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An Experimental Study on Surface Roughness and Cutting Force in Turning operation by using Vegetable oils as Cutting Fluid

Sutanu Misra[1] and Asish Bandyopadhay[2,*]
[1] Automobile Engineering Department, Dr. Sudhir Chandra Sur Degree Engineering College, Kolkata- 700074, INDIA
[2] Mechanical Engineering Department, Jadavpur University, Kolkata-700032, INDIA

Abstract

In manufacturing industries the demand is growing for low cost, high productivity and good product quality. Cutting fluid is an important factor in a machining process to increase the productivity, tool life, better dimensional accuracy and good surface quality. In the present work, an attempted has been made to investigate and identify the effect of some important input parameters on the quality of surface and cutting force while using vegetable oil as cutting fluid. The input parameters are spindle speed, feed and depth of cut. Responses considered are cutting force and surface roughness of the work material (mild steel). Fifteen experiments have been carried out using Response Surface Methodology (RSM). Data related to surface roughness and cutting force have further been analyzed for optimization of the process. After optimizing the experimented data, it is found that in case of multiple optimization mustard oil appears as the best cutting fluid among the three oil (Sunflower oil, Soya-bean oil, and Mustard oil) used in the present study for minimizing surface roughness and cutting force.

Keywords: Response surface methodology, Surface roughness, Cutting force, Cutting fluid, Vegetable oil, ANOVA

1. INTRODUCTION

The use of the vegetable oil as cutting fluid has significant effect on productivity and longer tool life. Use of vegetable oil-based cutting fluids during machining can produce surface finish and dimensional tolerance with comfortable margins. Vegetable oils have an ability to deliver good machining performances in most of the machining applications. Vegetable oil based fluids achieves reduction in cycle time, delivers smooth operation and gives superior work quality.

Lawal *et al.* [1] suggested about the advantages of cutting fluids and its performances with respect to the cutting force, surface finish of work piece, tool wear and temperature at the cutting zone. Debnath *et al.* [2] have investigated about the developments in bio-based cutting fluids by using various vegetable oils which have significantly reduced the ecological problems caused by mineral based cutting fluids. Kuram *et al.* [3] have described about environmentally friendly vegetable oil based cutting fluids. Chinchanikar *et al.* [4] have discussed about the comparative evaluations of surface roughness during turning with water based cutting fluid and vegetable oil based cutting fluid. Aouicia *et al.* [5] have done some experiment on hard turning of X38CrMoV5-1 with CBN tool using response surface methodology with surface roughness and cutting forces as response. Rao *et al.* [6] have conducted experiments about the influence of cutting parameters on cutting force and surface finish in turning AISI 1050 steel with ceramic tool with an Al2O3+TiC matrix using Taguchi methodology. Kumar and Chauhan [7] have performed study on surface roughness measurement for turning of Al 7075/10/SiCp and Al 7075 hybrid composites by using RSM and ANN (artificial neural networking). Feed rate provides most significant effect on the surface roughness. Srithara *et al.* [8] have indicated about the experimental investigation and surface roughness analysis on hard turning of AISI D2 Steel using coated carbide insert.

From the above literature review, it is clear that a lot of research works have been done on vegetable oil as cutting fluids in turning process. But a comparative study is not available while using different vegetable oils for turning operation. Hence the present work is an attempt to study the effect of cutting parameters on surface roughness and cutting force in turning operation using three different vegetable oils.

2. EXPERIMENTAL DETAILS

In this experiment the cutting parameters are spindle speed (N), feed (f) and depth of cut (d). Their levels have been selected by prior experimentation. According to Box-Behnken method, fifteen experiments have been conducted (3 factors & 3 levels). The job selected for this experiment is a cylindrical mild steel work piece $\emptyset\, 90 \times 630$ mm long. The HSS turning tool with 18^0 side cutting edge angle, 29^0 end cutting edge angle, 0.5 mm nose radius, 10^0 principle clearance angle, and 11^0 back rake angle is used [9]. The cutting fluid at flow rate of 0.6 l/min has been applied in the cutting zone. A two dimensional dynamometer along with carrier frequency bridge (Make - German Philips & Model-PR9307) and oscilloscope (Make – Tektronix & Model –TDS 210) is used to measure the tangential

Table 1 : Limits of cutting parameter

Parameters	Notations	Unit	Values		
			-1	0	1
Depth of cut	d	mm	0.3	0.4	0.5
Spindle speed	N	rpm	235	310	385
Feed	f	mm/rev	0.0055	0.0073	0.0091

component of cutting force (P_Z). Surface roughness has been measured with the help of a portable surface roughness tester (Make-Mitutoyo & Model-99MBB079A6). **Table 1** shows the process parameter and their limits. The schematic diagram of experimental set up has been shown in Fig. 1.

