An Experimental Investigation on Effect of Al_2O_3 Nanofluids Minimum Quantity Lubrication (MQL) in CNC Machining of EN353

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Abstract— The growing demands for high productivity of machining need use of high cutting velocity and feed rate. Such machining inherently produces high cutting temperature, which not only reduces tool life but also impairs the product quality. Application of cutting fluids changes the performance of machining operations because of their lubrication, cooling, and chip flushing functions. But the conventional cutting fluids are not that effective in such high production machining, particularly in continuous cutting of materials likes steels. So Nano fluids have novel properties that make them potentially useful in heat transfer medium in cutting zone And Minimum quantity lubrication (MQL) presents itself as a viable alternative for turning with respect to tool wear, heat dissipation, and machined surface quality. This study compares the mechanical performance of MQL Vegetable oil & MQL Nanoluids for the turning of EN353 based on experimental measurement of cutting temperature, cutting forces, surface finish, and dimensional deviations. This study prepares the effect of MQL and Nano fluids with 3% volume Al2O3 on the machinability characteristics of EN353 mainly with respect to Surface Roughness and Temperature dissipation. Experimental analysis for two different conditions –MQL oil and MQL + Al2O3 Nanoparticles was carried out.

Key words: Al_2O_3 Nanofluids, MQL, CNC Machining, EN353, Surface roughness, Temperature

I. INTRODUCTION

Machining experiences high temperatures due to friction between the tool and work piece, thus influencing the workpiece dimensional accuracy and surface quality. Machining temperatures can be controlled by reducing the friction between tool–work-piece and tool–chip interface with the help of effective lubrication. Cutting fluids are the conventional choice to act as both lubricants and coolants. But, their application has several adverse effects such as environmental pollution, dermatitis to operators, water pollution and soil contamination during disposal [1,2]. Further, the cutting fluids also incur a major portion of the total manufacturing cost. All these factors prompted investigations into the use of biodegradable coolants or coolant free machining. Hence, as an alternative to cutting fluids, researchers experimented with dry machining, coated tools, cryogenic cooling, minimum quantity lubrication (MQL) and solid lubricants. Dry machining, has been reported to be capable of eliminating cutting fluids with the advancement of the cutting tool materials [3]. Dry machining requires less power and produces smoother surface than wet machining at specified cutting conditions [4]. In tribological applications of hard protective coatings the toughness is as important as their hardness, since both properties shave great influence on the wear resistance of coated tools [5]. Ita kura etal. [6] conducted dry turning experiments to identify the tool wear mechanisms with coated cemented carbide tool while machining Inconel 718.During continuous cutting almost no rake wear but only flank wear appeared.

The primary function of a cutting fluid in wet machining operations is to cool, to lubricate, and to remove the chips. Emulsions or straight oils are generally used depending on the manufacturing operation and machining task involved. Straight oil is a cutting fluid that is composed of mineral oil or vegetable oil and is mainly used as a lubricant. Research by Rao DN, Srikant RR (2006) showed straight oil is not intended to be mixed with water. Emulsions possess excellent heat transfer characteristics because of their high water content. Straight oils excel when a high degree of lubricity is required. Both media guarantee efficient chip transport, when compressed air is used instead of a cooling lubricant, the lubrication benefit of the fluid is lost. The coolant effect is much less pronounced than with water or oil. Water and oil are also superior to air in terms of chip transport characteristics. In wet machining, machining with cutting fluids causes environment, water source pollution and soil become polluted during disposal of the cutting fluid. In MQL operations, the media used is generally straight oil, but some applications have also utilized an emulsion or water as showed by M. N. Morgan (2012). These fluid media is fed to the tool and work piece interface in tiny quantities. This is done with or without the assistance of a transport medium, e.g., air. In many machining operations, minimum quantity cooling lubrication (MQL) is the key to successful dry machining. Nanofluids are engineered colloidal suspensions of Nanoparticles in a base fluid. It has been found by M. M. A. Khan (2009), that Nanofluids have much higher and strongly temperature dependent thermal conductivity at very low particle concentration, which is considered to be a key parameter for enhanced performance for many of the applications. Al2O3 Nanoparticles have been analysed by Pil-Ho Lee (2012) and it was found to be most suitable as it increases wettability, reduces cutting forces, and shows enhanced tribological effects (like ball / roller effect) along with minimum toxic nature.

II. EXPERIMENTAL SETUP

A. *Selection of Work Material*

The work piece material will EN353 steel in the form of round bars of 30 mm diameter and length of 80 mm axial cutting length.

