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RESEARCH ARTICLE

TOPSIS BASED OPTIMIZATION OF PROCESS PARAMETERS WHILE HARD TURNING OF AISI 52100 STEEL

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ARTICLE DETAILS

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ABSTRACT

In the present work optimization of machining parameters is performed by employing Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) while AISI 52100 steel hard turning with polycrystalline cubic boron nitride (PCBN) tools. Based on Central Composite Design (CCD) of Response Surface Method (RSM) experiments are planned and conducted. Experiments were accomplished by varying machining parameters such as cutting speed, feed, depth of cut, nose radius and negative rake angle. In this study surface roughness and workpiece surface temperature are measured during experiment. To determine the influence of cutting parameters, Analysis of variance (ANOVA) was deployed. Optimal turning parameters are cutting speed 200 rpm, feed 0.1 mm/rev, depth of cut 0.7 mm, nose radius 1.2 mm and negative rake angle 45º.

KEYWORDS

surface roughness, workpiece surface temperature, TOPSIS, Optimization, ANOVA.

1. INTRODUCTION

Hard turning became a viable process in contrast to grinding due to its large benefits such as high accuracy, shorter setup time, fewer process steps, and absence of cutting fluid, etc [1-2]. To control the surface roughness, the cutting time, tool life, to avoid high levels of tool vibrations and cutting forces, the selection of optimal cutting parameters is very essential. Multi response optimization of hard turning parameters was accomplished by using the TOPSIS approach. Palanisamy and Selvaraj [3] optimized the process parameters in turning of INCOLOY 800H, with cryogenically treated multi-layer coated tools. Results revealed that the feed rate was the most crucial parameter followed by cutting speed and depth of cut. Himadri Majumder and Abhijit Saha optimized process parameters in turning of ASTM A588 mild steel using hybrid optimization tool i.e. MOORA-PCA and TOPSIS-PCA approach [4]. Tian Syung Lan used TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) for optimization of input parameters in CNC machining of S45C steel [5]. Ankita Singh et al. adopted the TOPSIS concept combined with the Taguchi method to optimize multiple surface roughness parameters of machined GFRP polyester composites [6]. Results showed that feed rate is the most significant factor influencing MPCIs followed by the depth of cut and spindle speed. Suneel and Srinivasa Rao performed optimization using GRA and TOPSIS in turning of AISI 52100 steel [7]. Results revealed that feed is the significant parameter affecting surface roughness followed by cutting speed, nose radius, and rake angle.

Ananthakumar et al. determined the optimum cutting conditions in plasma arc cutting of Monel 400 superalloy employing TOPSIS [8]. Akhtar Khan and Kalipada Maity employed fuzzy and TOPSIS for determining optimal combination of process parameters while turning of commercially pure titanium [9]. Process parameters optimization was done by using various techniques like GRA-PCA, GA, ANN [10-15]. In solving Multi Criteria Decision Making (MCDM) problems TOPSIS was reported to be more efficient due to less computational time, easily understandable and simple [16-17]. Hence, the TOPSIS was employed for present work to optimize machining parameters for AISI 52100 steel hard turning.

2. EXPERIMENTAL DETAILS

Machining details and experimental matrix with responses are shown in Table 1 & Table 2 respectively. In the current study, Kirloskar Turn master-35 type lathe was employed for conducting experiments in dry condition and AISI 52100 steel was deployed as workpiece having a diameter of 48 mm and length of 500 mm. For this experimentation, five process variables are chosen such as cutting speed, feed, depth of cut, nose radius and negative rake angles. The Experimental setup is shown in Fig. 1. PCBN inserts are given in Fig. 2.

