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An Experimental Investigation towards Multi Objective Optimization during Hard Turning of Tool Steel Using a Novel MCDM Technique

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Abstract

Environmental and Ecological issues call for the reduction in usage of cutting fluids in metal cutting industry. New techniques are being inquired to achieve this objective. Hard turning with minimum quantity lubrication is one such technique which can alleviate the pollution problems associated with cutting fluids. In the present work, vegetable oil based cutting fluids like castor oil, palm oil and ground nut oil is made to drop at tool-work interface using over-head system. The present paper deals with experimental investigation carried out for machinability study of hardened AISI D3 steel in combination with CVD coated cemented carbide inserts of different styles and to obtain optimum process parameters using WASPAS method. An orthogonal array, overall performance index 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 consumption and flank wear. Finally a clear presentation is made for WASPAS method.

Keywords: Hardened AISI D3 steel, CVD coated tool, Surface roughness, Material removal rate, interface temperature, Specific energy consumption, flank wear, ANOVA, Minimum quantity lubrication, WASPAS method.

INTRODUCTION

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 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 to the cutting zone to improve cutting performance. The primary function of cutting fluid is to reduce interface temperature between tool 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, 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, WASPAS approach was performed to combine the multiple performance characteristics in to one numerical score called Overall performance index 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.

LITERATURE REVIEW

W.H.Yang & Y.S Tang [1] envisages that the Taguchi method is a powerful tool to design optimization for quality and is used to find the optimal cutting parameters for turning operations. An orthogonal array , the signal to noise ratios and ANOVA are employed to investigate the cutting characteristics of S45C steel bars using Tungsten carbide cutting tools. Through this study, not only optimal cutting parameters for turning operations obtained, but also the main cutting parameters that affect the cutting performance in turning operations are found.

Shankar Chakraborty et.al [2] presented the the applicability of weighted aggregated sum product assessment (WASPAS) method is explored for parametric optimization of five non traditional machining processes. It is concluded that WASPAS method can be deployed as an effective tool for both single response and multi response optimization of the NTM processes. It is also observed that this method is quite robust.

Shankar Chakraborty and Edmundas Kazimieras Zavadskas [3] depicted the 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. It is observed that this method has the capability of accurately ranking the alternatives in all the considered selection problems.

Madic milos et. al [4] focused on multi-criteria analysis of VCGT cutting inserts for aluminum alloys turning by applying recently developed MCDM method, i.e. weighted aggregated sum product assessment (WASPAS) method. The MCDM model was defined using the available catalogue data from cutting tool manufacturers

Papiya Bhowmik etal [5] 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 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.

Hossein safari and Ehsan Khanmohammadali [7] proposed a new MADM method. This similarity based method effectively makes use of ideal solution concept in such a way that the most preferred alternative should have highest degree of similarity to the positive ideal solution and the lowest degree of similarity to the negative ideal solution. The overall performance index of each alternative with in all criteria is determined based on the concept of degree of similarity between each alternative and the ideal solution using alternative gradient and magnitude.

Madic M et.al [8] focused on multi-criteria economic analysis of various machining processes by applying recently developed MCDM method, i.e. weighted aggregated sum product assessment (WASPAS) method. By using available data from literature MCDM model consisting of eight different machining processes and five economical criteria was defined. In order to determine relative significance of considered criteria a pairwise comparison matrix was applied.

Dinesh kumar kasdekar and Vishal parashar [9] carried out experimentation on EDM using En-353 steel which highlights the application of technique for order preference by similarity to an ideal solution. In this TOPSIS, SAW based MCDM methods are used and conducted study through computational experiments.

