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Selection of best novel MCDM method during turning of hardened AISI D3 tool steel under minimum quantity lubrication using Bio-degradable oils as cutting fluids

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Abstract

Modern manufacturing industries show thrust towards the reduction on environmental and ecological issues by introducing the usage of vegetable oils as cutting fluids which are bio-degradable. New techniques are being inquired to achieve this objective. Minimum quantity lubrication with vegetable based cutting fluids is one such technique which can alleviate the pollution problems and restore bio-degradability. The present paper deals with experimental investigation carried out for machinability study of hardened AISI D3 tool steel in combination with CVD coated inserts of different styles using vegetable oils as cutting fluid under minimum quantity lubrication and to obtain optimum process parameters using novel MCDM method viz., Deng's method and WASPAS method. An orthogonal array, single performance measure and analysis of variance (ANOVA) are applied to study the performance of process parameters such as insert style, cutting fluid, cutting speed, feed and depth of cut with consideration of quality characteristics i.e., surface roughness, material removal rate, interface temperature, specific energy and flank wear. Finally the best MCDM method towards multi objective optimization is presented.

Keywords: Minimum quantity lubrication, Hardened AISI D3 steel, CVD coated inserts, Deng's method, WASPAS method, ANOVA.

INTRODUCTION

Quality responsive excellence is the most important business objective. The purpose of undertaking cutting parameter optimization is two- fold: Quality and Economics. Turning is widely used industrial manufacturing process for circular cross-section components. A manufacturing process involves a number of process parameters (controllable and uncontrollable) which affects the output (response). The basic idea of optimization is to increase quality and reduce cost. Optimal process parameters are usually picked by an experiences human technician (process planner or machine operator) driven by wisdom, combination of material and size of work, material and size of cutter, available range of machine variables and machine accuracy limitations and data from standard industrial handbooks. Reduced machining time, good tool life and good surface finish are some of the important considerations during effective machining. Bio-degradable oils are used as cutting fluids under minimum quantity lubrication. 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. In the present work, hardened 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 economical consequences of quality engineering in the world of manufacturing can be clearly got through. In the present study, novel MCDM techniques viz., Deng's similarity approach and WASPAS approach was performed to combine the multiple performance characteristics in to one numerical score called single performance measure 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, interface temperature, specific energy and flank wear when all the responses are considered simultaneously. Wojciech Zębala and Jakub Siwiec [1] presented example of hard turning application, comparison with grinding technology and results of hard turning researches on cold work tool steel with cubic boron nitride tools. The influence of cutting conditions and material hardness on cutting forces and surface roughness are presented. Varaprasad.Bh et al [2] has made an attempt to develop a model and predict tool flank wear of hard turned AISI D3 hardened steel in combination with Al2O3/TiC mixed ceramic tool using Response Surface Methodology (RSM). The adequacy of the developed models is checked using Analysis of Variance (ANOVA). Rahim and Sasahara [3] studied the potency of minimum quantity lubricant palm oil (MQLPO) and minimum quantity lubricant synthetic ester (MQLSE) during drilling of titanium alloys with carbide drill coated with AlTiN along with other cutting environments. The study revealed that thrust force and torque is lowered with palm oil as lubricant as compared to synthetic ester for the same cutting conditions. Mohamed Handawi Saad Elmunafi [4] studied the viability of using castor oil as lubricant in machining of hardened stainless steel with minimum quantity lubrication. It was found that MQL produced better results as compared to dry cutting in terms of longer tool life. Paul and pal [5] investigated the performance of different types of cutting fluids (Karanji oil, neem oil and conventional fluid) as compared to dry cutting conditions during turning of mild steel. The use of vegetable based cutting fluid improved surface quality as compared to dry turning and conventional cutting fluid. Ojolo, S.J et al [6] in their paper investigated the effect of some vegetable based oils such as groundnut oil, coconut oil, palm kernel oil and shear butter oil on cutting force during cylindrical machining of mild steel, aluminium and copper with tungsten carbide tool. Anthony Xavior M and M. Adithan [7] in their work determined the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304 with carbide tool, identified the influence of coconut oil in reducing the tool wear and surface roughness during turning process. The results indicated that the performance of coconut oil is better as compared to two cutting fluids namely an emulsion and a neat cutting oil (immiscible with water). Nalbant et al [8] presented an application of the parameter design of the Taguchi method in the optimization of the machining parameters for surface roughness in turning AISI 1030 steel bars using TiN coated tools. Yang W H and Tang Y S [9] used Taguchi method to find out the optimal cutting parameters in turning of S45C steel bars. They employed an orthogonal array, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) to investigate the machining characteristics of S45C steel bars using tungsten carbide cutting tools. Zavadskas Edmundas Kazimieras et. al [10] presented a novel method based on multiple attribute Weighted Aggregated Sum Product Assessment with the grey attributes scores –WASPAS-G method. Vikas Sonkar et. al [11] attempted to do investigations on the machinability aspects during drilling of GFRP composite. with drill speed, feed rate, drill diameter, plate thickness etc are process variables and.., drill force (thrust), torque, surface roughness (Ra) and delamination behavior (of the drilled hole) as a response characteristics with the aim to determine an optimal machining conditions using MCDM methods namely the 'Degree of Similarity Measure' and the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution. Shankar Chakraborty and Edmundas Kazimieras Zavadskas [12] presented the applicability of weighted aggregated sum product assessment (WASPAS) method is explored as an effective MCDM tool while solving eight manufacturing decision making problems, such as selection of cutting fluid, electroplating system, forging condition, arc welding process, industrial robot, milling condition, machinability of materials, and electro-discharge micro-machining process parameters.