The composition of material is

chemical composition of EN 353 Steel					
C	**Mn**	**Cr**	**Si**	**Mo**	**Ni**
0.18%	0.93%	1.11%	0.26%	0.11%	1.34%

Table 1: Composition of EN353

EN353 is widely used for Machining components in various industries. This material has significant application in automotive industry. Typical applications of this material are crown wheel, crown pinion, bevel pinion, bevel wheel, timing gears, king pin, pinion shaft, differential turning etc. The gears especially crown wheel and pinion are one of the most stress prone parts of a vehicle, which are made of EN353 steel. The work piece of EN353 was firstly hardened followed by oil quenching at a temperature of 850°C to achieve a hardness of 60 HRC throughout. A rough turning pass was conducted initially to eliminate the run out of the work piece, after that diameter obtained for experimentation is approximately 60mm.

B. *Selection of Insert:*

Based on Literature survey, The Tool selected for this process was CBN CNGX1204L025-18AXA (Cubic Boron Nitride) Manufactured by Sandiwik Having Specifications are 120408.

C. *Selection of Lubricant*

Selection of cutting fluid is important in order to maintain better tool life, less cutting forces, lower power consumption, high machining accuracy and better surface integrity etc. Here Vegetable Oil {Max mix ST-2020}, is used as cutting fluid in MQL. ST-2020 is an environmentally acceptable vegetables oil based lubricant.ST-2020 will yield the lowest net manufacturing costs of any fluid as found byJung Soo, et al. (2011.)

D. *Preparation of Nano Fluids*

For preparation of Al2O3 Nano Particles the PRECIPITATION Method is Used. Alumina Prepared by this method is used for preparation of Nanofluids. In this work the alumina (Al2O3) Nano particles are mixed with vegetable oil, as a base fluid to make Al2O3Nanofluid. Nano Al2O3 particles are selected due to their superior tribological and antitoxic properties based on study of Pil-Ho Lee, et al. (2012). The method used to make Nano fluid is given below. Take one gram of Al2O3 Nano particles and directly mix with 100 ml vegetable oil as a base fluid and prepare the sample.1Vol% of Al2O3 Nano fluid = 100 ml of vegetable oil + 1gm of Al2O3 Nano particles. 3Vol% of Al2O3 Nano fluid = 100 ml of vegetable oil + 3gm of Al2O3 Nano particles. The above composition has to be mixed continuously about 8 to 9 hours using Magnetic stirrer. The size of Al2O3 particles is about 5 Nm. Here after Nano fluid means a mix of MQL and Al2O3 particles.

E. *Selection of process parameter*

Input process Parameters were selected after studying the literature on minimum quantity lubrication/near dry machining. Cutting speed (Vc), cutting feed (f) and Depth of cut (dc) were the input parameters chosen for present work. Therefore some output process parameters were selected to investigate the effect of input parameters under the application of MQL on EN353 machining technique. The output process parameters chosen were surface roughness (Ra), temperature (T) at cutting zone during the turning of EN353 Case Hardening material with CBN CNGX1204L025-18AXA insert.

1) *Machine:*

A high speed precision CNC Lathe (HASS - MAKE) having Maximum turning diameter 406mm, Height of centers over carriage 60 mm Maximum turning length: 762mm, Headstock A2-5 / CAMLOCK D1-3’’ Spindle speed 2,000 rev/min, AC motor drive: Power consumption 9kW, Transverse stroke X-axis 209mm, AC motor drive: intermittent torque 4 to 14 Nm Longitudinal stroke, Z-axis 762mm, Number of fixed tool stations/rotating tool stations. Weight of CNC Lathe 1860kg Power Requirement: 9KVA, 1-Phase:240V@40A, 3-Phase: 208V

Sr. no.	Parameter	Selected Parameter
1	Machine tool:	high speed precision CNC Lathe (HASS – MAKE)
2	Work pieces	EN353 Case Hardening material
3	Cutting tool inserts	CBN CNGX1204L025-18AXA
4	Cutting speed	800 – 1200 rpm
5	Feed rate, f:	0.05 - 0.09 mm/rev
6	Depth of cut,(d)	0.05 - 0.09 mm
7	MQL supply:	Air:4 bar, Lubricant: 50 ml/h
8	Environment:	MQL and MQL with Nanofluids.
9	Measurement of surface roughness	Surf Test
10	Measurement of cutting temperature	Infrared thermometer

Table 2: Selected Parameter

F. *Experimental Procedure*

By performing OVAT analysis and from graph it is found that cutting speed, feed rate, depth of cut are influencing parameters on Surface Finish. According to OVAT analysis following input parameters namely cutting speed, feed rate and depth of cut are selected by keeping other process parameters constant at minimum level which is less influencing on surface finish [15]. On the basis of surface finish, the selected levels of input parameters which are as follows.

