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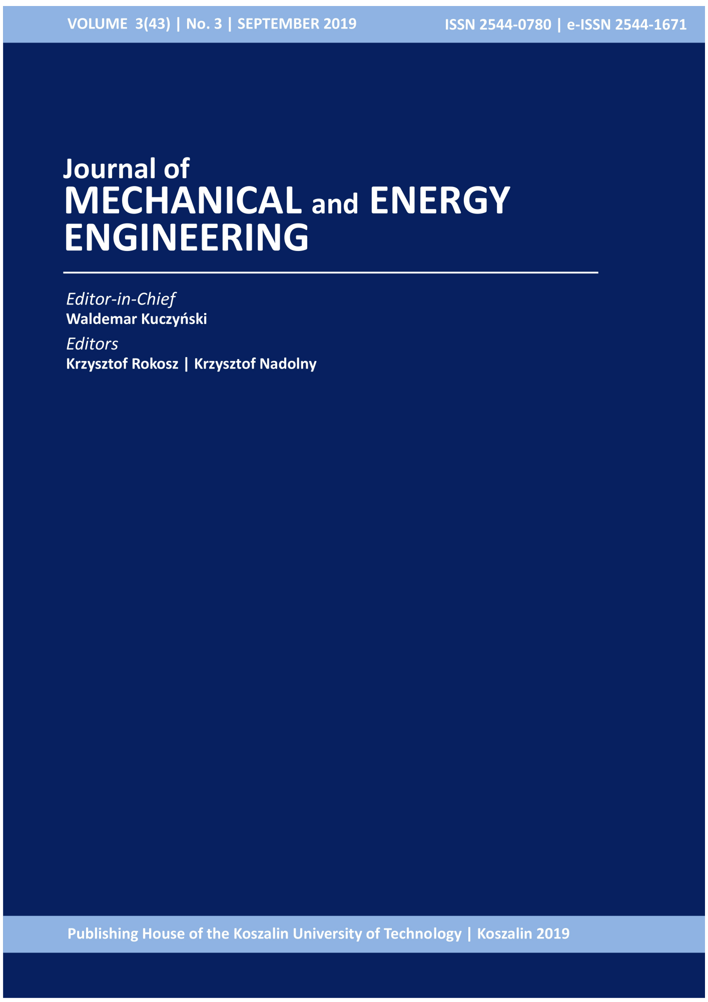

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OPTIMIZING CUTTING PARAMETERS IN HARD TURNING OF AISI 52100 STEEL USING TOPSIS APPROACH

Ponugoti UMAMAHESWARRAO[1*, 2], D. RANGA RAJU[3], Koka Naga Sai SUMAN[4], B. RAVI SANKAR[5]

[1*] Research Scholar, Department of Mechanical Engineering, Andhra University College of Engineering, Visakhapatnam, A.P. India, e-mail: maheshponugoti@gmail.com
[2] Department of Mechanical Engineering, Bapatla Engineering College, Bapatla, A.P. India
[3] Department of Mechanical Engineering, Srinivasa Institute of Engineering and Technology, Amalapuram, A.P. India
[4] Department of Mechanical Engineering, Andhra University College of Engineering, Visakhapatnam, A.P. India
[5] Department of Mechanical Engineering, Bapatla Engineering College, Bapatla, A.P. India

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Abstract: In the present work optimization of cutting parameters is performed while hard turning of AISI 52100 steel with polycrystalline cubic boron nitride (PCBN) tools using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Experiments are planned and conducted based on Center Composite Rotatable Design (CCD) of the Response Surface Method (RSM). Cutting speed, feed, depth of cut, nose radius and negative rake angle are considered as input parameters. In this study machining force (F) and surface roughness (Ra) are measured during the experiment. Analysis of variance (ANOVA) is deployed to determine the influence of process parameters. Obtained optimal parameters are speed 200 rpm, feed 0.1 mm/rev, depth of cut 0.8 mm, nose radius 1.2 mm and negative rake angle 45º.

Keywords: machining force, surface roughness, TOPSIS, optimization

1. INTRODUCTION

Hard turning evolved as an improved machining process incontrast to grinding due to numerous merits such as process flexibility, economic, less setup time, complex parts fabrication and absence of coolant [1-2]. AISI 52100 steel was widely accepted material for abundant applications such as bearings, rollers, and dies etc and the turning process was inevitable for the aforementioned applications. Optimal process parameters selection was essential for higher-order machining performance, Multi criteria decision making methods (MCDM) were proved as tools in several manufacturing applications [3]. Among many TOPSIS method was adopted and gained acceptance for optimizing machining parameters [4].