Based on the extensive study of past research, it is observed that the two multi response optimization MCDM techniques viz., Deng's method and WASPAS method are quite simple /robust in accordance with computational procedures. There are other techniques which use Evolutionary algorithms which are quite complicated and the industry personnel feel inconvenient of using Evolutionary algorithms with little background in statistics and knowledge in software. Because of the computational simplicity, the current study aims to use multi criteria decision making methods for multi response optimization. The aim of this paper is to compare the above methods using the experimental data and to report the best method within the given domain.

EXPERIMENTATION

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

Table 1. 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	IS	DNMG	TNMG	CNMG
Cutting fluid	CF	Castor oil	Palm oil	Ground nut oil
Cutting speed(m/min)	V	100	150	200
Feed(mm/rev)	F	0.05	0.07	0.09
Depth of cut(mm)	d	0.10	0.15	0.20

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The different types of CVD coated inserts of different styles are presented in Fig. 1 and the corresponding tool holders for holding DNMG, TNMG AND CNMG inserts are shown in Fig. 2, Fig. 3 and Fig. 4 respectively

Figure 1: CVD coated DNMG, TNMG and CNMG cutting inserts

Figure 2: PDJNR 2020M15 WIDAX

Figure 3: MTJNR 2020K16 WIDAX

Figure 4: PCLNR 2020K12 V tool

The turning tests were carried out on Kirloskar model centre lathe machine shown in Fig. 5 and Fig. 6 to determine the responses for various runs of experiment. The lathe has a capacity of 4 H.P and the speed has a range varies from 280 rpm to 1800 rpm. Also the machine is fixed firmly by foundation bolts to avoid vibration.

Figure 5: Kirloskar model Turn master 35 centre lathe

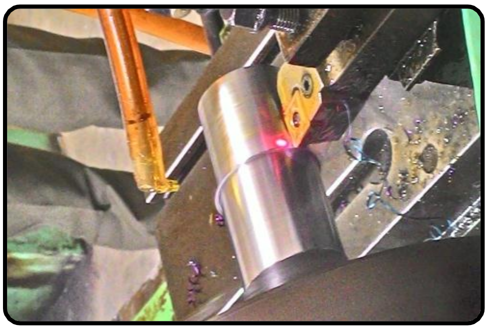

Figure 6: Lubricant impinging on cutting zone

Surface roughness is measured using "SJ 201-P" surface roughness measuring instrument.