Parameters	Units	Level 1	Level 2	Level 3
Speed (V)	Rpm	800	1000	1200
Feed (F)	mm/rev	0.05	0.07	0.09
DOC (D)	Mm	0.05	0.07	0.09

Table 3: Selection of Levels from OVAT

G. *Experimental Reading*

1) *MQL & Vegetable Oil*

Expt. No.	**Speed**	**Feed**	**DOC**	**Ra avg. (μm)**	**Temp (ºC)**
1	800	0.05	0.05	0.2360	41
2	800	0.07	0.07	0.4600	43
3	800	0.09	0.09	0.3185	44
4	1000	0.05	0.07	0.3775	43
5	1000	0.07	0.09	0.5585	45
6	1000	0.09	0.05	0.6030	43
7	1200	0.05	0.09	0.3433	44
8	1200	0.07	0.05	0.4371	46
9	1200	0.09	0.07	0.5778	47

Table 4: Reading of Vegetable oil & MQL

2) *MQL & Al2O3 Nanofluids-*

Expt. No.	Speed	Feed	DOC	Ra avg. (µm)	Temp (°C)
1	800	0.05	0.05	0.2465	38
2	800	0.07	0.07	0.4423	39
3	800	0.09	0.09	0.3125	42
4	1000	0.05	0.07	0.3924	40
5	1000	0.07	0.09	0.4133	42
6	1000	0.09	0.05	0.4806	41
7	1200	0.05	0.09	0.3392	39
8	1200	0.07	0.05	0.3495	40
9	1200	0.09	0.07	0.4346	42

Table 5: Reading of Nanofluids & MQL

III. Grey Relational Analysis

GRA is a new analysis method, which has been proposed in the Grey system theory and it is founded by Professor Deng Julong from Huazhong University of Science and Technology, People's Republic of China. GRA is based on geometrical mathematics, which compliance with the principles of normality, symmetry, entirety, and proximity. GRA is suitable for solving complicated interrelationships between multiple factors and variables and has been successfully applied on cluster analysis, robot path planning, project selection, prediction analysis, performance evaluation, and factor effect evaluation and multiple criteria decision [14]. Detailed explanation about GRA method is presented in the following section.

In grey relational generation, the normalized data corresponding to lower-the-better (LB) criterion can be expressed as:

$$x_i^*(k) = \frac{x_{imax}(k) - x_i(k)}{x_{imax}(k) - x_{imin}(k)}$$

For higher-the-better (HB) criterion, the normalized data can be expressed as:

$$x_i^*(k) = \frac{x_i(k) - x_{imin}(k)}{x_{imax}(k) - x_{imin}(k)}$$

Where, $x_i^*(k)$ and $x_i(k)$ are the normalized data and observed data, respectively, for i^{th} experiment using k^{th} response. The smallest and largest values of $x_i(k)$ in the k^{th} response are $x_{imin}(k)$ and $x_{imax}(k)$, respectively.

After pre-processing the data, the grey relation coefficient (GRC) $\zeta_i(k)$ for the k^{th} response characteristics in the i^{th} experiment can be expressed as following:

$$\zeta_i(k) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_i(k) + \zeta\Delta_{max}}$$

Where,

- $x_i^*(k)$= denotes reference sequence.
- $x_j^*(k)$ = denotes the comparability sequence
- $\zeta \in$ [0, 1] is the distinguishing factor; 0.5 is widely accepted.
- $\Delta_i = x_i^*(k) - x_j^*(k)$ = difference in absolute value between $x_i^*(k)$ and $x_j^*(k)$
- $\Delta_{min} = min_{(\forall j \in i)} min_{(\forall k)} \mid x_o^*(k) - x_j^*(k) \mid$ = smallest value of Δ_i.
- $\Delta_{max} = max_{(\forall j \in i)} max_{(\forall k)} \mid x_o^*(k) - x_j^*(k) \mid$= largest value of Δ_i.

After calculating GRC, the grey relational grade (GRG) is obtained as:

$$\gamma_i - \frac{1}{m}\sum_{k=1}^{n} w\,\zeta_i(k)$$

Here is the Grey Relational Grade, n is the number of responses, m is the number of run and w is the weight factor. We can control the amount of influence of a response in deciding the optimum machining parameters varying the value of w keeping in mind that it should be equal to 1.