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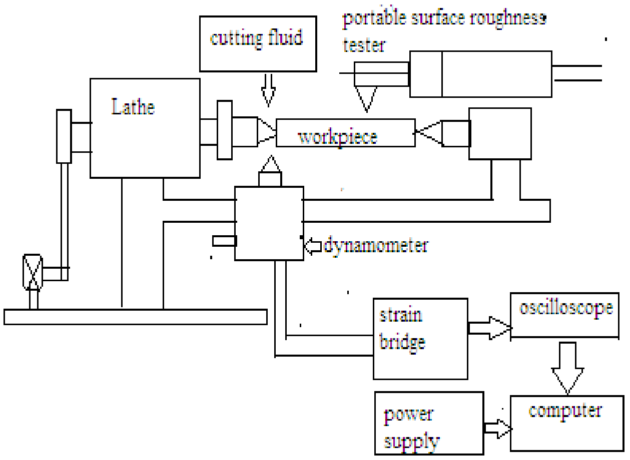

Fig.1. Schematic diagram of experimental set up

3. RESULTS AND DISCUSSION

The result sets in **Table** 2 and 3 show the measured value of surface roughness and cutting force respectively.

Table 2: Measured values of surface roughness (Ra) using three different vegetable oils

Ex No.	N (rpm)	f (mm/rev)	d (mm)	For Mustard oil (Ra)	For Soya bean oil (μm)	For Sunflower oil in (μm)
1	310	0.0055	0.3	5.15	5.83	4.98
2	310	0.0091	0.3	4.87	6.33	6.01
3	235	0.0073	0.3	5.31	8.19	5.22
4	385	0.0073	0.3	4.54	7.80	3.25
5	310	0.0073	0.4	5.65	5.12	3.99
6	310	0.0073	0.4	6.01	7.11	4.39
7	310	0.0073	0.4	6.45	8.13	4.99
8	235	0.0055	0.4	5.27	6.84	3.51
9	235	0.0091	0.4	5.80	6.49	7.44
10	385	0.0091	0.4	3.67	3.40	5.80
11	385	0.0055	0.4	4.62	4.27	4.16
12	304	0.0055	0.5	4.57	6.07	4.83
13	304	0.0091	0.5	4.83	6.04	4.52
14	235	0.0073	0.5	5.00	6.98	5.06
15	385	0.0073	0.5	3.89	2.19	4.73

Surface roughness has been obtained minimum in experiment no 10 for mustard oil, experiment no 15 for soya bean oil, experiment no 4 for sunflower oil (**Table 2**). Cutting force has been obtained minimum in experiment no 13 for mustard oil, experiment no 14 for soya-bean oil and experiment no 2 for sunflower oil (**Table 3**).

3.1. Mathematical modeling and response surface plots

To analyze the influence of process parameters on surface roughness and cutting force (tangential force) in RSM based analysis is made and mathematical modeling is, thus, developed. The relation between process parameters with response parameters can be shown by using second order equations as follows:

Table 3: Measured value of cutting force (tangential force) (P_Z) using three different vegetable oils

Ex No	N (rpm)	f (mm/rev)	d (mm)	For Mustard oil (N)	For Soya bean oil (N)	For Sunflower oil (N)
1	310	0.0055	0.3	5.04	7.69	3.33
2	310	0.0091	0.3	4.35	9.27	2.33
3	235	0.0073	0.3	4.12	6.11	4.60
4	385	0.0073	0.3	4.57	6.53	3.79
5	310	0.0073	0.4	3.98	12.60	6.93
6	310	0.0073	0.4	4.76	15.05	7.06
7	310	0.0073	0.4	5.07	15.64	7.37
8	235	0.0055	0.4	3.59	8.18	3.16
9	235	0.0091	0.4	2.97	12.74	5.07
10	385	0.0091	0.4	3.21	10.40	7.89
11	385	0.0055	0.4	5.44	11.15	3.95
12	304	0.0055	0.5	3.74	6.44	5.86
13	304	0.0091	0.5	2.85	8.58	11.77
14	235	0.0073	0.5	3.19	4.94	8.82
15	385	0.0073	0.5	5.17	8.65	12.07