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

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

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

The cutting zone temperature is measure using Model IRT-4 make infrared thermometer with the laser targeting the specifications of IR temperature range of -50^0C to 550^0C with response time 500 ms & (8-14) µm.

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 a lathe machine. Flank wear is found out by Tool maker's microscope.

Multi Objective Optimization Techniques

In the arena of advanced manufacturing technology, the only objective of all Engineers is to obtain the effective process performance. Hence the multi optimization has become a main tool in manufacturing decision making process. The main objective of multi optimization is to reduce cost of production but at the same time to increase production rate which subsequently yield more profits to the organization.

Entropy approach for weight determination

Entropy method is an objective weighing technique which is widely used method to calculate the criteria of decision weights [13]. W_1,W_2, W_3, W_4 and W_5 are weights assigned to the surface roughness, material removal rate, interface temperature, specific energy consumption and flank wear respectively, where W_1= 0.191, W_2= 0.308 , W_3= 0.017, W_4 = 0.189 and W_5 = 0.295.

Deng's method

Hepu Deng [14] proposed a new approach to find out the best alternative of the multi-criteria decision problem. 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.

Step1: The decision matrix can be established by considering the response characteristics

Step2: The normalized decision matrix can be found out by determining the normalized value r_{ij} as

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_1^n x_{ij}^2}} \quad (2)$$

Step 3: The weighted normalized decision matrix can be determined as:

$$V_{IJ} = W_i x\, r_{ij} \quad (3)$$

Step 4: The positive ideal solutions and negative ideal solutions are determined as:

For positive ideal solution, in case of smaller the better, select lowest of column values, in case of larger the better, select largest of column values

For negative ideal solution, in case of smaller the better, select largest of column values, in case of larger the better, select largest of column values

Step 5: 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:

$$\cos\theta + = \frac{\sum_1^n y_{ij} y_j^+}{\sqrt{(\sum_1^n y_{ij}^2)(\sum_1^n y_j^{+2)}}} \qquad \cos\theta - = \frac{\sum_1^n y_{ij} y_j^-}{\sqrt{(\sum_1^n y_{ij}^2)(\sum_1^n y_j^{-2)}}}$$

WASPAS method

Weighted aggregated sum product assessment (WASPAS) method for solving MCDM problems was proposed by Zavadskas et.al [15]. The procedural steps being involved in solving multi objective optimization problems is presented below

Step 1. Set the initial decision matrix

Step 2. Normalization of the decision matrix by using the following equations:

$$\overline{x_{ij}} = x_{ij}/max_i x_{ij} \qquad \text{(eq. 1)}$$

$$\overline{x_{ij}} = mix_i x_{ij}/x_{ij} \qquad \text{(eq. 2)}$$

Where x_{ij} is the assessment value of the *i*-th alternative with respect to the *j*-th criterion, and eqs. 1 and 2 are used for maximization and minimization criteria, respectively.

Step 3. The total relative importance of the *i*-th alternative, based on weighted sum method (WSM), is calculated as follows:

$$Q_i^{(1)} = \sum_{j=1}^{n} \overline{x_{ij}} . w_j$$

Step 4. The total relative importance of the *i*-th alternative, based on weighted product method (WPM), is calculated as follows:

$$Q_i^{(2)} = \prod_{j=1}^{n} \overline{x_{ij}}^{w_j}$$

Step 5. In order to have increased ranking accuracy and effectiveness of the decision making process, in

the WASPAS method, a more generalized equation for determining the total relative importance of alternatives is developed as below:

$$Q_i = \lambda . Q_i^{(1)} + (1-\lambda). Q_i^{(2)}$$

Where, λ = 0, 0.1… 1.

