Available online at www.sciencedirect.com

ScienceDirect

Materials Today: Proceedings XX (2016) XXX–XXX

www.materialstoday.com/proceedings

PMME 2016

Optimization of Process Parameters based on Surface Roughness and Cutting Force in MQL Turning of AISI 4340 using Nano Fluid

Patole P.B.[1], Kulkarni V.V.[2]

[1]Department of Mechanical Engineering Bharati Vidyapeeth's College of Engineering, Kolhapur, Maharashtra India
[1]pb.patole@rediffmail.com,

[2]Department of Mechanical Engineering Sanjay Ghodawat Group of institution, Kolhapur, Maharashtra India
[2]kulkarni.vv@sginstitute.in

Abstract

The aim of this research work is focused on optimization of process parameters under Minimum Quantity Lubrication (MQL) using nano fluid in turning of AISI 4340. A study of effect of process parameters in turning of AISI 4340 under MQL condition with nano fluid (Multiwalled Carbon Nano Tube) on the cutting force generated and machined surface roughness is carried out. In the experiment conducted, five values of feed rate, three values of depth of cut, two values of spindle speed and tool nose radius respectively, are used.

The chemical composition of the work material was tested using arc spectrometer and verified to be of grade AISI 4340. The test pieces were turned on a CNC lathe machine under MQL mode using nano fluid with different levels of process parameters by using full factorial design of experiment orthogonal array. The surface roughness of the machined surface was measured using surface measurement tester. Taguchi methodology was used to optimize process parameters. The results were analyzed using Analysis of Variance (ANOVA). From result analysis, it was found that, feed rate played a major role in producing lower surface roughness followed by depth of cut whereas spindle speed has least significance in producing lower surface roughness under MQL using nano coolant. It was observed that MQL with nano fluid (MWCNT) showed lowest surface roughness as compared to conventional flood system. Thus, with proper selection of process parameters under MQL mode with nano coolant, it is possible to achieve good surface roughness, reduce tool wear while maintaining the cutting forces and temperatures at reasonable levels.

Keywords: Minimum Quantity Lubrication; Nano Fluid; Taguchi Method; CNC Turning; Surface Roughness.

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

1. INTRODUCTION

In recent times, modern machining industries are trying to achieve high quality, dimensional accuracy, surface finish, high production rate and cost saving along with reduced environmental impact. In the machining process, turning can be carried out on variety of machines like lathe, special purpose machine or CNC machine. The quality of turning is measured in terms of tolerances and roughness of surface. Surface finish is a quality specified by customer for machined parts [Narana and Satyanarayana, 2011]. In turning operation, parameters such as cutting speed, depth of cut, feed rate and tool nose radius have great impact on the surface finish [Adheil, Ismail, (2010)]. The turning operation seems very simple; through high speed turning of steel inherently generates high cutting zone temperature. Such high temperature causes dimensional deviation and premature failure of cutting tools. It also impairs the surface integrity of the product by inducing tensile residual stresses and surface and subsurface micro cracks in addition to rapid oxidation and corrosion [Dhar et al, 2007]. In high speed machining, conventional cutting fluid application fails to penetrate the chip tool interface and thus cannot remove heat effectively The lubricant has a strong effect on machined surface quality and tool wear. The costs related to cutting fluid represent a large amount of total machining cost; also cause health of machining operator and correct disposal [Dhar et al, 2006]. An alternative to conventional flood machining is the application of cutting fluids, in very small quantities to the small area where actual machining takes place. This technique is known as minimum quantity lubrication (MQL). In MQL the heat removal can be done and it also provides sufficient lubrication to prevent the generation of heat [Tasdelen, 2008]. The advanced heat transfer and tribological properties of nano fluids can provide better cooling and lubricating in the MQL machining process, and make it production-feasible [Shen Bin, 2008].