Table 1: Machining details

Machining condition	Notation	Description
Workpiece material		AISI 52100 steel
Dimensions		48 mm diameter and 500 mm length
Hardness		57 HRC
Cutting speed (rpm)	ν	200, 400, 600, 800, 1000 rpm
Feed (mm/rev)	f	0.02, 0.04, 0.06, 0.08, 0.1 mm/rev
Depth of cut (mm)	d	0.4, 0.5, 0.6, 0.7, 0.8 mm
Nose radius	r	0.4, 0.6, 0.8, 1, 1.2 mm
Negative rake angle	α	-5, -15, -25,-35,-45
Cutting environment		Dry
Cutting inserts		Polycrystalline cubic boron nitride (PCBN)
Tool holder		PSBNR 2525 M12
Tool geometry		CNMG120404, CNMG120406, CNMG120410, CNMG120412
Machining length		30 mm
Responses	R_a WST	surface roughness Workpiece surface temperature

Figure 1: Experimental setup

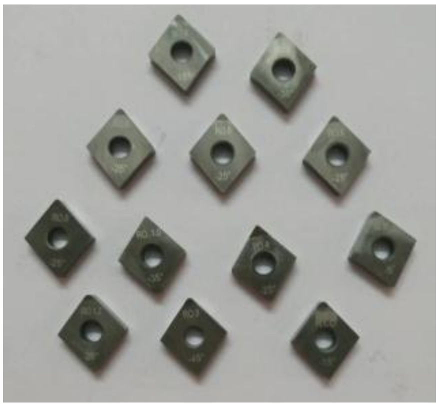

Figure 2: PCBN inserts

Table 2: Experimental matrix with responses

Exp. No	ν (rpm)	f (mm/rev)	d (mm)	r (mm)	α (º)	R_a (μm)	WST (ºC)
1	400	0.04	0.5	0.6	35	0.525	57.43
2	800	0.04	0.5	0.6	15	0.465	74.4
3	400	0.08	0.5	0.6	15	0.453	65.19
4	800	0.08	0.5	0.6	35	0.545	77.68
5	400	0.04	0.7	0.6	15	0.552	71.96
6	800	0.04	0.7	0.6	35	0.507	82.88
7	400	0.08	0.7	0.6	35	0.539	70.27
8	800	0.08	0.7	0.6	15	0.471	65.48
9	400	0.04	0.5	1	15	0.485	66.3
10	800	0.04	0.5	1	35	0.401	66.3
11	400	0.08	0.5	1	35	0.507	84.38
12	800	0.08	0.5	1	15	0.502	80.11
13	400	0.04	0.7	1	35	0.508	67.07
14	800	0.04	0.7	1	15	0.408	80.3
15	400	0.08	0.7	1	15	0.604	68.76
16	800	0.08	0.7	1	35	0.498	76.5
17	200	0.06	0.6	0.8	25	0.559	66.61
18	1000	0.06	0.6	0.8	25	0.456	82.73
19	600	0.02	0.6	0.8	25	0.468	70.85
20	600	0.1	0.6	0.8	25	0.53	74.88
21	600	0.06	0.4	0.8	25	0.45	71.39
22	600	0.06	0.8	0.8	25	0.48	74.2
23	600	0.06	0.6	0.4	25	0.514	67.18
24	600	0.06	0.6	1.2	25	0.485	76.05
25	600	0.06	0.6	0.8	5	0.484	70.32
26	600	0.06	0.6	0.8	45	0.509	73.68
27	600	0.06	0.6	0.8	25	0.507	68.6
28	600	0.06	0.6	0.8	25	0.518	74.94
29	600	0.06	0.6	0.8	25	0.52	71.41
30	600	0.06	0.6	0.8	25	0.512	66.36
31	600	0.06	0.6	0.8	25	0.488	76
32	600	0.06	0.6	0.8	25	0.522	69