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

Degree of conflict:

$$C^+ = (\cos\theta +_I) X(A_i) \qquad C^- = (\cos\theta -_I) X(A_i)$$

where $A_i = \sqrt{\sum_1^n y_{ij}^2}$

Degree of similarity

$$S^+ = \frac{C^+}{A^+} \qquad \text{Where, } A^+ = \sqrt{\sum_1^n y_{ij}^{+2}}$$

$$S^+ = \frac{C^-}{A^-} \qquad \text{Where, } A^- = \sqrt{\sum_1^n y_{ij}^{-2}}$$

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

$$P_i = \frac{S_i^+}{S_i^+ + S_i^-}$$

Step 8: Ranking is done based on descending order with respect to overall performance index.

RESULTS AND DISCUSSIONS

In this section, the experimental data given in Table 3 are analyzed by the two prospective multi response optimization techniques which are described earlier. An analysis of variance (ANOVA) is applied to estimate the contributions made by each process parameter on optimization of multi performance characteristics of the turning process. Based on the results of single performance measure (SPM) and ANOVA results, optimal machining parameters in consideration of multiple performance characteristics have been obtained and verified.

Analysis of experimental data

In this present study, the larger the better and smaller the better principles are considered to maximize material removal rate and to minimize surface roughness, interface temperature, specific energy consumption and flank wear respectively. The single performance measures for the two multi response optimization techniques obtained by using the standard formulae stated earlier are given in Table 4. Since the experimental design is orthogonal, it is possible to separate out the effect of each process parameter at different levels. The calculated mean for Deng’s method and WASPAS method of each process parameter at different factor levels are presented in Table 5. The optimal factor levels can easily determined by examining the level averages of various factors.

Table 3: Experimental results for response characteristics

SlNo	Insert style	Cutting fluid	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	SR (µm)	MRR (mm^3/sec)	IT (^OC)	Specific Energy (J/mm^3)	Flank Wear (mm)
1	DNMG	CO	100	0.05	0.10	0.268	55.190	35.67	36.445	0.094
2	DNMG	CO	100	0.05	0.15	0.738	80.909	38.67	26.675	0.106
3	DNMG	CO	100	0.05	0.20	1.113	116.664	40.00	19.441	0.118
4	DNMG	PO	150	0.07	0.10	0.336	73.896	38.67	32.177	0.105
5	DNMG	PO	150	0.07	0.15	0.680	138.459	43.67	18.229	0.109
6	DNMG	PO	150	0.07	0.20	0.854	177.686	45.6	14.823	0.113
7	DNMG	GO	200	0.09	0.10	0.184	206.897	37.00	14.145	0.012
8	DNMG	GO	200	0.09	0.15	0.452	263.404	38.25	11.666	0.023
9	DNMG	GO	200	0.09	0.20	0.596	349.252	39.33	9.112	0.052
10	TNMG	CO	150	0.09	0.10	0.232	126.373	37.40	19.394	0.051
11	TNMG	CO	150	0.09	0.15	0.582	180.543	42.00	14.791	0.068
12	TNMG	CO	150	0.09	0.20	0.682	260.220	44.00	10.824	0.101
13	TNMG	PO	200	0.05	0.10	0.432	114.151	35.60	24.035	0.042
14	TNMG	PO	200	0.05	0.15	0.648	158.305	35.75	18.024	0.109
15	TNMG	PO	200	0.05	0.20	0.878	194.311	46.80	15.249	0.113
16	TNMG	GO	100	0.07	0.10	0.322	44.159	43.20	42.248	0.114
17	TNMG	GO	100	0.07	0.15	0.510	60.537	43.40	32.631	0.118
18	TNMG	GO	100	0.07	0.20	0.568	88.332	47.00	24.848	0.145
19	CNMG	CO	200	0.07	0.10	0.567	146.216	33.00	19.765	0.025
20	CNMG	CO	200	0.07	0.15	0.728	216.592	35.25	14.018	0.033
21	CNMG	CO	200	0.07	0.20	1.047	282.822	35.50	11.123	0.061
22	CNMG	PO	100	0.09	0.10	0.334	76.273	41.00	25.419	0.125
23	CNMG	PO	100	0.09	0.15	0.438	111.533	44.00	19.023	0.131
24	CNMG	PO	100	0.09	0.20	0.690	140.177	52.75	15.926	0.140
25	CNMG	GO	150	0.05	0.10	0.448	61.848	42.00	37.854	0.031
26	CNMG	GO	150	0.05	0.15	0.526	105.896	43.30	23.489	0.063
27	CNMG	GO	150	0.05	0.20	0.700	135.025	44.00	19.235	0.082