The higher value of the GRG corresponds to a relational degree between the Reference Sequence $x_i^*(k)$ and the given sequence $x_j^*(k)$. The Reference Sequence $x_i^*(k)$ represents the best process sequence. Therefore, a higher GRG means that the corresponding parameter combination is closer corresponding parameter combination is closer to the optimal. The mean response for the GRG and the main effect plot of the GRG are very important because the optimal process condition can be evaluated from this plot [12].

IV. Effects of MQL and Nanofluids And Comparative Study

Two different conditions has been taken to study comparative study of experimentations. These two conditions are

- Vegetable Oil and MQL
- Nano fluid (3% Al2O3 and MQL

To check Effect of these two Condition on mainly in terms of Surface roughness and Cutting Temperature. The observations for machining EN353 under two different cutting fluid conditions are tabulated in Table 4 & 5.

A. *Surface Roughness*

The surface roughness Ra value was found out using Surf Test surface roughness measuring instrument SJ-201P. It is observed that Nano Fluid & MQL condition gives better surface finish than the Simple vegetable oil & MQL process. Graph 1 depicts surface roughness v/s speed, feed and depth of cut in two different environmental conditions i.e. MQL and Nano fluid, it is clear from the Figures that the range of the surface roughness is gradually decreasing from MQL with vegetable oil to MQL with Nano fluid as shown in following Table 6

	Range of Surface Roughness(µm)	% of reduction
Vegetable oil & MQL	0.2360-0.6030	
(3% Al2O3) Nano Fluid & MQL	0.246-0.4806	0-30 %

Table 6: % of avg. of reduction

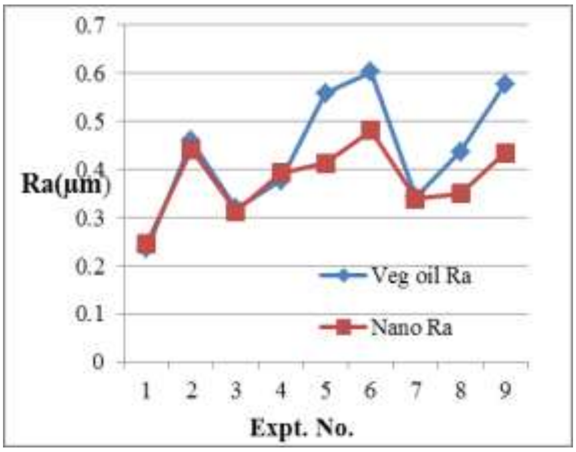

Fig. 1: Variation in Ra(µm)

B. Temperature

The Temperature (c) Value was found out using INFRARED THERMOMETER. It is observed that Nano Fluid & MQL condition gives better Temperature Reduction than the Simple vegetable oil & MQL process.

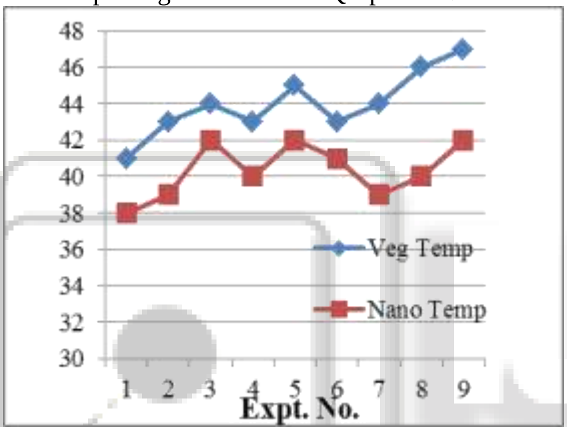

Fig. 2: Variation in Temp.(^{0}c)

It is observed because Nanofluids exhibit enhanced thermal properties such as higher thermal conductivity and heat transfer coefficients compared with plain MQL. Graph 2 depicts Temp. v/s speed, feed and depth of cut in two different environmental conditions i.e. MQL and Nano fluid, it is clear from the Figures that the range of the Temperature Reduction is gradually decreasing from MQL with vegetable oil to MQL with Nano fluid as shown in following Table 7

	Range of Tempt. (ºC)	% of Reduction
Vegetable oil & MQL	41-47	
(3% Al2O3) Nano Fluid & MQL	38-42	4 to 12%