To improve the surface characteristics from micro level to nano level, nano fluids are useful in the machining process [Prabhu and Vinayagam, 2011]. In machining, large nose radius and cutting edge angle values may improve the surface finish of the machined part and also control tool vibration [Lohar and Nanavte, 2013]. Taguchi and Analysis of variance (ANOVA) can conveniently optimize the cutting parameters with several experimental runs well designed [Berger and Maurer, 2002]. Taguchi parameter design can optimize the performance characteristics through settings of design parameters and reduce the sensitivity of the system performance to source of variation [Rayn, 2000]. Analysis of variance used to identify the most significant variables and interaction effects [Henderson, 2006]. This study evaluate how to select the control parameter levels under MQL mode with nano fluid such as spindle speed, feed rate, depth of cut and tool nose radius that can minimize the effect of nuisance factor on response variable surface roughness. An experimental work is carried out to analyze the effect of process parameters on surface roughness and cutting force, then select the optimal cutting parameters condition which will lead high cutting performance and reduce cost and computing time during turning process.

2. EXPERIMENTAL PROCEDURE AND CONDITIONS

2.1 Work Piece Material

Alloy steel AISI 4340 has been selected as a work piece material. It is widely used for gears, shafts, couplings and other parts. The diameter and length of work piece was 24 mm and 100 mm length respectively. Chemical composition of this material is Fe 95.80%, Ni 1.3%, Cr 1.15%, Mn 0.59%, C 0.421%, Mo 0.228%, Si 0,216%, S 0.0278%.

2.2 Cutting Insert

The experimental trials were performed by using tungsten coated carbide insert with specification CCMT-090308. It’s having superior toughness and heat resistance. Right hand side cutting tool holder of grade K10 has been used.

2.3 Cutting Fluid

In order to perform the experiment in MQL cutting environment ethylene glycol as a base fluid with Multiwalled Carbon Nano Tube (MWCNT) nano particles has been used as a cutting fluid. The cutting fluid is prepared with mixture of ethylene glycol and the Multiwalled Carbon Nano Tube in the concentration of 0.2%. According to supplying direction and distance of the cutting fluid, in this experiment the distance between nozzle and insert tip was fixed at 11 mm and cutting fluid were supplied at a 30o angle [Attanasio and Gelfi, 2006]. The general purpose of Multiwalled Carbon Nano Tube is improvement in cutting performance because it having maximum heat carrying capacity which improves cooling effect and results in better surface finish [Shen Bin, 2008].

2.4 Experimental Equipment

The experimental trials of specimen work piece alloy steel AISI 4340 under MQL mode with nano fluid is conducted on CNC lathe turning machine having following specifications. Swing over bed 410 mm, Maximum turning length 360 mm, Standard turning diameter 200 mm, Weight 2500 Kg, X axis travel 140 mm, Longitudinal (Z axis) travel 380 mm, Rapid feed (X&Z axis) 30 m/min., Spindle motor power 7KW, Spindle bore 52 mm, Spindle speed range 50-6000 rpm., Number of station 8, Tool size (C/S) 25 X 25 mm.

2.5 Measurement Surface Roughness and Cutting Force

The surface roughness of the turned work piece was measured with Mitutoyo make surface roughness tester (SJ-201P). All measurements were repeated three times and the average value was taken as the final value. The cutting forces measured with the help of Kistler Dynamometer, a charge amplifier and PC software.

2.6 Design of Experiment

According to manufacturer's catalogue range and levels of input parameters are selected. In this study four controllable variables namely, spindle speed, feed rate depth of cut and tool nose radius has been selected. Factors with level value as shown in table 1.

Table1: Factors and Levels:

Sr.No.	Factor	Level				
1	Spindle Speed (rpm)	1000	1200			
2	Feed rate (mm/rev.)	0.04	0.06	0.08	0.1	0.12
3	Depth of Cut (mm)	0.5		1		1.5
4	Tool nose Radius (mm)	0.4		0.8		
5	Air pressure (bar)	6				
6	Fluid flow rate (ml/lit.)	140				

As per table1, full factorial orthogonal array has been selected for the experimental work. Two values of spindle speed and tool nose radius respectively, five values of feed rate and three values of depth of cut were used. In this experimental work under MQL mode with nano fluid total sixty trials were carried out ($2^2x5^1x3^1$ = 60 Runs). In this work surface roughness and cutting force has been selected as a response variable.