Himadri Majumder and Abhijit Saha [5] optimized process parameters in turning of ASTM A588 mild steel using a hybrid optimization tool i.e. MOORA-PCA and TOPSIS-PCA approach. Tian [6] used TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) for optimization of input parameters in CNC machining of S45C steel. Palanisamy and Senthil [7] carried out of process parameters optimization in turning of 15-5 PH stainless steel using Taguchi based Grey approach and TOPSIS. It is concluded that force and surface roughness are predominantly affected by feed rate.

Maheswararao and Venkata subbaiah [8] employed TOPSIS for optimization of process parameters in the CNC machining of AA7075. Results concluded that feed rate has a significant influence on responses. Sagar Bhise et al. [9] studied the effect of input parameters on surface roughness in hard turning of M42 austenitic stainless steel using CBN and carbide inserts by deploying PCR-TOPSIS. Maity and Khan [10] determined an optimal combination of process parameters during turning of commercially pure titanium (CP-Ti) grade 2 using the MCDM-based TOPSIS method.

Singaravel et al. [11] optimized machining parameters and nose radius in turning of EN25 steel by the application of combined MOORA and entropy measurement method. Singaravel et al. [12] determined optimum process parameters using the Additive Ratio Assessment (ARAS) method in turning of AISI 4340 steel. Optimization of process parameters is performed using various techniques like GRA-PCA [13-15], GA [16], ANN [17], TOPSIS [18-19]. Hence, the present work aimed to optimize process parameters for AISI 52100 steel hard turning using TOPSIS.

2. EXPERIMENTAL DETAILS

Machining details and experimental matrix with responses are shown in Table 1 and Table 2 respectively. The experimental setup is depicted in Figure 1. 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 a 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. PCBN tools with designation (CNMG 120404, CNMG 120406, CNMG 120408, CNMG 120410, CNMG 120412) manufactured by Zen Diamond Tools, Chennai, India are depicted in Figure 2.

Tab. 1 Machining Conditions

Designation	Notation	Adopted for the present study
Workpiece material		AISI 52100 steel
Dimensions		48 mm diameter and 500 mm length
Hardness		57 HRC
Cutting speed (rpm)	*v*	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	F_m *Ra*	Machining force, Arithmetic mean roughness

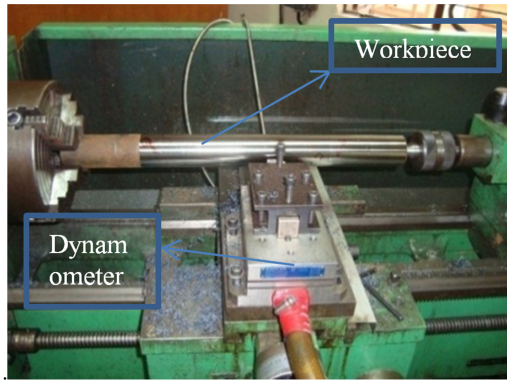

Fig. 1. Experimental setup

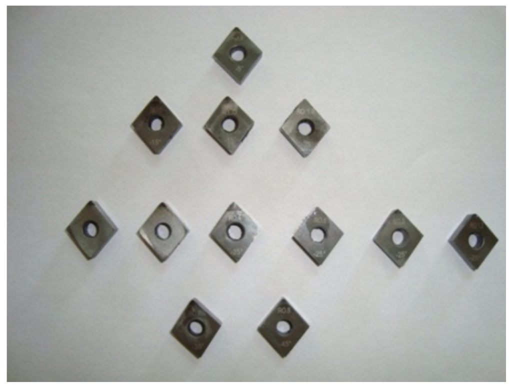

Fig. 2. PCBN tools

3. TECHNIQUE FOR ORDER OF 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 [20]. Normalized and weighted normalised values are shown in Table 3. Positive ideal, Negative ideal solutions, separation measures, closeness coefficient values, and rank are given in Table 4.