Table 4: Performance index values for Deng's method and WASPAS method

Experiment Number	Single process measure (SPM)	
	Deng's index	WASPAS index
1	0.2861	0.2506
2	0.3157	0.2204
3	0.3524	0.2448
4	0.3166	0.2502
5	0.4148	0.2902
6	0.4515	0.3206
7	0.7177	0.7935
8	0.6959	0.6165
9	0.6827	0.5776
10	0.5155	0.4155
11	0.5297	0.3791
12	0.5617	0.4318
13	0.4785	0.3498
14	0.4420	0.3099
15	0.4663	0.3280
16	0.2422	0.2076
17	0.2731	0.2046
18	0.3080	0.2268
19	0.5483	0.4329
20	0.6044	0.4694
21	0.5902	0.4559
22	0.3113	0.2559
23	0.3685	0.2819
24	0.3906	0.2861
25	0.3551	0.2954
26	0.4217	0.2959
27	0.4365	0.2991

Table 5: Level averages of the factors & Ranking for different single performance values

Process parameter	Level	Deng's method					WASPAS method				
		IS	CF	V	F	d	IS	CF	V	F	D
Average value	1	**0.4704**	**0.4782**	0.3164	0.3949	0.4190	**0.3960**	0.3667	0.2421	0.2882	**0.3613**
	2	0.4241	0.4045	0.4448	0.4166	0.4518	0.3170	0.2969	0.3309	0.3176	0.3409
	3	0.4474	0.4592	**0.5807**	**0.5304**	**0.4711**	0.3414	**0.3908**	**0.4815**	**0.4487**	0.3523
Delta(Max-Min)		0.0463	0.0738	0.2624	0.1355	0.0521	0.0790	0.0938	0.2394	0.1605	0.0204
Rank		5	3	1	2	4	4	3	1	2	5
Optimum levels: Deng's method **$IS_1CF_1V_3F_3d_3$**; WASPAS method **$IS_1CF_3V_3F_3d_1$**											

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Taguchi Analysis and ANOVA

After calculating the single performance measure for each experiment, the next step is to estimate optimal level of machining parameters by considering multi objective optimization which is depicted in Figures 7 and Figures 8.

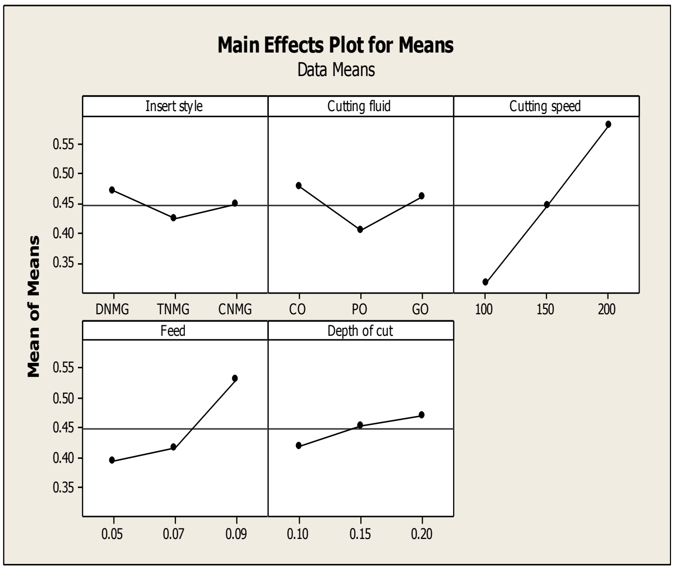

Figure 7: Response graph for Deng's index (SPM)