$Y = \beta_0 + \beta_1(N) + \beta_2(f) + \beta_3(d) + \beta_{11}(N^2) + \beta_{22}(f^2) + \beta_{33}(d^2) + \beta_{12}(Nf) + \beta_{13}(Nd) + \beta_{23}(fd)$ ……………… (1)

Where $Y =$ output responses

Based on experimented result (given in Table 2 and Table 3), mathematical relationships between the surface roughness and cutting force with the cutting parameters have been developed. The Equations are:

Mathematical modeling of surface roughness with Sunflower oil

$Ra_{sun} = 7 - 412f - 2d + 199203 f^2 - 2d^2 - 4Nf - 1861\ fd$ ………………………………………………………….... (2)

Mathematical modeling of surface roughness with Soya bean oil

$Ra_{soya} = -29 + 4504f + 29d - 271476 f^2 + 16d^2 - Nf - 736\ fd$ ………………………………………………….…..………. (3)

Mathematical modeling of surface roughness with Mustard oil

$Ra_{mus} = -27 + 2832f + 50d - 158436 f^2 - 67d^2 - 3\ Nf + 750\ fd$……………………………………………..…………. (4)

Mathematical modeling of cutting force with Sunflower oil

$P_{z_{sun}} = -10 + 3135f - 12d - 164866 f^2 - 7d^2 - 3\ Nf - 278\ fd$ …………………………………………………………..….. (5)

Mathematical modeling of cutting force with Mustard oil

$P_{z_{mus}} = 13 + 3854f - 122d - 555556\ f^2 + 50d^2 + 4\ Nf + 9597\ fd$………………………………………………………………. (6)

Mathematical modeling of cutting force with Soya bean oil

$P_{z_{soya}} = -146 + 8611f + 379d - 366512 f^2 - 525d^2 - 10\ Nf + 778\ fd$ ……………………………………………..……. (7)

The 3D response surface plots have been done keeping one of the process parameters constant while other two are varied. From Fig. 2(a), it is found that surface roughness decreases with feed rate up to a threshold value and thereafter it start increasing. It indicates that feed is a significant process parameter incase of sunflower oil. It is evident from Fig. 2(b) that with increase of feed rate, cutting force value first increases and then after some stage it decreases for sunflower oil. In case of mustard oil spindle speed has more significance than other two. Fig. 3(a) shows that with increase in spindle speed, surface roughness value decreases. With increase of feed rate and depth of cut, roughness value first increases and then decreases. Depth of cut and feed are the most significant parameter on cutting force in case of mustard oil. Cutting force increases with the increase in depth of cut (Fig 3b). It is seen from Fig. 4 (a) that with increase in feed rate, roughness value first increases and then decreases for soya-bean oil. With increase in spindle speed, surface roughness value decreases continuously. Feed has more significant effect on cutting force in case of soya-bean oil. Fig. 4 (b) indicates that cutting force is increases with increasing value of feed and spindle speed.

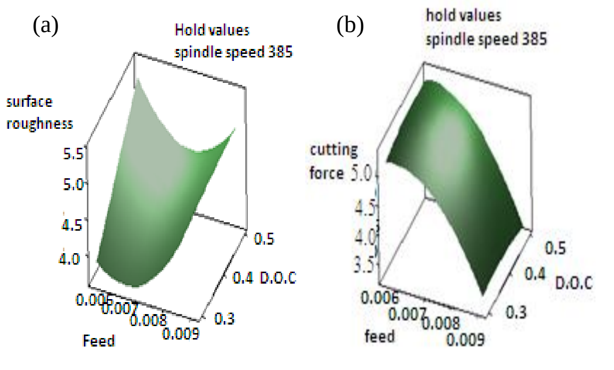

Fig.2.Response surface plot for sunflower oil showing the interaction effects of f and d on (a) surface roughness (b) cutting force, while third parameter is hold at N= 385 rpm