Table 3: Normalized and weighted normalised value

Exp. No	Normalized value		Weighted Normalized value	
	Surface Roughness	WST	Surface Roughness	WST
1	0.185324	0.140203	0.092662	0.070101
2	0.164144	0.181632	0.082072	0.090815
3	0.159908	0.159148	0.079954	0.079573
4	0.192384	0.189639	0.096192	0.094819
5	0.194855	0.175675	0.097427	0.087837
6	0.178970	0.202334	0.089485	0.101166
7	0.190266	0.171549	0.095133	0.085774
8	0.166262	0.159856	0.083131	0.079927
9	0.171204	0.161857	0.085602	0.080928
10	0.141552	0.161857	0.070776	0.080928
11	0.178970	0.205996	0.089485	0.102997
12	0.177205	0.195572	0.088602	0.097785
13	0.179323	0.163737	0.089661	0.081868
14	0.144023	0.196035	0.072011	0.098017
15	0.213211	0.167863	0.106605	0.083931
16	0.175793	0.186759	0.087896	0.093379
17	0.197326	0.162614	0.098663	0.081307
18	0.160967	0.201968	0.080483	0.100983
19	0.165203	0.172965	0.082601	0.086482
20	0.187089	0.182804	0.093544	0.091401
21	0.158849	0.174284	0.079424	0.087141
22	0.169439	0.181144	0.084719	0.090571
23	0.181441	0.164006	0.090720	0.082002
24	0.171204	0.18566	0.085602	0.092829
25	0.170851	0.171671	0.085425	0.085835
26	0.179676	0.179874	0.089838	0.089937
27	0.178970	0.167472	0.089485	0.083736
28	0.182853	0.18295	0.091426	0.091475
29	0.183559	0.174332	0.091779	0.087166
30	0.180735	0.162004	0.090367	0.081001
31	0.172263	0.185538	0.086131	0.092768
32	0.184265	0.168449	0.092132	0.084224

3. TECHNIQUE FOR ORDER PREFERENCE BY SIMILARITY TO IDEAL SOLUTION (TOPSIS)

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) was developed by Hwang and Yoon based on the concept that the chosen parameter should have the shortest distance from the best solution and the longest distance from the worst solution [18]. Normalized and weighted normalized values are shown in Table 3. Positive ideal, Negative ideal solutions, separation measures, closeness coefficient values, and rank are depicted in Table 4.

The normalized value (r_{ij}) is obtained using the equation (1).

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^{2}}} \quad i = 1,2,3\ldots\ldots32;\ j = 1,2,3 \tag{1}$$

By multiplying the normalized value with related weights the weighted normalized value (v_{ij}) is calculated and is shown in equation (2),

$$v_{ij} = w_j * r_{ij} \quad i = 1,2,3\ldots32;\ j = 1,2,3 \tag{2}$$

Then the positive ideal solution (S^+) and negative ideal solution (S^-) calculated using equation (3),

$$S^+ = \{(\mathrm{Max}\ (v_{ij}) \mid j \in J), (\mathrm{Min}\ (v_{ij}) \mid j \in J') \mid i=1,2\ldots32\}$$
$$S^- = \{(\mathrm{Min}\ (v_{ij}) \mid j \in J), (\mathrm{Max}\ (v_{ij}) \mid j \in J') \mid i=1,2\ldots32\} \tag{3}$$

The separation of each alternative from positive ideal solution (S^+) and negative ideal solution (S^-) is found as per equation (4) and equation (5),

$$D_i^+ = \sqrt{\sum_{i=1}^{32} \left(v_{ij} - s_j^+\right)^2} \quad i = 1,2\ldots32 \tag{4}$$

$$D_i^- = \sqrt{\sum_{i=1}^{32} \left(v_{ij} - s_j^-\right)^2} \quad j = 1,2,3 \tag{5}$$

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The closeness coefficient value of each alternative (C_i) is calculated using equation (6),