2.7 Experimental Set up Diagram

The experimental setup consists of MAXTURN++ (MTAB) CNC lathe machine (Speed 50-6000 rpm, motor 7 KW). During the experimentation MQL system supplied ethylene with nano particle at pressure 5 bar and flow rate140 ml/lit. The work piece material used is a cylindrical bar of AISI 4340 having BHN 217, 100 mm length and

24 mm diameter. The cutting insert used for the experimental work is tungsten carbide coated with specification CCMT-090308. Figure 1 shows the block diagram of experimental setup.

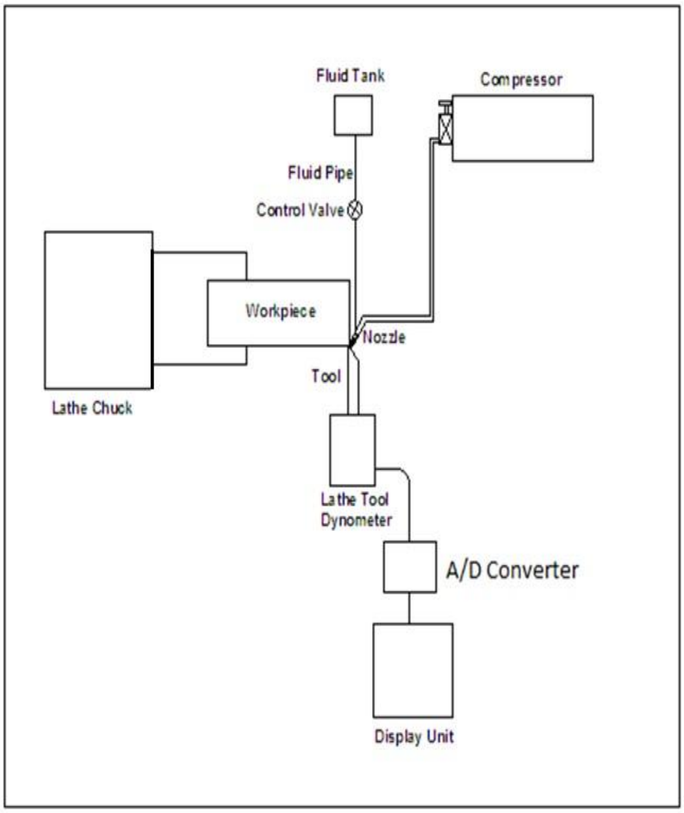

Fig.1 Schematic diagram of Experimental set up

3. RESULTS AND DISCUSSION:

The experimental trials under MQL mode with nano fluid were carried out to optimize process parameters (spindle speed, feed rate, depth of cut and tool nose radius) on the output response variable surface roughness and cutting force and full factorial orthogonal array was used for designing the experiments. The measured values of surface roughness and cutting force for the machined surfaces corresponding to all the experimental trials shown in table 2.