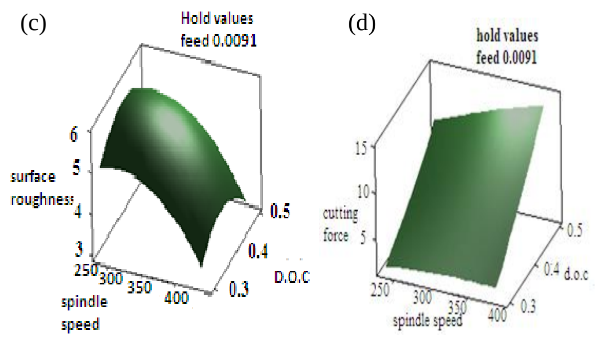

Fig.3.Response surface plot for mustard oil showing the interaction effects of N and d on (c) surface roughness (d) cutting force, while third parameter is hold at f=0.0091 mm/rev

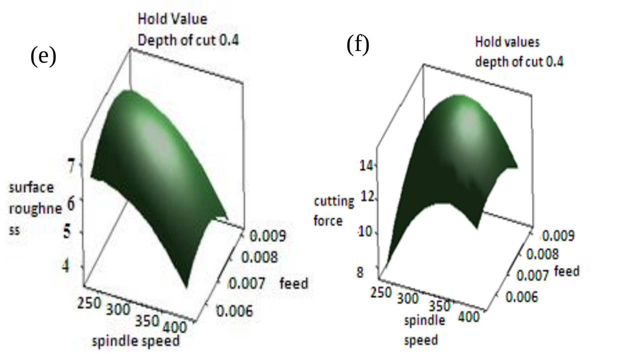

Fig..4. Response surface plot for soya bean oil showing the interaction effects of N and f on (e) surface roughness (f) cutting force, while third parameter is hold at d= 0.4

3.2 Analysis of Experimental Data

Analysis has been done for multi-objective optimization of surface roughness and cutting force with different vegetable oils as cutting fluid. For this purpose response surface methodology (RSM) has been adopted. The target is to determine the optimum parametric combination for minimization of surface roughness and minimization of cutting force, simultaneously. The statistical software MINITAB 16 has been used for this experimental analysis.

3.2.1 *Multi-objective optimization of surface roughness and cutting force using Response Surface Methodology (RSM)*

Optimizing technique has been used for getting minimum surface roughness and cutting force value using each of the vegetable oil. From multi optimization technique, it is an attempt to find out the best vegetable oil as cutting fluid among three different types of vegetable oil with the best optimal cutting condition. Multi-response optimization plots with sunflower oil for surface roughness and cutting force have been shown in Fig 5. From this figure it is observed that the optimum condition is: spindle speed (n) = 235rpm, feed (f) = 0.0055 mm/min and depth of cut (d) =0.5 mm. The corresponding value of surface roughness is 4.1479 μm with desirability =0.95700 and cutting force is 2.5908 N with desirability = 0.96910.

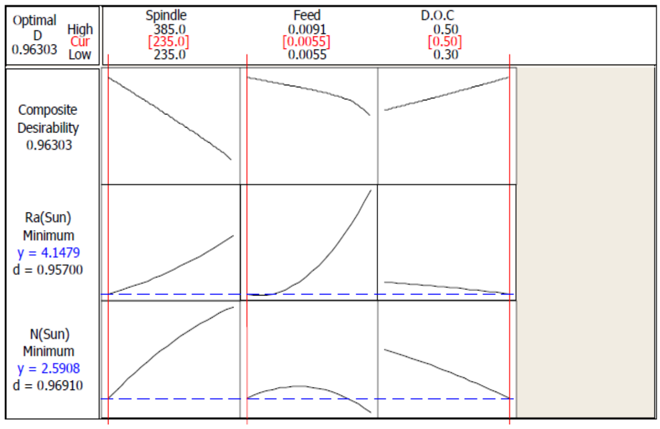

Fig. 5. Multiple optimization plot for Sunflower oil

Multi-response optimization plots using mustard oil for surface roughness and cutting force have been shown in Fig. 6. From this figure it is observed that the optimum condition is: spindle speed (n) = 385 rpm, feed (f) = 0.0091 mm/min and depth of cut (d) =0.3 mm. The corresponding value of surface roughness is 3.3117 μm with desirability =0.90966 and cutting force is 2.3275 N with desirability = 0.98708. Multi-response optimization plots with soya bean oil for surface roughness and cutting force have been shown in Fig 7. From this figure it is observed that the optimum condition is: spindle speed (n) = 385rpm, feed (f) = 0.0091 mm/min and depth of cut (d) =0.5 mm. The corresponding value of surface roughness is 1.7404 μm with desirability =0.96406 and cutting force is 6.4175 N with desirability = 0.98175.