$$C_i = \frac{D_i^-}{D_i^- + D_i^+} \tag{6}$$

Table 4: Separation measures, Closeness coefficient values and rank

Exp. No	PIS	NIS	D_i^+	D_i^-	C_i	Rank
1	0.0926	0.0701	0.0357	0.0218	0.3797	27
2	0.0820	0.0908	0.0273	0.0235	0.4627	21
3	0.0799	0.0795	0.0354	0.0131	0.2709	31
4	0.0961	0.0948	0.0132	0.0354	**0.7280**	1
5	0.0974	0.0878	0.0177	0.0320	0.6436	5
6	0.0894	0.1011	0.0172	0.0362	0.6779	3
7	0.0951	0.0857	0.0206	0.0289	0.5831	9
8	0.0831	0.0799	0.0329	0.0157	0.3240	30
9	0.0856	0.0809	0.0304	0.0183	0.3759	29
10	0.0707	0.0809	0.0420	0.0108	0.2046	32
11	0.0894	0.1030	0.0171	0.0378	0.6884	2
12	0.0886	0.0977	0.0187	0.0329	0.6372	7
13	0.0896	0.0818	0.0270	0.0222	0.4509	22
14	0.0720	0.0980	0.0349	0.0279	0.4442	24
15	0.1066	0.0839	0.0190	0.0384	0.6682	4
16	0.0879	0.0933	0.0210	0.0288	0.5786	10
17	0.0986	0.0813	0.0231	0.0300	0.5653	11
18	0.0804	0.1009	0.0262	0.0323	0.5526	14
19	0.0826	0.0864	0.0291	0.0202	0.4094	26
20	0.0935	0.0914	0.0174	0.0311	0.6408	6
21	0.0794	0.0871	0.0314	0.0191	0.3777	28
22	0.0847	0.0905	0.0251	0.0247	0.4959	18
23	0.0907	0.0820	0.0263	0.0232	0.4686	20
24	0.0856	0.0928	0.0233	0.0271	0.5376	16
25	0.0854	0.0858	0.0272	0.0214	0.4408	25
26	0.0898	0.0899	0.0212	0.0275	0.5640	12
27	0.0894	0.0837	0.0257	0.0231	0.4731	19
28	0.0914	0.0914	0.0190	0.0297	0.6092	8
29	0.0917	0.0871	0.0216	0.0270	0.5550	13
30	0.0903	0.0810	0.0273	0.0224	0.4504	23
31	0.0861	0.0927	0.0228	0.0273	0.5446	15
32	0.0921	0.08422	0.02379	0.0256	0.5191	17

4. RESULTS AND DISCUSSION

From the main effects plot (shown in Fig. 3.) optimum parameters were identified at speed 200 rpm, feed 0.1 mm/rev, depth of cut 0.7 mm, nose radius 1.2 mm and negative rake angle 45º. Exp. No Vs closeness coefficient is depicted in Fig. 4. In the response table (Table 5) it can be seen that feed has been assigned a rank 1 which means it is the most considerable parameter in controlling the response followed by the depth of cut, Negative rake angle, nose radius and cutting speed.

Table 5: Mean response table for Closeness Coefficient

Level	Factor				
	ν	f	d	r	α
1	**0.56536**	0.40942	0.37778	0.46863	0.44085
2	0.50764	0.45499	0.46846	0.50879	0.47837
3	0.50620	0.51104	0.52365	0.51419	0.51428
4	0.50719	0.55984	**0.54637**	0.50604	0.53646
5	0.55265	**0.64087**	0.49594	**0.5376**	**0.56407**
Max-Min	0.05915	0.23145	0.16858	0.06896	0.12322
Rank	5	1	2	4	3

The higher value of closeness coefficient indicates better performance. From Table 4, it is evident that the experiment number 4 has attained the maximum value of closeness coefficient among the 32 number of experiments and the optimum condition to achieve the multiple performance characteristics (cutting speed = 200 rpm, feed rate = 0.1 mm/rev, depth of cut = 0.7 mm, nose radius = 1.2 mm and negative rake angle = 45º). From Table 4, it is evident that the experiment number 4 was the better performer. The order of the experimental run obtained by TOPSIS was given by 4-11-6-15-5-20-12-28-7-16-17-26-29-18-31-24-32-22-27-23-2-13-30-14-25-19-1-21-9-8-3-10.

From the ANOVA table (Table 6) nose radius (43.18%) has major influence on responses followed by depth of cut (35.63%), Feed (14.95%), negative rake angle (1.73%), and speed (1.072 %). Closeness coefficient for the obtained optimum combination of parameters was 0.813836 estimated from Eq. 7 and was 11.79% higher than the maximum closeness coefficient corresponding to rank 1 in Table 4. Hence the values obtained were optimum.