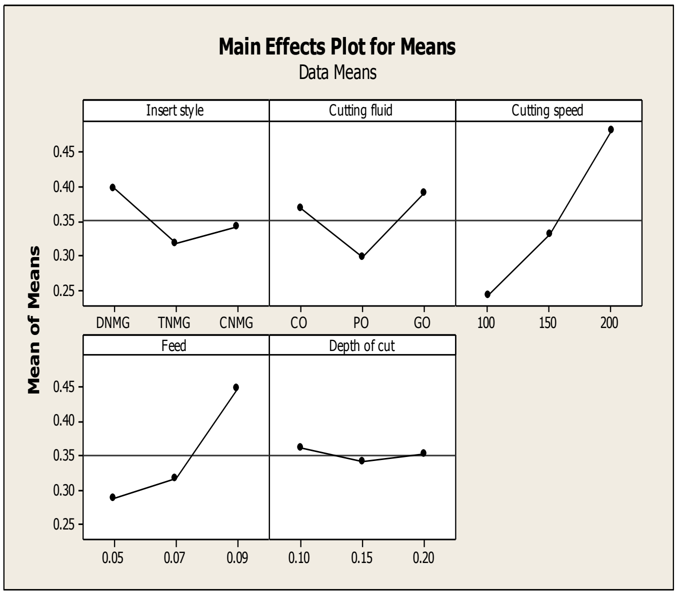

Figure 8: Response graph for WASPAS index (SPM)

Linear regression are developed and accuracy of models are validated by considering R-Square values, R-Square(adj) and R-square(pred) and is found that the two MCDM techniques are found to be within the accuracy limits. Also from residual plots, for the two techniques, predicted and actual values are closely related and hence the accuracy of the techniques are confirmed. Residual plots are presented in the Figures 9 and Figures 10.

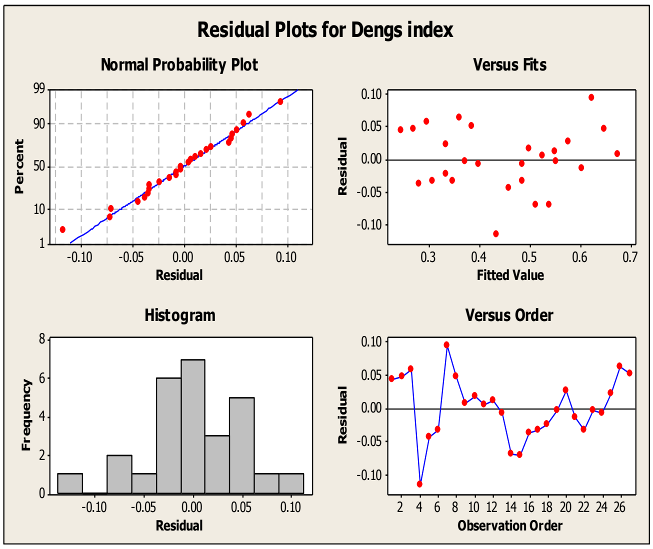

Figure 9: Residual plots for Deng's index (SPM)