ANOVA has been conducted to validate the developed model (Eq.4 and Eq.6). From the multi-objective optimizations, it is found that the mustard oil is the best cutting fluid among the three for machining. The ANOVA tests for surface roughness and cutting force for mustard oil are presented in **Table 4** and **Table 5** respectively.

From the **Table 4**, it is clear that all three parameters are significant, because the P-value of these three parameters is less than 0.05. The ANOVA indicates (**Table 4**) that spindle speed (N), feed (f), depth of cut (d), quadratic effect of the spindle speed (N^2), feed (f^2) and depth of cut (d^2) are the significant process parameters for surface roughness. For cutting force, feed (f), depth of cut (d), quadratic effect of the feed (f^2) , depth of cut (d^2), interaction effects of spindle speed –feed (N*f), spindle speed-depth of cut (N*d) and feed-depth of cut (f*d) are the significant process parameters (**Table 5**). The R-Sq values (**Table 4** and **Table 5)** are close to 100%, which are responsible and indicate adequate models. The standard deviation of errors (S) shows the significance of model.

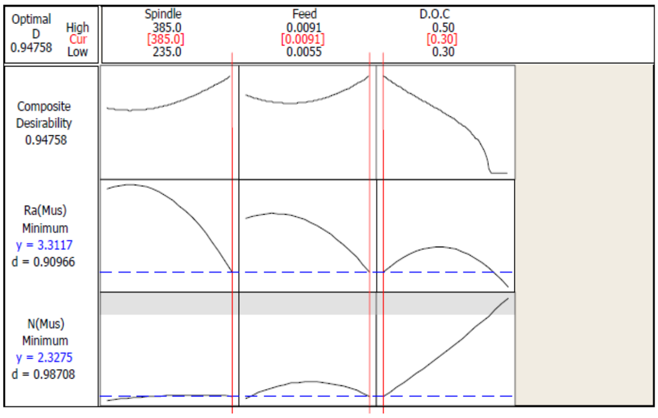

Fig 6. Multiple optimization plot for Mustard oil

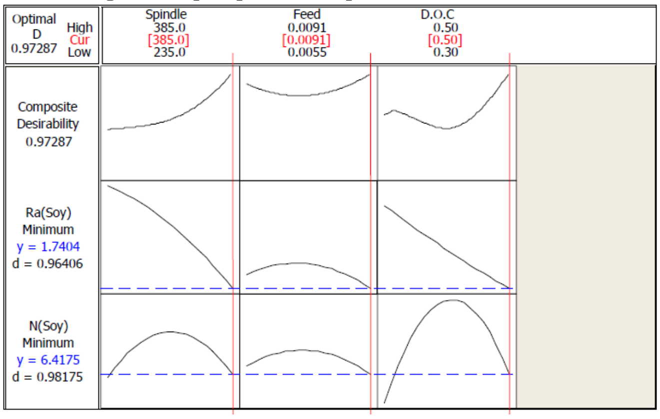

Fig 7. Multiple optimization plot for Soya-bean oil

Table 4: Analysis of variance for Surface roughness in case of Mustard oil

Source	DF	Seq SS	Adj SS	Adj MS	F value	P value
N	1	2.71445	1.78373	1.78373	19.53	0.007
f	1	0.02420	0.99144	0.99144	10.85	0.022
d	1	0.31205	0.94934	0.94934	10.39	0.023
N*N	1	1.33920	1.72410	1.72410	18.87	0.007
f*f	1	0.79253	0.97296	0.97296	10.65	0.022
d*d	1	1.64924	1.64924	1.64924	18.05	0.008
N*f	1	0.54760	0.54760	0.54760	5.99	0.058
N*d	1	0.02890	0.02890	0.02890	0.32	0.598
f*d	1	0.07290	0.07290	0.07290	0.80	0.413
Lack of fit	3	0.13570	0.13570	0.04523	0.28	0.838
Pure error	2	0.32107	0.32107	0.16053		
Total	14	7.93784				
S=0.302247		R-Sq=94.25%	R-Sq (adj) =83.89%			