3.1. Step 1

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

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \quad i = 1,2,3......32;\ j = 1,2,3. \qquad (1)$$

3.2. Step 2

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

$$v_{ij} = w_j * r_{ij} \quad i= 1,2,3...32;\ j=1,2,3. \qquad (2)$$

3.3. Step 3

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

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

3.4. Step 4

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

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

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

3.5. Step 5

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

$$C_i = \frac{D_i^-}{D_i^- + D_i^+}. \quad (6)$$

Tab. 2 Experimental matrix with responses

Exp. No	*v*	*f*	*d* (mm)	*r* (mm)	*α* (º)	F_m (N)	*Ra* (µm)
1	400	0.04	0.5	0.6	35	404.7	0.52
2	800	0.04	0.5	0.6	15	233.4	0.46
3	400	0.08	0.5	0.6	15	322.1	0.45
4	800	0.08	0.5	0.6	35	473.0	0.54
5	400	0.04	0.7	0.6	15	317.4	0.55
6	800	0.04	0.7	0.6	35	376.3	0.50
7	400	0.08	0.7	0.6	35	583.0	0.53
8	800	0.08	0.7	0.6	15	380.4	0.47
9	400	0.04	0.5	1	15	273.5	0.48
10	800	0.04	0.5	1	35	425.4	0.40
11	400	0.08	0.5	1	35	561.1	0.50
12	800	0.08	0.5	1	15	350.2	0.50
13	400	0.04	0.7	1	35	443.7	0.50
14	800	0.04	0.7	1	15	323.6	0.40
15	400	0.08	0.7	1	15	411.7	0.60
16	800	0.08	0.7	1	35	523.3	0.49
17	200	0.06	0.6	0.8	25	430.8	0.55
18	1000	0.06	0.6	0.8	25	355.4	0.45
19	600	0.02	0.6	0.8	25	309.5	0.46
20	600	0.1	0.6	0.8	25	534.4	0.53
21	600	0.06	0.4	0.8	25	344.4	0.45
22	600	0.06	0.8	0.8	25	449.2	0.48
23	600	0.06	0.6	0.4	25	359.3	0.51
24	600	0.06	0.6	1.2	25	446.2	0.48
25	600	0.06	0.6	0.8	5	279.9	0.48
26	600	0.06	0.6	0.8	45	601.2	0.50
27	600	0.06	0.6	0.8	25	358.5	0.50
28	600	0.06	0.6	0.8	25	370.7	0.51
29	600	0.06	0.6	0.8	25	378.5	0.52
30	600	0.06	0.6	0.8	25	403.9	0.51
31	600	0.06	0.6	0.8	25	380.2	0.48
32	600	0.06	0.6	0.8	25	370.6	0.52

Tab. 3 Normalized and weighted normalised value

Exp. No	Normalized value		Weighted Normalized value	
	Machining Force	Surface Roughness	Machining Force	Surface Roughness
1	0.17501	0.18532	0.08750	0.09266
2	0.10095	0.16414	0.05047	0.08207
3	0.13928	0.15991	0.06964	0.07995
4	0.20454	0.19238	0.10227	0.09619
5	0.13728	0.19486	0.06864	0.09743
6	0.16275	0.17897	0.08137	0.08948
7	0.25211	0.19027	0.12605	0.09513
8	0.16449	0.16626	0.08224	0.08313
9	0.11830	0.17120	0.05915	0.08560
10	0.18397	0.14155	0.09198	0.07077
11	0.24265	0.17897	0.12132	0.08948
12	0.15146	0.17720	0.07573	0.08860
13	0.19189	0.17932	0.09594	0.08966
14	0.13993	0.14402	0.06996	0.07201
15	0.17806	0.21321	0.08903	0.10660
16	0.22631	0.17579	0.11315	0.08789
17	0.18629	0.19733	0.09314	0.09866
18	0.15369	0.16097	0.07684	0.08048
19	0.13387	0.16520	0.06693	0.08260
20	0.23111	0.18709	0.11555	0.09354
21	0.14893	0.15885	0.07446	0.07942
22	0.19424	0.16944	0.09712	0.08472
23	0.15540	0.18144	0.07770	0.09072
24	0.19295	0.17120	0.09647	0.08560
25	0.12105	0.17085	0.06052	0.08542
26	0.26000	0.17968	0.13000	0.08984
27	0.15503	0.17897	0.07751	0.08948
28	0.16031	0.18285	0.08015	0.09142
29	0.16367	0.18356	0.08183	0.09178
30	0.17468	0.18073	0.08734	0.09036
31	0.16442	0.17226	0.08221	0.08613
32	0.16027	0.18426	0.08013	0.09213