Table 2: Experimental Results

Sr. No	SS (rpm)	NR (mm)	FR (mm/rev.)	DOC (mm)	Avg. Ra (μm)	Avg. Force (kgf)	Sr. No	SS (rpm)	NR (mm)	FR (mm/rev.)	DOC (mm)	Avg. Ra (μm)	Avg. Force (kgf)
1	1000	0.8	0.04	1.5	1.01	22.45	**31**	1000	0.4	0.04	1.5	1.09	22.56
2	1000	0.8	0.04	1	1.06	15.52	**32**	1000	0.4	0.04	1	1.21	15.16
3	1000	0.8	0.04	0.5	1.26	7.67	**33**	1000	0.4	0.04	0.5	1.5	6.62
4	1000	0.8	0.06	1.5	1.24	33.21	**34**	1000	0.4	0.06	1.5	1.12	31.44
5	1000	0.8	0.06	1	1.32	23.15	**35**	1000	0.4	0.06	1	1.32	21.19
6	1000	0.8	0.06	0.5	1.35	11.7	**36**	1000	0.4	0.06	0.5	1.64	9.71
7	1000	0.8	0.08	1.5	1.42	39.85	**37**	1000	0.4	0.08	1.5	1.15	38.82
8	1000	0.8	0.08	1	1.5	28.07	**38**	1000	0.4	0.08	1	1.4	27.5
9	1000	0.8	0.08	0.5	1.61	13.58	**39**	1000	0.4	0.08	0.5	1.93	12.64
10	1000	0.8	0.1	1.5	1.6	45.42	**40**	1000	0.4	0.1	1.5	1.28	45.55
11	1000	0.8	0.1	1	1.64	32.82	**41**	1000	0.4	0.1	1	1.56	31.73
12	1000	0.8	0.1	0.5	1.75	16.94	**42**	1000	0.4	0.1	0.5	2.08	15.48
13	1000	0.8	0.12	1.5	1.7	52.26	**43**	1000	0.4	0.12	1.5	1.47	52.8
14	1000	0.8	0.12	1	1.78	37.25	**44**	1000	0.4	0.12	1	1.82	37.14
15	1000	0.8	0.12	0.5	1.88	19.15	**45**	1000	0.4	0.12	0.5	2.32	17.57
16	1200	0.8	0.04	1.5	1.29	20.72	**46**	1200	0.4	0.04	1.5	2.07	22.78
17	1200	0.8	0.04	1	1.37	14.14	**47**	1200	0.4	0.04	1	1.42	14.56
18	1200	0.8	0.04	0.5	1.4	7.81	**48**	1200	0.4	0.04	0.5	1.75	6.87
19	1200	0.8	0.06	1.5	1.41	31.38	**49**	1200	0.4	0.06	1.5	2.22	30.81
20	1200	0.8	0.06	1	1.5	21.45	**50**	1200	0.4	0.06	1	1.5	20.5
21	1200	0.8	0.06	0.5	1.56	10.66	**51**	1200	0.4	0.06	0.5	1.88	10.2
22	1200	0.8	0.08	1.5	1.67	39.14	**52**	1200	0.4	0.08	1.5	2.31	39.8
23	1200	0.8	0.08	1	1.72	28.21	**53**	1200	0.4	0.08	1	1.67	27.48
24	1200	0.8	0.08	0.5	1.8	14.74	**54**	1200	0.4	0.08	0.5	2.15	13.44
25	1200	0.8	0.1	1.5	1.78	44.22	**55**	1200	0.4	0.1	1.5	2.52	46.15
26	1200	0.8	0.1	1	1.82	31.56	**56**	1200	0.4	0.1	1	1.82	31.88
27	1200	0.8	0.1	0.5	1.93	16.52	**57**	1200	0.4	0.1	0.5	2.28	16.25
28	1200	0.8	0.12	1.5	1.93	50.61	**58**	1200	0.4	0.12	1.5	2.9	51.12
29	1200	0.8	0.12	1	2.02	36.72	**59**	1200	0.4	0.12	1	2.07	36.57
30	1200	0.8	0.12	0.5	2.16	19.46	**60**	1200	0.4	0.12	0.5	2.52	18.7

3.1 Analysis of variance

To achieve optimum condition, the smaller the better performance characteristic for surface roughness and cutting force was taken [Nalbant et al., 2007]. ANOVA was carried out to show the effect of cutting parameters that significantly affect on surface roughness and cutting force. ANOVA table is generated and S/N ratio was calculated by using Minitab software. The results of ANOVA with surface roughness and cutting force are shown in table 3, 4, 5 and 6 respectively. The influence of each control factor can be more clearly presented with response graphs.