Table 5: Analysis of variance for cutting force in case of Mustard oil

Source	DF	Seq SS	Adj SS	Adj MS	F value	P value
N	1	4.575	0.306	0.3061	3.65	0.114
f	1	14.472	1.836	1.8359	21.91	0.005
d	1	74.842	5.724	5.7245	68.33	0.000
N*N	1	0.164	0.338	0.3379	4.03	0.101
f*f	1	12.557	11.963	11.9631	142.80	0.000
d*d	1	0.932	0.932	0.9323	11.13	0.021
N*f	1	1.030	1.030	1.0302	12.30	0.017
N*d	1	4.121	4.121	4.1209	49.19	0.001
f*d	1	11.937	11.937	11.9370	142.49	0.000
Lack of fit	3	0.317	0.317	0.0830	2.07	0.343
Pure error	2	0.102	0.102	0.0511		
Total	14	125.056				
S=0.289439		R-Sq=99.67%		R-Sq (adj) =99.06%		

3.3 Confirmatory test for multi objective optimization

After getting the optimal cutting condition for minimum surface roughness and cutting force for each of the vegetable oil, confirmatory tests have been done for comparing the values with analytical result. Table 6 shows the confirmatory test for multi objective optimization.

Table 6: Confirmatory test

Name of the oil	Surface roughness(μm)	Cutting force(N)
Sunflower oil	4.6574	2.9102
Mustard oil	3.5714	2.4275
Soya bean oil	1.8501	6.6532

4. CONCLUSIONS

Based on the observations and analyses made in the study, some conclusions are drawn here. After optimizing the experimented data based on the mathematical model, it is found that mustard oil appears as the best cutting fluid among the three cutting fluids used in this study. The corresponding value of surface roughness is 3.3117 μm and cutting force is 2.3275 N for mustard oil. The above values are much lesser than other two cutting fluids. It is observed from the study that for mustard oil spindle speed is most significant parameter regarding surface roughness. Depth of cut and feed are the most significant parameters regarding cutting force.

References

[1] Lawal S. A., Choudhury I. A. and Nukman Y. "Application of vegetable oil-based metalworking fluids in machining ferrous metals—A review", *International Journal of Machine Tools & Manufacture,* **52,** (2012), 1–12.

[2] Debnath S., Reddy M. M. and Yi Q. S. "Environmental friendly cutting fluids and cooling techniques in machining: a review" *Journal of Cleaner Production*, **83**, (2014), 33-47.

[3] Kuram E., Ozcelik B. and Demirbas E. “Environmentally Friendly Machining: Vegetable Based Cutting Fluids” *Green Manufacturing Processes and Systems, Materials Forming, Machining and Tribology,* 2013.

[4] Chinchanikar S., Salve A.V., Netake P., More A., Kendre S. and Kumar R. ‘The comparative evaluations of surface roughness during turning with water based and vegetable oil based cutting fluids” *Procedia Material science*, **5**, (2014), 1966 – 1975.

[5] Aouicia H., Yallese M A., Belbah A., Ameur M. F. and Elbah M. “Experimental investigation of cutting parameters influence on surface roughness and cutting forces in hard turning of X38CrMoV5-1 with CBN tool” *Sadhana @ Indian Academy of Sciences,*. **38**, (2013), 429–445.

[6] Rao C. J., Rao D. N. and Srihari P.“Influence of cutting parameters on cutting force and surface finish in turning operation” *Procedia Engineering,* **64**, (2013), 1405 – 1415.

[7] Kumar R. and Chauhan S. ‘Study on surface roughness measurement for turning of Al 7075/10/SiCp and Al 7075 hybrid composites by using response surface methodology (RSM) and artificial neural networking (ANN)’ *Measurement*, **65**, (2015), 166–180.

[8] Srithara A., Palanikumarb K. and Durgaprasad B. “Experimental Investigation and Surface roughness Analysis on Hard turning of AISI D2 Steel using Coated Carbide Insert” *Procedia Engineering,* **97**, (2014), 72 – 77.

[9] Kumari K. V., Jana D.R. and Kumar A. “Effects of tool setting on tool cutting angle on turning operation” *ARPN journal of Engineering and Applied Science,* **5**, (2010), 27-31.