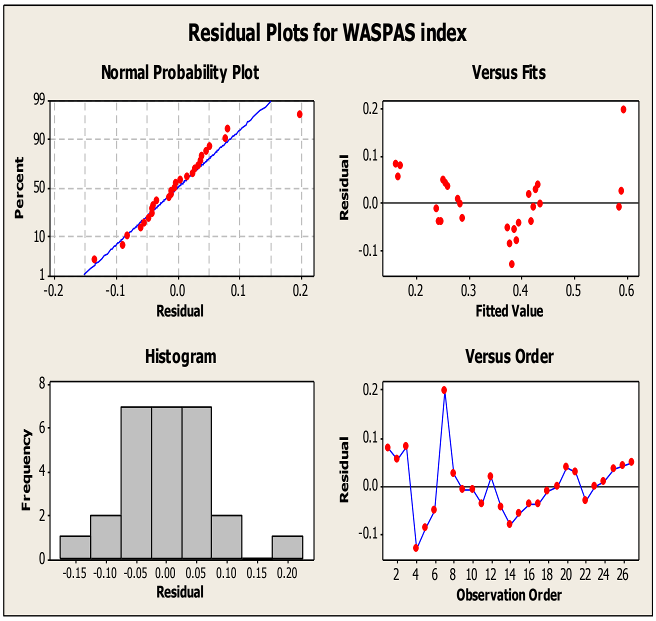

Figure 10: Residual plots for WASPAS index (SPM)

Analysis of variance (ANOVA) is performed and the tabular representation are depicted in Tables 6, Table 7 for Deng's index and WASPAS index respectively.

Table 6: ANOVA for mean values of Deng's index

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F-ratio	Percent contribution
Insert style	2	0.00979	0.00490	6.2367	2.082
Cutting fluid	2	0.02671	0.01336	16.999	5.674
Cutting speed (m/min)	2	0.31333	0.15666	199.414	66.555
Feed mm/rev)	2	0.09570	0.04785	60.909	20.324
Depth of cut (mm)	2	0.01267	0.00634	8.064	2.691
Residual error	16	0.01257	0.00078		2.670
Total	26				100.000

Table 7 ANOVA for mean values of WASPAS index

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F-ratio	Percent contribution
Insert style	2	0.02949	0.01475	7.51506	5.891
Cutting fluid	2	0.04274	0.02137	10.89241	8.539
Cutting speed (m/min)	2	0.26369	0.13184	67.19595	52.676
Feed mm/rev)	2	0.13138	0.06569	33.48076	26.246
Depth of cut (mm)	2	0.00188	0.00094	0.479719	0.376
Residual error	16	0.03139	0.00196		6.273
Total	26				100.000

Verification of experiments

The objective of the prediction at optimum levels is to validate the conclusions drawn during the analysis phase. Once the optimal level of process parameters is selected, the next step is to verify the improvement in response characteristics using optimum level of parameters. A conformity test is conducted using the following equation:

$$\Upsilon = \Upsilon_m + \sum_{i=1}^{n}(\Upsilon_i - \Upsilon_m) \qquad \text{(Eq. 1)}$$

Where,

γ_m = total mean of the required responses.

γ_i = mean of required responses at optimal level.

n = the number of process parameters that significantly affects the multiple performance characteristics.

The confirmatory results and their comparison with predicted values for the two MCDM techniques viz., Deng's method, WASPAS method are presented in Tables 8 and Table 9 respectively.

Confidence interval

Confidence interval is calculated using the formula:

$$\boldsymbol{C.I} = \sqrt{F_{\alpha(1,f_e)}\,V_e\left(\frac{1}{n_{eff}} + \frac{1}{R}\right)} \qquad \text{(Eq. 2)}$$

Where

f_e = Degrees of freedom for error component

F_α = F-ration from table

$F_{\alpha(1,16)}$ = 4.49 (F-ratio at α = 0.05, 95% confidence level)

V_e = Mean square of error component

n_{eff} = N/(1+ total dof) = 27/(1+10) = 2.4545

Estimation of confidence interval for Deng's index

The predicted value of Deng's index at optimum level of process parameters (IS1-CF1-V3-F3-d3)

is calculated from the Eq. 1 and is found to be Y_{DI} = 0.7417. A confidence interval of Deng's index on a confirmation run is computed using the Eq. 2.

The calculated C.I are + or- 0.0702

The 95% confidence interval of the predicted optimal Deng's index is:

Y_{DI} –C.I < DI_{expt} < Y_{DI} +C.I

0.6715 < DI_{expt} < 0.8119

The confirmation test is carried-out at optimal setting gives a value of 0.7587 is well with-in confidence interval and hence the optimal setting of process parameters can be implemented. Further the deviation between predicted and experimental value is found to be very low (about 2.29%) hence accepted

Estimation of confidence interval for WASPAS index

The predicted value of Deng's index at optimum level of process parameters (IS1-CF3-V3-F3-d1) is calculated from the Eq. 1and is found to be Y_{WI} = 0.6723. A confidence interval of Deng's index on a confirmation run is computed using the Eq. 2.