Thaman Balgassim etal [10] conducted experimentation on EDM machine using AISI D3 tool steel. An L9 orthogonal array based on Taguchi method is used to conduct a series of experiments to optimize the EDM parameters. Experimental data were evaluated statistically by analysis of Variance(ANOVA). The experimental results have given optimal combination of input parameters which give the optimum surface finish of machined surface

J S Dureja etal [11] investigated tool wear (flank wear) and surface roughness during finish hard turning of AISI D3 steel (58HRC) with coated carbide (TiSiN-TiAlN coated) cutting tool. Taguchi L9 $(3)^3$ orthogonal array has been applied for experimental design. S/N ratio and ANOVA analyses were performed to identify significant parameters influencing tool wear and surface roughness. The cutting speed and feed were the most significant factors influencing tool wear (flank wear), and feed is the most significant factor influencing surface roughness (Ra). Mathematical models for both response parameters i.e. tool wear and surface roughness were obtained through regression analysis. The confirmation experiments carried out at optimal combination of parameters given by Taguchi's analysis, predicted the response factors with less than 5% error. In addition, Desirability function module in RSM was applied to arrive at the optimal setting of input parameters to minimize tool wear and surface roughness. The optimal solution provided by desirability function optimization was compared with the optimal setting of parameters given by Taguchi analysis. The optimization results provided by both techniques are in close proximity.

Varaprasad BH etal [12] developed a model and predict tool flank wear of hard turned AISI D3 hardened steel using Response Surface Methodology (RSM). The combined effects of cutting speed, feed rate and depth of cut are investigated using contour plots and surface plots. RSM based Central Composite Design (CCD) is applied as an experimental design. Al2O3/TiC mixed ceramic tool with corner radius 0.8 mm is employed to accomplish 20 tests with six centre points. The adequacy of the developed models is checked using Analysis of Variance (ANOVA). Main and interaction plots are drawn to study the effect of process parameters on output responses.

Akash saini et. al [13] investigated the influence of approach angle, feed rate, cutting speed and depth of cut has been on cutting forces and tool tip temperature during turning of AISI 4340 steel. Before conducting experiments on the AISI 4340 steel work-piece, the chemical composition test, microstructure test were performed and hardness of the work-piece was improved by heat treatment. A total of 64 experiments each by two different coated carbide inserts (PVD and CVD-coated) were conducted on AISI-4340 steel under different environmental conditions (dry and MQL machining). It is observed that the main cutting force was largest among the three cutting force components in case of AISI 4340 steel turning and MQL machining show beneficial effects compared to dry machining.

From the literature survey, it is evident that little work has been reported on hardened AISI D3 tool steel work with combination of CVD coated tools with different styles. Also little work has been reported on novel MCDM technique-WASPAS approach which is a combination of aggregated sum and product method. Hence the experimentation is done on above said combination of work piece and tool and multi objective optimization technique namely WASPAS method is put forth.

EXPERIMENTATION

In the present study, three 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 hardened AISI D3 steel has been done by chemical Analyzer and is reported as below in Table1.

The process parameters and their corresponding levels are depicted in Table 2. The experimental condition is presented in Table 3.

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

Turning parameters	Level 1	Level 2	Level 3
Insert style (S)	DNMG	TNMG	CNMG
Cutting fluid (CF)	Castor oil	Palm oil	Ground nut oil
Cutting speed, V(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 Experimental condition

Machine used	
Turn master conventional lathe, power: 4 HP	
Work material	
Hardened AISI D3 steel	
Size of work piece	
Diameter 40 mm x 100 mm	
Cutting length	70 mm
Cutting tool holder	
PDJNR 2020M15 WIDAX, MTJNR 2020K16 WIDAX PCLNR 2020K12 V tool	
Cutting insert	
DNMG 150608 EN-TMR CTC 2135 TNMG 160408 EN- TM CTC 2135 CNMG 120408 EN- TMR CTC 2135	
MQL supply	
Castor oil, Palm oil and ground nut oil (500 ml/ hour)	
Cutting parameters:	
Insert style	
DNMG, TNMG and CNMG	
Cutting fluid	
Castor oil(CO), Palm oil(PO) and Ground nut oil (GO)	
Cutting velocity	100-200 mm/min
Feed	0.05-0.09 mm/rev
Depth of cut	1.0-2.0 mm
Response variables measured	
Surface roughness, SR(µm), Material removal rate, MRR(mm^3/sec) Interface temperature(^{0}C), Specific energy, SE (J/mm^3) and flank wear(mm)	

The different styles of CVD coated inserts and the corresponding tool holders are shown in figures 1-4.