Response graphs for all control factors are shown in fig.2 and 3. In addition fig. 4 and 5 present the analysis of interactions plot for S/N ratios for cutting force and surface roughness respectively.

Table 3: Response table for S/N Ratio for Ra

Level	SS	NR	FR	DOC
1	-3.54314	-5.00892	-2.72185	-5.27895
2	-5.50332	-4.03754	-3.51389	-4.05583
3			-4.73632	-4.23490
4			-5.32470	
5			-6.31938	
Delta	1.96018	0.97138	3.59753	1.22312
Rank	2	4	1	3

Table 4: Response table for S/N Ratio for Cutting Force

Level	SS	NR	FR	DOC
1	-27.1402	- 26.9535	-22.4879	-21.9865
2	-27.0669	-27.2537	-25.7032	-28.0813
3			-27.8136	-31.2430
4			-29.1548	
5			-30.3585	
Delta	0.0733	0.3002	7.8706	9.2564
Rank	4	3	2	1

Table 5: Analysis of Variance for RA, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contr.
SS	1	57.634	57.634	57.634	45.48	0.000	22.87
NR	1	14.154	14.154	14.154	11.17	0.002	5.61
FR	4	98.132	98.132	24.533	19.36	0.000	38.94
DOC	2	17.454	17.454	8.727	6.89	0.002	6.92
Error	51	64.629	64.629	1.267			25.64
Total	59	252.003					100

Table 6: Analysis of Variance for Force, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contr.
SS	1	0.08	0.08	0.08	0.61	0.439	0.006
NR	1	1.35	1.35	1.35	10.21	0.002	0.1
FR	4	462.86	462.86	115.71	874.16	0.000	34.12
DOC	2	885.49	885.49	442.75	3344.71	0.000	65.27
Error	51	6.75	6.75	0.13			0.49
Total	59	1356.53					100

3.2: Confirmation test

At optimal level of the cutting parameters under MQL lubrication system with nano fluid the predicted S/N ratio was calculated and surface roughness value was measured. The predicted value was compared with observed value and % error was obtained as shown in Table 7.

Table 7: Confirmation test

Cutting Method	Pred. S/N Ratio	Cal. S/N Ratio	Pred. Surface roug.	Obs. Surface Roug.	% Error
MQL	-0.78866	-1.3519	0.970667	1.06	8.49