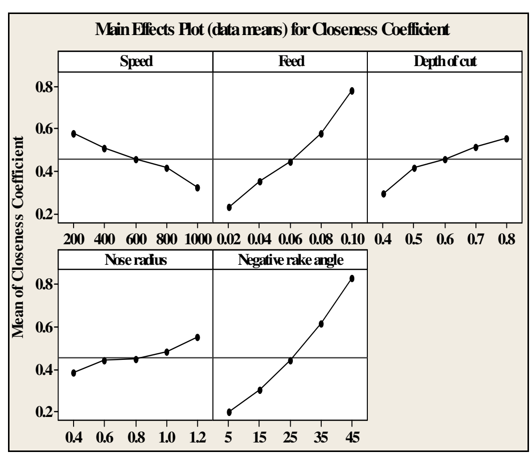

Fig. 3. Main effects plot

Tab. 4 Separation measures, Closeness coefficient values and rank

Exp. No	PIS	NIS	D_i^+	D_i^-	C_i	Rank
1	0.08	0.09	0.04	0.04	0.490	12
2	0.05	0.08	0.08	0.01	0.119	32
3	0.07	0.08	0.06	0.02	0.244	27
4	0.10	0.09	0.03	0.05	0.661	6
5	0.06	0.09	0.06	0.03	0.342	24
6	0.08	0.08	0.05	0.03	0.412	17
7	0.12	0.09	0.01	0.07	0.867	1
8	0.08	0.08	0.05	0.03	0.390	20
9	0.05	0.08	0.07	0.01	0.189	31
10	0.09	0.07	0.05	0.04	0.443	14
11	0.12	0.08	0.01	0.07	0.792	3
12	0.07	0.08	0.05	0.03	0.351	23
13	0.09	0.09	0.03	0.04	0.564	8
14	0.07	0.07	0.06	0.02	0.220	29
15	0.08	0.10	0.04	0.05	0.562	9
16	0.11	0.08	0.02	0.06	0.721	5
17	0.09	0.09	0.03	0.05	0.575	7
18	0.07	0.08	0.05	0.02	0.322	25
19	0.06	0.08	0.06	0.02	0.231	28
20	0.11	0.09	0.01	0.06	0.780	4
21	0.07	0.07	0.06	0.02	0.292	26
22	0.09	0.08	0.03	0.04	0.552	10
23	0.07	0.09	0.05	0.03	0.382	21
24	0.09	0.08	0.04	0.04	0.550	11
25	0.06	0.08	0.07	0.01	0.197	30
26	0.13	0.09	0.01	0.08	0.830	2
27	0.07	0.08	0.05	0.03	0.373	22
28	0.08	0.09	0.05	0.03	0.410	18
29	0.08	0.09	0.05	0.03	0.428	15
30	0.08	0.09	0.04	0.04	0.478	13
31	0.08	0.08	0.05	0.03	0.404	19
32	0.08	0.09	0.05	0.03	0.413	16

Tab. 5 Mean response table for Closeness Coefficient

Level	Factor				
	ν	f	d	r	α
1	0.5748	0.2309	0.292	0.3817	0.1965
2	0.5063	0.3473	0.41109	0.4407	0.3021
3	0.4513	0.4431	0.45509	0.4488	0.4420
4	0.4146	0.5735	0.5098	0.4802	0.6188
5	0.3217	0.77977	0.5521	0.54988	0.8299
Max-Min	0.2530	0.5488	0.2601	0.1681	0.6334
Rank	4	2	3	5	1

4. RESULTS AND DISCUSSION

The higher the value of closeness coefficient indicates better performance. From Table 4, it is evident that the experiment number 7 having the highest value of closeness coefficient was the better performer amongst the 32 number of experiments.

The order of the experimental run obtained by TOPSIS was given by 7>26>11>20>16>4>17>13>15>22>24>1>30>10>29>32>6>28>31>8>23>27>12>5>18>21>3>19>14>25>9>2.

Optimum closeness coefficients are observed (Shown in Fig.3.) at v = 200 rpm, f = 0.1 mm/rev, d = 0.8 mm, r = 1.2 mm and α = 45° and similar observations are made from mean response table for closeness coefficient shown in Table 5.

Tab. 6 ANOVA for Closeness Coefficient

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% C
ν	1	0.064	0.003	0.003	1.8	0.19	5.36
f	1	0.352	0.007	0.007	4.3	0.06	29.48
d	1	0.072	0.009	0.009	5.8	0.03	5.99
r	1	0.018	0.000	0.000	0.0	0.79	1.48
α	1	0.602	0.009	0.009	5.5	0.03	50.36
ν*ν	1	0.000	0.000	0.000	0.2	0.65	0.00
ν*f	1	0.000	0.000	0.000	0.09	0.76	0.01
ν*d	1	0.013	0.013	0.013	8.2	0.015	1.07
ν*r	1	0.000	0.000	0.000	0.01	0.93	0.00
ν*α	1	0.003	0.003	0.003	1.9	0.18	0.26
f*f	1	0.008	0.009	0.009	5.8	0.03	0.63
f*d	1	0.002	0.002	0.002	1.5	0.23	0.20
f*r	1	0.003	0.003	0.003	1.8	0.20	0.24
f*α	1	0.064	0.003	0.003	8.3	0.01	1.08
d*d	1	0.352	0.007	0.007	0.2	0.66	0.07
d*r	1	0.072	0.009	0.009	1.7	0.21	0.22
d*α	1	0.018	0.000	0.000	7.5	0.01	0.99
r*r	1	0.602	0.009	0.009	1.1	0.31	0.09
r*α	1	0.000	0.000	0.000	0.7	0.40	0.10
α*α	1	0.000	0.000	0.000	7.2	0.02	0.94
Error	11	0.013	0.013	0.013			1.43
Total	31	1.194					
S = 0.0394242 R-Sq = 98.57% R-Sq(adj) = 95.97%							