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

Figure 2. PDJNR2020M15WIDAX

Figure 3. MTJNR 2020K16 WIDAX

Figure 4. PCLNR 2020K12 V tool

The turning tests were carried out on Kirloskar model centre lathe machine presented in Figures 5-6 to determine the responses characteristics for various runs of experiment.

Figure 5. Kirloskar model Turn master 35 centre lathe

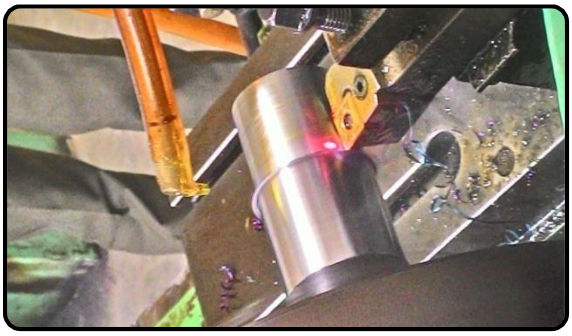

Figure 6. Lubricant dropping on cutting zone

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

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

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

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

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 Ding S and Shi Z [14]. 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. W_{SR},W_{MRR}, W_{Temp}, W_{SE} , W_{FW} are the weights assigned to the Ra, MRR Temp, SE and FW, W_{SR}= 0.191, W_{MRR}= 0.308 W_{Temp}= 0.017, W_{SE} = 0.189 and W_{FW} = 0.295

B. 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:

$$\overline{x_{ij}} = x_{ij}/max_i x_{ij} \tag{1}$$

$$\overline{x_{ij}} = mix_i x_{ij}/x_{ij} \tag{2}$$

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:

$$Q_i^{(1)} = \sum_{j=1}^{n} \overline{x_{ij}} \,.\, w_j \tag{3}$$

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

$$Q_i^{(2)} = \prod_{j=1}^{n} \overline{x_{ij}}^{\,w_j} \tag{4}$$

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:

$$Q_i = \lambda . Q_i^{(1)} + (1-\lambda). Q_i^{(2)} \qquad (5)$$

Where, λ = 0, 0.1… 1.

RESULTS

A series of turning tests were conducted to assess the effect of turning parameters on surface roughness and material removal rate and the results of experimentation are shown in table.3

Table 3: Experimental data and results for 5 parameters, corresponding SR, MRR . TEMP, Specific energy and flank wear for CVD tool