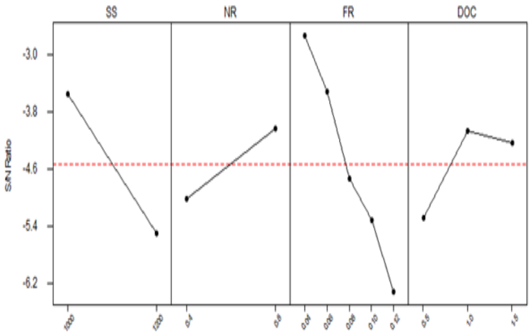

Fig.2: Main effects plot for S/N ratio for surface roughness

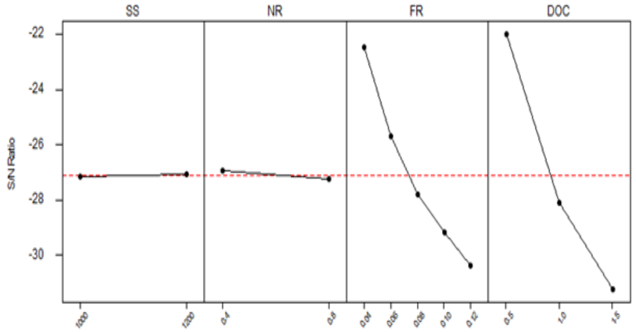

Fig.3: Main effects plot for S/N ratio for Cutting force

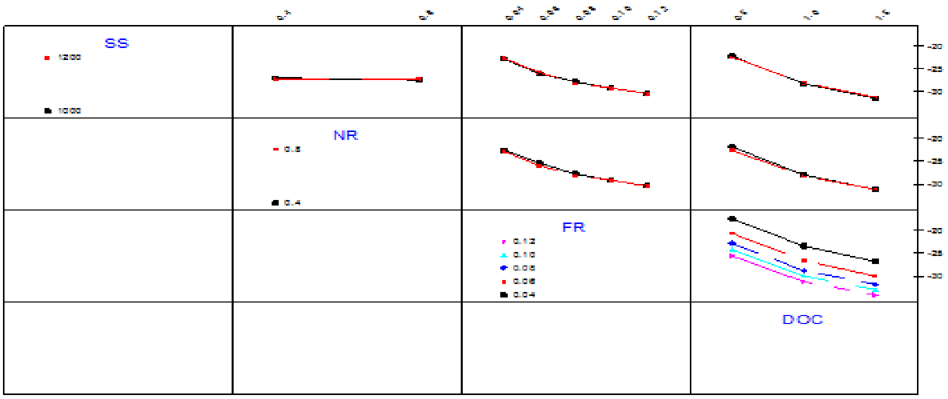

Fig.4: Interaction plot for S/N ratio for cutting force

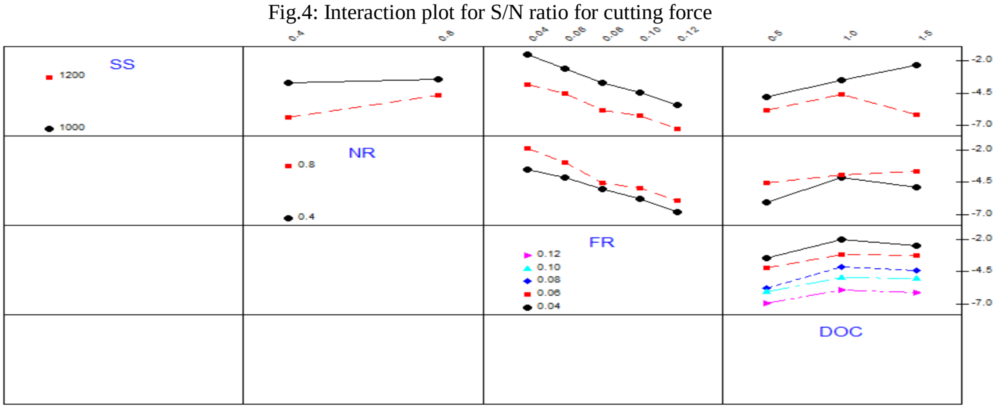

Fig.5: Interaction plot for S/N ratio for surface roughness

3.3: Regression Analysis

Regression analysis was implemented to develop prediction models using the predictors such as spindle speed, feed rate, depth of cut and tool nose radius under MQL mode with nano fluid in turning of AISI 4340. The Minitab software was used for the analysis of experimental work and to develop the predictive model for surface roughness and cutting force.

Avg. Surface Roughness = 7.54 - 0.00994 SS + 2.50 NR - 45.7 FR + 1.04 DOC

Avg. Cutting Force = - 10.3 + 0.00039 SS - 0.702 NR - 95.5 FR - 9.17 DOC

Table 8: Summary of the model

Cooling system	**Response variable**	**S**	**R-Sq %**	**R-Sq (adj) %**	**PRESS**	**R-Sq (pred) %**
MQL	Avg. Ra	1.148	71.9	69.9	86.91	66.31
	Avg. Force	0.9915	95.9	95.7	64.03	95.20

4. CONCLUSIONS

This study focused on the application of the design of experiment method for optimizing the process parameters in CNC turning of AISI 4340 under MQL mode with nano fluid using combined of two performance measures, surface roughness and cutting force. To obtain optimal machining performance, the smaller the better performance characteristics for surface roughness the optimal parameters are as lowest feed rate (FR = 0.04 m/min.), the spindle speed (SS = 1000 rpm), depth of cut (DOC = 1mm) and tool nose radius (NR = 0.8 mm). Similarly the lower the better characteristics for cutting force the optimal parameters are as lowest feed rate (FR = 0.04 m/min.), the spindle speed (SS = 1200 rpm), depth of cut (DOC = 0.5 mm) and tool nose radius (NR = 0.4 mm). From confirmation test it is seen that, the % error between observed and predicted surface roughness at optimum level is below ±10%. Finally the experimental results show that cutting force can be measured and used effectively as an in process signal for process parameters optimization.