$$\gamma = \gamma_m + \sum_{i=1}^{q} (\overline{\gamma_j} - \gamma_m) \tag{7}$$

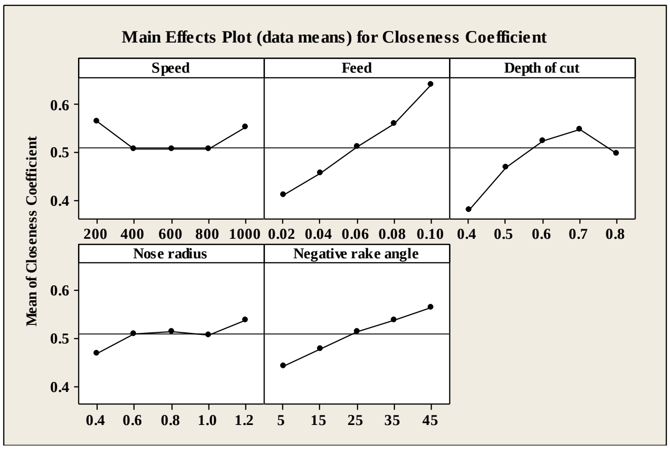

Figure 3: Main effects plot

Table 6: ANOVA for Closeness Coefficient

Source	DF	SS	MS	% Contribution
Speed	4	0.0052	0.0013	1.072
Feed	4	0.0725	0.0181	14.95
Depth of cut	6	0.1727	0.0288	35.63
Nose radius	10	0.2093	0.0209	43.18
Negative rake angle	2	0.0084	0.0042	1.73
Error	5	0.0167	0.0033	3.4
Total	31	0.4847		

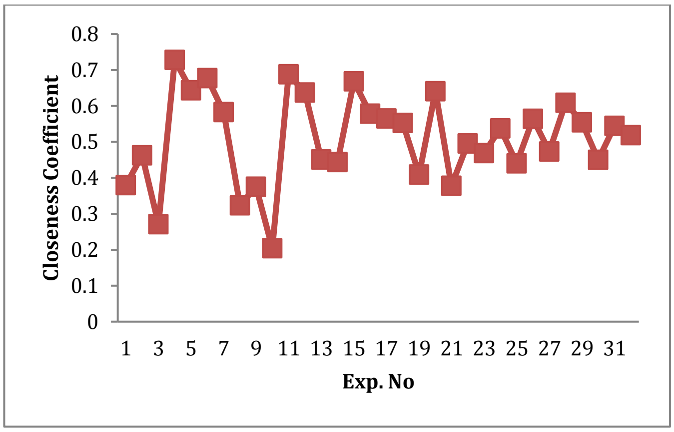

Figure 4: Exp. No Vs Closeness coefficient

5. CONCLUSIONS

In the current study, optimal settings of cutting parameters were found while turning of hardened AISI 52100 steel using PCBN inserts and following conclusions are drawn.

- The feed is the most momentous parameter in controlling the response followed by the depth of cut, negative rake angle, nose radius and cutting speed.
- From the ANOVA nose radius (43.18%) has significant influence followed by depth of cut (35.63%), feed (14.95%), negative rake angle (1.73%) and speed (1.07%)
- It is clear from results of TOPSIS experiment number 4 has the highest closeness coefficient value. Thus the optimal parametric combinations are at speed 200 rpm, feed 0.1 mm/rev, depth of cut 0.7 mm, nose radius 1.2 mm and negative rake angle 45º.
- From the values of closeness coefficient, the machining parameters best combination can be arranged in the order 4-11-6-15-5-20-12-28-7-16-17-26-29-18-31-24-32-22-27-23-2-13-30-14-25-19-1-21-9-8-3-10 respectively.
- An enhancement of 11.79% of predicted weighted closeness coefficient confirms the optimality of obtained results.

NOMENCLATURE

ν	cutting speed
f	feed
d	depth of cut
r	nose radius
α	Negative rake angle
Ra	Surface roughness
C_i	Closeness coefficient
γ_m	Total mean of closeness coefficient
$\overline{\gamma_j}$	Mean of closeness coefficient at the optimal level
DF	Degrees of Freedom
SS	Sum of squares
MS	Mean squares
GA	Genetic algorithm
ANN	Artificial neural network
RSM	Response Surface Method
GRA	Grey relational analysis
PCA	Principle component analysis
CCD	Central Composite Design
PIS	Positive ideal solution
NIS	Negative ideal solution
WST	Workpiece surface temperature
ANOVA	Analysis of variance
PCBN	Polycrystalline cubic boron nitride
MOORA	Multi-objective optimization on the basis of ratio analysis
MCDM	Multi criteria decision making
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution

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