SNo	Insert style	Cutting fluid	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut(mm)	SR (µm)	MRR (mm^3/sec)	TEMP (^OC)	Specific Energy (J/mm^3)	Flank Wear (mm)
1	DNMG	CO	100	0.05	1.0	0.268	55.190	35.67	36.445	0.094
2	DNMG	CO	100	0.05	1.5	0.738	80.909	38.67	26.675	0.106
3	DNMG	CO	100	0.05	2.0	1.113	116.664	40.00	19.441	0.118
4	DNMG	PO	150	0.07	1.0	0.336	73.896	38.67	32.177	0.105
5	DNMG	PO	150	0.07	1.5	0.680	138.459	43.67	18.229	0.109
6	DNMG	PO	150	0.07	2.0	0.854	177.686	45.60	14.823	0.113
7	DNMG	GO	200	0.09	1.0	0.184	206.897	37.00	14.145	0.012
8	DNMG	GO	200	0.09	1.5	0.452	263.404	38.25	11.666	0.023
9	DNMG	GO	200	0.09	2.0	0.596	349.252	39.33	9.112	0.052
10	TNMG	CO	150	0.09	1.0	0.232	126.373	37.40	19.394	0.051
11	TNMG	CO	150	0.09	1.5	0.582	180.543	42.00	14.791	0.068
12	TNMG	CO	150	0.09	2.0	0.682	260.220	44.00	10.824	0.101
13	TNMG	PO	200	0.05	1.0	0.432	114.151	35.60	24.035	0.042
14	TNMG	PO	200	0.05	1.5	0.648	158.305	35.75	18.024	0.109
15	TNMG	PO	200	0.05	2.0	0.878	194.311	46.80	15.249	0.113
16	TNMG	GO	100	0.07	1.0	0.322	44.159	43.20	42.248	0.114
17	TNMG	GO	100	0.07	1.5	0.510	60.537	43.40	32.631	0.118
18	TNMG	GO	100	0.07	2.0	0.568	88.332	47.00	24.848	0.145
19	CNMG	CO	200	0.07	1.0	0.567	146.216	33.00	19.765	0.025
20	CNMG	CO	200	0.07	1.5	0.728	216.592	35.25	14.018	0.033
21	CNMG	CO	200	0.07	2.0	1.047	282.822	35.50	11.123	0.061
22	CNMG	PO	100	0.09	1.0	0.334	76.273	41.00	25.419	0.125
23	CNMG	PO	100	0.09	1.5	0.438	111.533	44.00	19.023	0.131
24	CNMG	PO	100	0.09	2.0	0.690	140.177	52.75	15.926	0.140
25	CNMG	GO	150	0.05	1.0	0.448	61.848	42.00	37.854	0.031
26	CNMG	GO	150	0.05	1.5	0.526	105.896	43.30	23.489	0.063
27	CNMG	GO	150	0.05	2.0	0.700	135.025	44.00	19.235	0.082

Tables 4,5.6,7, and 8 depicts the results related with WASPAS method

Table 4: Normalized decision matrix

SNo	Insert style	Cutting fluid	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut(mm)	Normalized values (f_{ij})				
						SR (µm)	MRR (mm^3/sec)	TEMP (^OC)	Specific Energy (J/mm^3)	Flank Wear (mm)
1	DNMG	CO	100	0.05	1.0	0.686567	0.158023	0.925225	0.250021	0.12766
2	DNMG	CO	100	0.05	1.5	0.249322	0.231664	0.853441	0.341593	0.113208
3	DNMG	CO	100	0.05	2.0	0.165319	0.33404	0.825	0.4687	0.101695
4	DNMG	PO	150	0.07	1.0	0.547619	0.211584	0.853441	0.283184	0.114286
5	DNMG	PO	150	0.07	1.5	0.270588	0.396444	0.755719	0.499863	0.110092
6	DNMG	PO	150	0.07	2.0	0.215457	0.508762	0.723684	0.61472	0.106195
7	DNMG	GO	200	0.09	1.0	1.000000	0.5924	0.891892	0.644185	1.000000
8	DNMG	GO	200	0.09	1.5	0.40708	0.754195	0.862745	0.781073	0.521739
9	DNMG	GO	200	0.09	2.0	0.308725	1.000000	0.83899	1.000000	0.230769
10	TNMG	CO	150	0.09	1.0	0.793103	0.361839	0.882353	0.469836	0.235294
11	TNMG	CO	150	0.09	1.5	0.316151	0.516942	0.785714	0.61605	0.176471
12	TNMG	CO	150	0.09	2.0	0.292994	0.745078	0.75	0.841833	0.118812
13	TNMG	PO	200	0.05	1.0	0.425926	0.326844	0.926966	0.379114	0.285714
14	TNMG	PO	200	0.05	1.5	0.283951	0.453269	0.923077	0.505548	0.110092
15	TNMG	PO	200	0.05	2.0	0.209567	0.556363	0.705128	0.597547	0.106195
16	TNMG	GO	100	0.07	1.0	0.571429	0.126439	0.763889	0.215679	0.105263
17	TNMG	GO	100	0.07	1.5	0.360784	0.173333	0.760369	0.279244	0.101695
18	TNMG	GO	100	0.07	2.0	0.323944	0.252918	0.702128	0.36671	0.082759
19	CNMG	CO	200	0.07	1.0	0.324515	0.418655	1.000000	0.461017	0.48
20	CNMG	CO	200	0.07	1.5	0.252747	0.62016	0.93617	0.650021	0.363636
21	CNMG	CO	200	0.07	2.0	0.17574	0.809794	0.929577	0.819203	0.196721
22	CNMG	PO	100	0.09	1.0	0.550898	0.21839	0.804878	0.358472	0.096
23	CNMG	PO	100	0.09	1.5	0.420091	0.319348	0.743243	0.478999	0.091603
24	CNMG	PO	100	0.09	2.0	0.266667	0.401192	0.625592	0.572146	0.085714
25	CNMG	GO	150	0.05	1.0	0.410714	0.177087	0.785714	0.240714	0.387097
26	CNMG	GO	150	0.05	1.5	0.34981	0.303214	0.762125	0.387926	0.190476
27	CNMG	GO	150	0.05	2.0	0.262857	0.386612	0.75	0.47372	0.146341