From regression equations, which can estimate the surface roughness and cutting force in the MQL with nano fluid in turning process of AISI 4340 work material. From analysis it is seen that the cutting force equation is more appropriate as compared to surface roughness equation for accurate prediction. From regression analysis it is seen that high R-Sq value is obtained in case of cutting force as compared to surface roughness. It is concluded that the application of MQL with nano fluid is an alternative for a conventional flood system, if it can be properly applied. There is a considerable improvement in surface roughness and cutting force.

REFERENCES

[1] Narana Rao S., Dr. B. S. Satyanarayana, (2011), Experimental Estimation of Tool Wear and Cutting Temperatures in MQL using Cutting Fluids with CNT Inclusion, International Journal of Industrial Engineering Science and Technology, ISSN:0975-5462.

[2] Suhil Adheil H., Ismail N., (2010), Optimization of Cutting Parameters of Turning Operations by using Geometric Programming, American J. of Engineering and Applied sciences, 3(1) pp102-108.

[3] Dhar Nikhil Ranjan, Sumaiya Islam, Mohmmad Kamruzzaman, (2007), Effect of Minimum Quantity Lubrication(MQL) on Tool Wear, Surface Roughness and Dimensional Deviation in Turning AISI-4340 Steel, G. U. Journal of Science 20(2), pp23-32.

[4] Dhar N. R., Kamruzzaman M., Mahiuddin Ahmed, (2006), Effect of Minimum Quantity Lubrication (MQL) on Tool Wear and Surface Roughness in Turning AISI 4340 Steel, Journal of Material Processing Technology, 172, pp299-304.

[5] Tasdelen B., Thordenberg H., Olofsson D., (2008), An Experimental Investigation on Contact Length During MQL Machining, Journal of Material Processing Technology,pp221-231.

[6] Shen Bin, (2008), Minimum Quantity Lubrication Grinding Using Nano fluids, A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy(Mechanical Engineering)in the University of Michigan.

[7] Prabhu S., Vinayagam B. K., (2011) Fractal Dimensional Surface Analysis of AISI D2 Tool Steel Material with Nano fluids in Grinding Process Using Atomic Force Microscopy, 466 / Vol. XXXIII, No. 4.

[8] Lohar D. V., Nanavte C. R., (2013), Performance Evaluation of Minimum Quantity Lubrication (MQL) Using CBN Tool during Hard Turning of AISI 4340 and its Comparison with Dry and Wet Turning, International Journal of Industrial Engineering and Management Science, Vol. 3, No. 3.

[9] Berger P.D. and R. E. Maurer, 2001. Experimental design with Applications in Management, Engineering and the Sciences. Ist Edn., DuxburyPress, USA., ISBN: 10:0534358225, pp: 496.

[10] Ryan, T.P., 2000.Statistical methods for Quality Improvement. 2 nd Edn., John Wiley and Sons, USA, ISBN: 10: 0471197750, pp: 592.

[11] Henderson, G. R., 2006. Six sigma: Quality improvement with MINITAB. John Wiley and Sons, England, ISBN: 10: 0470011556, pp: 452.

[12] A. Attanasio, Gelfi, C. Giardini and C. Remino, Minimal quantity lubrication in turning: effect on tool wear, International Journal on the Science and Technology of Friction, Lubrication and Wear, 260(2006) 333-338.

[13] Nalbant M., Gokkaya H, Sur G., (2007), Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning, Materials and Design, 28, pp. 1379-1385.