The calculated C.I are + or- 0.1113

The 95% confidence interval of the predicted optimal Deng's index is:

$$Y_{WI} - C.I < WI_{expt} < Y_{WI} + C.I$$

$$0.5610 < WI_{expt} < 0.7836$$

The confirmation test is carried-out at optimal setting gives a value of 0.6819 is well with-in confidence interval and hence the optimal setting of process parameters can be implemented. Further the deviation between predicted and experimental value is found to be very low (about 1.43%) hence accepted

Table 8: Results of Confirmatory experiment for Deng's method

Response characteristics	Initial Factor setting	Optimal cutting parameters	
		Prediction	Experiment
	IS1CF1V1F1d1	IS1CF1V3F3d3	IS1CF1V3F3d3
SR (µm)	0.268	0.800	0.754
MRR (mm^3/sec)	55.190	336.822	345.546
IT (^{O}C)	35.67	37.22	35.52
SE (J/mm^3)	36.445	3.446	3.355
FW (mm)	0.094	0.049	0.045
SPM	0.2861	0.7417	0.7587

Table 9: Results of Confirmatory experiment for WASPAS method

Response characteristics	Initial Factor setting	Optimal cutting parameters	
		Prediction	Experiment
	IS1CF1V1F1d1	IS1CF3V3F3d1	IS1CF3V3F3d1
SR (µm)	0.268	0.183	0.179
MRR (mm^3/sec)	55.190	226.866	233.788
IT (^{O}C)	35.67	35.51	34.25
SE (J/mm^3)	36.445	18.449	17.890
FW (mm)	0.094	0.0109	0.0105
SPM	0.2506	0.6723	0.6819

CONCLUSIONS

In the present paper, two novel MCDM techniques viz., Deng's method and WASPAS method have been employed to obtain the optimal turning parameters that lead to maximum material removal rate, minimum surface roughness, Interface temperature. Specific energy and flank wear. The results obtained from the analysis are depicted as follows

From the confirmation test, it is found that between the two methods selected, WASPAS method yielded best results as the percentage deviation is very low as compared with Deng's method. Also percentage increase of Experimental WASPAS index (SPM) as compared to initial setting is exceptionally high for WASPAS method as compared with Deng's method. Hence the WASPAS method is the best suited method between the two novel MCDM techniques. Since the maximization of material removal rate and minimization of surface roughness, interface temperature, specific energy and flank wear are simultaneously optimized, the optimum process parameters are DNMG insert style, ground nut oil as cutting fluid, a cutting speed of 200 m/min, feed of 0.09 mm/rev and 0.10 mm of depth of cut are recommended. From the ANOVA analysis, the order of controllable cutting parameters is found to be in the sequence of cutting speed, feed, cutting fluid, insert style and depth of cut. The cutting speed is identified as the most significant controlled factor as it has a maximum percentage of contribution (52.676%) followed by feed (26.246%) during turning operation.

From the residual plots, it is evident that the adequacy of the MCDM models are validated and found to be within the accuracy limits.

The confirmation test is carried-out at optimal setting gives experimental Deng's index 0.7587 is well with-in confidence interval and hence the optimal setting of process parameters can be justified.

The confirmation test is carried-out at optimal setting gives experimental WASPAS index of 0.6819 is well with-in confidence interval and hence the optimal setting of process parameters can be justified.

The percentage deviation between experimental Deng's index and predicted Deng's index is 2.29% as also the percentage deviation between experimental WASPAS index and predicted WASPAS index is 1.43% hence it is concluded that the adequacy of the MCDM models can be accepted.

Between two methods, WASPAS method is the best novel method since the percent deviation between predicted and experimental WASPAS index is much lower than that of the deviation between predicted and experimental Deng's index.

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