Table 5: Ranking of alternatives using WASPAS method

SNo	Insert style	Cutting fluid	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut(mm)	WSM values $\boldsymbol{Q_i^{(1)}}$	WPM values $\boldsymbol{Q_i^{(2)}}$	(**Q**)	Rank
1	DNMG	CO	100	0.05	1.0	0.280448	0.220771	0.250609	21
2	DNMG	CO	100	0.05	1.5	0.231439	0.209273	0.220356	25
3	DNMG	CO	100	0.05	2.0	0.267069	0.222619	0.244844	23
4	DNMG	PO	150	0.07	1.0	0.271507	0.228916	0.250212	22
5	DNMG	PO	150	0.07	1.5	0.313586	0.266774	0.29018	17
6	DNMG	PO	150	0.07	2.0	0.357663	0.283564	0.320613	12
7	DNMG	GO	200	0.09	1.0	0.805372	0.781671	0.793522	1
8	DNMG	GO	200	0.09	1.5	0.626247	0.606724	0.616485	2
9	DNMG	GO	200	0.09	2.0	0.638306	0.516832	0.577569	3
10	TNMG	CO	150	0.09	1.0	0.43614	0.394906	0.415523	8
11	TNMG	CO	150	0.09	1.5	0.401452	0.356817	0.379135	9
12	TNMG	CO	150	0.09	2.0	0.492352	0.371224	0.431788	7
13	TNMG	PO	200	0.05	1.0	0.353717	0.345897	0.349807	10
14	TNMG	PO	200	0.05	1.5	0.337559	0.28214	0.30985	13
15	TNMG	PO	200	0.05	2.0	0.367638	0.288269	0.327954	11
16	TNMG	GO	100	0.07	1.0	0.232888	0.182235	0.207561	26
17	TNMG	GO	100	0.07	1.5	0.218	0.191175	0.204587	27
18	TNMG	GO	100	0.07	2.0	0.24543	0.20817	0.2268	24
19	CNMG	CO	200	0.07	1.0	0.43666	0.429127	0.432894	6
20	CNMG	CO	200	0.07	1.5	0.485326	0.453479	0.469402	4
21	CNMG	CO	200	0.07	2.0	0.511648	0.400247	0.455947	5
22	CNMG	PO	100	0.09	1.0	0.28224	0.229608	0.255924	20
23	CNMG	PO	100	0.09	1.5	0.308786	0.254993	0.281889	19
24	CNMG	PO	100	0.09	2.0	0.318557	0.2536	0.286078	18
25	CNMG	GO	150	0.05	1.0	0.306035	0.284681	0.295358	16
26	CNMG	GO	150	0.05	1.5	0.302668	0.289116	0.295892	15
27	CNMG	GO	150	0.05	2.0	0.314736	0.283387	0.299062	14

