sum_{j=1}^{m} y_{ij}^2\right)^{0.5}}{\left(\sum_{j=1}^{m} y_j^{-+2}\right)^{0.5}} \quad (4.8)$$

Step 7: The overall performance index for each alternative is calculate as:

$$P_i = \frac{S_i^+}{S_i^+ + S_i^-},\ i = 1,2,\ldots\ldots,\ n \quad (4.9)$$

Step 8: Ranking according to Deng's similarity based method

5. Results and Discussion

An experiment were conducted to assess the effect of turning parameters on surface roughness, material removal rate and power consumed and the results of experimentation are shown in table5.1

Table 5.1: Experimental data and results for 3parameters, corresponding Ra, MRR and power consumed for PVD tool

S. No	Cutting Speed (mm/ min)	Feed (mm /min)	Doc (mm)	Ra (µm)	MRR (g/sec)	Power (Watts)
1	100	0.05	1.0	0.374	62.529	2085.11
2	100	0.07	1.5	0.318	82.211	2121.69

3	100	0.09	2.0	0.646	257.71	2341.17
4	150	0.05	1.5	0.530	89.813	2524.08
5	150	0.07	2.0	0.344	168.33	2670.40
6	150	0.09	1.0	0.228	125.34	2487.50
7	200	0.05	2.0	1.096	195.14	2963.05
8	200	0.07	1.0	0.408	146.01	2780.14
9	200	0.09	1.5	0.770	267.97	2926.47

5.1Taguchi results:

The optimal parameter combinations obtained from Taguchi for individual response characteristics are tabulated in table 5.2.

Table 5.2: Optimal parameter combination of Individual Responses from Taguchi

Responses	**Cutting Speed (mm/min)**	**Feed (mm/rev)**	**Depth of Cut (mm)**
Ra	200	0.09	2.0
MRR	150	0.07	1.0
Power	100	0.05	1.0

5.3 Deng's Approach Results

By Entropy method, the weightages are calculated and depending on the values of the responses weights are assigned which are: For surface roughness, w1= 0.342, For MRR, w2= 0.344, for power consumed, w5= 0.314. The normalised and weighted normalized values are calculated and tabulated in Table 5.3.

Table 5.3: Normalized and weighted normalized data

Ex No.	**Normalized values**			**Weighted normalised values**		
	SR	**MRR**	**Power**	**SR**	**MRR**	**Power**
1	0.21 3	0.12 2	0.27 1	0.07 3	0.04 2	0.085 1
2	0.18 1	0.16 1	0.27 6	0.06 2	0.05 5	0.086 6
3	0.36 8	0.50 5	0.30 4	0.12 6	0.17 3	0.095 6
4	0.30 2	0.17 6	0.32 8	0.10 3	0.06 0	0.103 0
5	0.19 6	0.32 9	0.34 7	0.06 7	0.11 3	0.109 0
6	0.13 0	0.24 5	0.32 3	0.04 4	0.08 4	0.101 5
7	0.62 5	0.38 2	0.38 5	0.21 0	0.13 1	0.121 0
8	0.23	0.28 6	0.36 1	0.07 9	0.09 8	0.113 5
9	0.43 9	0.52 5	0.38 0	0.15 0	0.18 0	0.119 5

Then the positive ideal solutions and negative ideal solutions are determined using Equation 4.3 and 4.4. For MRR maximum value among the recorded values is considered as positive ideal solution and minimum value referred as negative ideal solution. Whereas for surface roughness and power consumption lower values are desirable. Hence, minimum value of the recorded value is regarded as positive ideal solution and maximum value represents the negative ideal solution. The positive ideal solution and negative ideal solution are determined and tabulated in Table 5.4

Table5.4: Positive ideal solution and negative ideal solution

$\mathbf{Y^+}$	0.04454	0.18064	0.08514904
$\mathbf{Y^-}$	0.21398	0.04215	0.12100123

Now the conflict angle, degree of conflict are calculated by using the equation 4.5, 4.6 4.7 and 4.8 and the values are tabulated in Table 5.5

Table 5.5: Degree of conflicts of the alternatives

Ex .N o.	$\mathbf{Cos\theta^+}$	$\mathbf{Cos\theta^-}$	$\mathbf{C^+}$	$\mathbf{C^-}$
1	1.932	0.928	0.231	0.111
2	1.832	0.872	0.220	0.104
3	1.990	0.782	0.467	0.184
4	2.03	0.944	0.321	0.149
5	1.705	0.759	0.291	0.129
6	1.533	0.731	0.213	0.101
7	2.267	0.950	0.632	0.265
8	1.808	0.825	0.307	0.140
9	2.034	0.826	0.536	0.217

Then the degree of similarity is calculated from eq.4.9. Finally overall performance index is calculated and tabulated in table 5.6**.** Rank is provided to the index in a descending order such that the highest value of the index will get the first rank.

Table 5.6: Degree of similarity and ranking of alternatives

Ex No	S^+	S^-	P	Rank
1	1.1319	0.4462	0.7172	9
2	1.0758	0.4204	0.7190	7
3	**2.2858**	**0.7389**	**0.7557**	**1**
4	1.5717	0.5986	0.7241	6
5	1.4259	0.5210	0.7323	4
6	1.0447	0.4087	0.7187	8
7	3.0902	1.062	0.7441	3
8	1.5030	0.5626	0.7276	5
9	2.6218	0.8736	0.7500	2

From the above table, it is clearly visible that run 3 is getting the 1st rank. Hence, the corresponding input parameter i.e. cutting speed of 100 mm/min, feed rate of 0.09 mm/rev and depth of cut of 2.0 mm is found to be the optimum combination.

Finally the optimal parameter combination on individual responses and multi responses are obtained by using Taguchi and Deng's approach which are tabulated in table 5.7

Table 5.7: Optimal parameter combinations

Method	**Responses**	**Process parameter levels**		
		Cutting Speed (mm/min)	**Feed (mm/rev)**	**Depth of Cut (mm)**
Taguchi	**Ra**	200	0.09	2.0
	MRR	150	0.07	1.0
	Power	100	0.05	1.0
Deng's	**Ra, MRR and Power**	100	0.09	2.0

5. CONCLUSIONS:

Turning experiments were conducted on TURNMASTER-35 lathe machine based on Taguchi DOE for AISI D3 alloy steel using PVD coated DNMG inserts. The experimentation data were subjected to MCDM technique of Deng's approach for multi objective optimization. From this analysis, the following conclusions were drawn for all the quality targets.

- Deng's similarity based approach is a very useful and effective tool for multi objective optimization. By using this technique, multiple performance characteristics is converted in to single response characteristic and is further used in the calculation of Overall Performance index.
- From Taguchi results the optimal parameter combination
    - For Surface roughness the cutting speed at level 3(200mm/min), feed at level 3 (0.09 mm/rev) and depth of cut at Level 3 (2.0 mm).
    - For Material removal rate the cutting speed at level 2 (150mm/min), feed at level 2 (0.05 mm/rev) and depth of cut at Level 1 (1.0 mm).
    - For power consumed the cutting speed at level 1 (100mm/min), feed at level 1 (0.05 mm/rev) and depth of cut at Level 1 (1.0 mm).
- When all the quality characteristics are optimized simultaneously, the optimality conditions for PVD insert are cutting speed at level 1(100 m/min), feed at level 3(0.09 mm/rev) and depth of cut at level 3 (2.0 mm)

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