In the response table (Table 5) it has shown that a negative rake angle has been assigned a rank 1 which means it is the most significant parameter in controlling the response followed by feed, depth of cut, cutting speed and nose radius.

From the ANOVA table 6, it is clear that the negative rake angle (50.36%) has significant influence followed by feed (29.47%), Depth of cut (5.98%), speed (5.36%) and nose radius (1.48%) has least influence.

The Closeness coefficient for the obtained optimum combination of parameters was 1.463687 estimated from equation 7 and was 68.73% higher than the maximum Closeness coefficient corresponding to rank 1 in Table 4. Hence the values obtained are optimum.

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

5. CONCLUSIONS

Experiments were conducted as per CCD of RSM and optimized cutting parameters in AISI 52100 steel hard turning using TOPSIS.

1. The negative rake angle is the most significant parameter in controlling the response followed by feed, depth of cut, cutting speed and nose radius.
2. From the ANOVA negative rake angle (50.36%) has significant influence followed by feed (29.47%), Depth of cut (5.98%), Speed (5.36%) and Nose radius (1.48%) has least influence.
3. It is clear from the results of TOPSIS experiment number 7 has the highest closeness coefficient value. Optimal parametric combinations are at speed 200 rpm, feed 0.1 mm/rev, depth of cut 0.8 mm, nose radius 1.2 mm and negative rake angle 45°.
4. From the values of closeness coefficient, the machining parameters best combination can be arranged in the order 7>26>11>20>16>4>17>13> 15>22>24>1>30>10>29>32>6>28>31>8>23>27> 12>5>18>21>3>19>14>25>9>2.
5. An improvement of 68.73% of the predicted weighted closeness coefficient establishes the optimality of obtained results.

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Nomenclature

Symbols

f	–	Feed, mm/rev
d	–	Depth of cut, mm
r	–	Nose radius, mm
F_m	–	Machining force, N
Ra	–	Arithmetic mean roughness, μm
C_i	–	Closeness coefficient

Greek letters

v	–	cutting speed, rpm
α	–	Negative rake angle, (°)

Acronyms

CCD	–	Central composite design
PCBN	–	Polycrystalline Cubic Boron Nitride
AISI	–	American Iron and Steel Institute
RSM	–	Response surface Method
TOPSIS	–	technique for order of preference by similarity to ideal solution
ANOVA	–	Analysis of Variance
PIS	–	Positive ideal Solution
NIS	–	Negative ideal Solution
GRA	–	Grey relational approach
PCA	–	Principle component analysis
MCDM	–	Multi criteria decision making
ANN	–	Artificial neural network
DF	–	Degrees of freedom

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Biographical notes

P. Umamaheswarrao obtained his M.Tech from Vellore Institute of Technology, Vellore. Currently he is working as an Assistant professor in the Department of Mechanical Engineering, Bapatla Engineering College, Bapatla, Andhra Pradesh. He has presented papers in various international conferences.

Dr. D. Ranga Raju Received his M.Tech and Ph.D from IIT Kharagpur. At present he is working as a professor in the Department of Mechanical Engineering, Srinivasa Institute of Engineering and Technology, Amalapuram, Andhra Pradesh. He has vast experience in teaching and administration.

Dr. Koka Naga Sai Suman is working as an Associate Professor in the Department of Mechanical Engineering, Andhra University College of Engineering, Visakhapatnam. He received best thesis award for his Ph.D work in the year 2010 by Andhra University. His areas of interests include Advanced Composites, Nano technology, Manufacturing.

Dr. B. Ravi Sankar working as a professor in the Department of Mechanical Engineering, Bapatla Engineering College, Bapatla, A.P. He obtained his Ph.D from Andhra University, Visakhapatnam. His scientific interests focus on Nanofluids, Alternative fuels, Machinabilty studies of hard materials, Composite materials, Friction stir welding. He has presented papers in various international conferences.