Table 6: Response table for WASPAS method

Process parameters	Average WASPAS index(SPM)				
	Level 1	Level 2	Level 3	Max-Min	Rank
Insert style	**0.396043**	0.317001	0.341383	0.079042	4
Cutting fluid	0.366722	0.296945	**0.39076**	0.093815	3
Cutting speed(V)	0.242072	0.330863	**0.481492**	0.23942	1
Feed (F)	0.288192	0.317577	**0.448657**	0.160465	2
Depth of cut(D)	**0.361268**	0.340864	0.352295	0.020404	5
Total mean value of the overall performance index = 0.351476 *****Optimum levels					

Table 7 : ANOVA based on WASPAS method`

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	2	0.26369	0.13184	67.19595		52.676
Feed	2	0.13138	0.06569	33.48076		26.246
Depth of cut	2	0.00188	0.00094	0.479719		0.376
Error	16	0.03139	0.00196			6.273
`	26					100.0000

Prediction at optimum levels

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:

$\gamma = \gamma_m + \sum_{i=1}^{n}(\gamma i - \gamma m)$, where γm is total mean of the required responses

γj is the mean of the required responses at optimum level

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

Table 8: Comparison of predicted and Experimental results using WASPAS method

	Optimum process parameters		
	Initial process parameters	Predicted values	Experimental values
Level of parameters setting	S1-CF1-V1-F1-D1	S1-CF3-V3-F3-D1	S1-CF3-V3-F3-D1
Surface roughness (µm)	0.268	0.183	0.179
MRR (mm^3/sec)	55.190	226.866	233.788
Interface temperature(^{0}C)	35.67	35.505	34.249
Specific energy(J/mm^3)	36.445	18.449	17.890
Flank wear(mm)	0.094	0.0109	0.0105
Single performance measure	0.25060	0.67231	0.68198

CONCLUSIONS

1. The optimal parameters setting lies at DNMG insert style, Ground nut oil cutting fluid, 200 m/min cutting speed, 0.09 mm/rev and 1.0 mm depth of cut. The optimum predicted value for surface roughness is 0.183 µm, MRR 226.866 mm^3/sec, interface temperature 35.505 ^{0}C, specific energy 18.449 J/mm^3, flank wear 0.0109 mm and performance index is 0.67232. Also the experimental value for surface roughness is 0.179 µm, MRR is 233.788 mm^3/sec, interface temperature 34.249 ^{0}C, specific energy 17.890 J/mm^3, flank wear 0.105 mm and performance index is 0.68198.
2. It is found that both predicted and experimental response characteristics are significantly better as compared to initial machining parameters. To be specific predicted MRR (226.866 mm^3/sec) and experimental MRR(233.788 mm^3/sec) are much higher as compared to MRR at initial setting level which paves way for higher productivity. Also predicted specific energy (18.449 J/mm^3) and experimental specific energy(17.890 J/mm^3) are much lower than initial setting which is highly expected for reduced machine vibration as also reduced power consumption .Also predicted flank wear (0.0109 mm) and experimental flank wear (0.0105 mm) are much lower than initial setting which is commendable for increased tool life which is desirable. It may be noted that there is a good agreement between the predicted single performance measure (0.6723) and experimental single performance measure (0.6819) and therefore the condition **S1-CF3-V3-F3-D1** of process parameters combination was tested as optimal. Further significant improvement in machinability is observed and measured that there is substantial improvement in MRR (both Experimental value and predicted) and effective improvement in specific energy (Experimental value and predicted value) as compared with initial machining parameters. This encourages applying WASPAS approach for optimizing multi response problems.

3. Further, from Analysis of variance (ANOVA) depicts that cutting speed is the most significant parameter followed by feed affecting multi response characteristics with cutting speed 52.676%, feed 26.246% ,cutting fluid 8.539% , insert style 5.891% and depth of cut almost negligible.

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