Table 7: % of avg. of reduction in Temperature

V. RESULTS AND DISCUSSION

A. Analysis of Variance (ANOVA) & Main Effect Plots-

1) Vegetable Oil

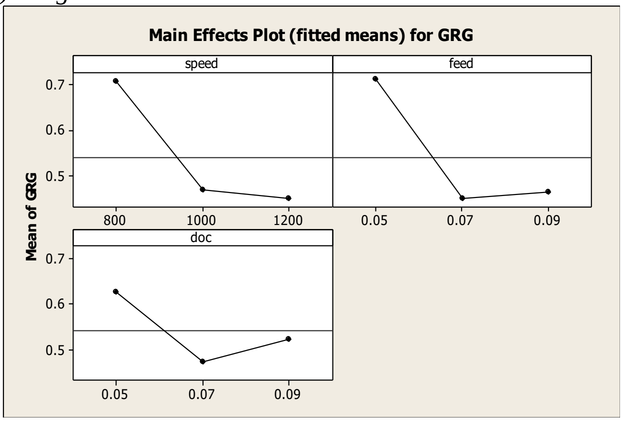

Fig. 3: Main effects plot for means for GRG

From the graphs, it can be said that finest combination values for maximizing the multiple performance characteristics or grey relational grade (GRG) were cutting speed of 800 rpm, feed rate of 0.05 mm/rev and depth of cut of 0.05 mm. The response table for the Mean effect plot of grey relational grade is shown in Table 8.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	C %
speed	2	0.112141	0.112141	0.056071	16.52	0.057	37.06
feed	2	0.136427	0.136427	0.068213	20.10	0.047	45.09
doc	2	0.047166	0.047166	0.023583	6.95	0.126	15.57
Error	2	0.006789	0.006789	0.003394			2.21
Total	8	0.302523					

Table 8: ANOVA for grey relational grade

S = 0.056850 R-Sq = 97.82% RSq (adj) = 91.3%

2) For Nanofluids & MQL

Here also, from the graphs, it can be said that finest combination values for maximizing the multiple performance characteristics or grey relational grade (GRG) were cutting speed of 800 rpm, feed rate of 0.05 mm/rev and depth of cut of 0.05 mm. The response table for the Mean effect plot of grey relational grade is shown in Table 9.

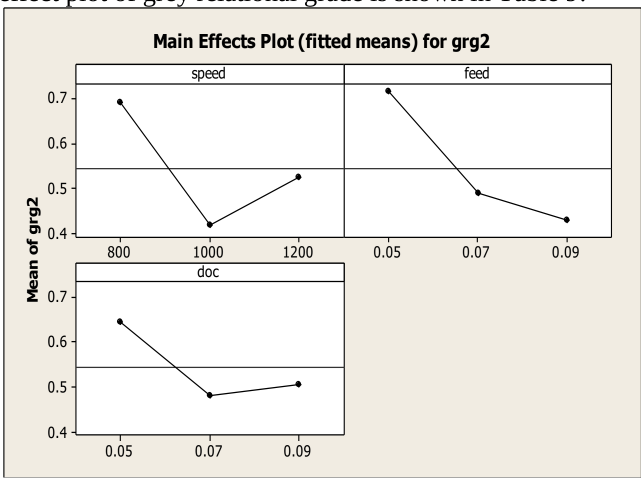

Fig. 4: Main effects plot for means for GRG

Source	DF	Sseq SS	Adj SS	Adj MS	F	P	C %
Speed	2	0.123182	0.123182	0.061591	19.06	0.050	41.44
Feed	2	0.130488	0.130488	0.065244	20.19	0.047	43.90
Doc	2	0.036944	0.036944	0.018472	5.72	0.149	12.42
Error	2	0.006464	0.006464	0.003232		0.0032	2.15
Total	8	0.297078					

Table 9: ANOVA for grey relational grade

S = 0.058260R-Sq = 97.76% R-Sq(adj) = 91.02%

ANOVA output of the multiple performance characteristics was given in Table 9 From the analysis of Table 8 & 9, it is concluded that feed rate followed by cutting speed and depth of cut are significantly affecting the grey relational grade.

B. *Conformation Experiments*

After the optimal level has been selected, one could predict the optimum response using the following equation

$$\gamma_{predicted} = \gamma_m + \sum_{i=1}^{n} (\gamma_i - \gamma_m)$$

Where, γ_m is the total mean from Table 9, γ_i is the mean S/N ratio at optimal level, n is the number of main design parameters that affect the quality characteristics [11]. The purpose of this confirmation experiment is to verify the improvement in the quality characteristics. Based on the above equation, the grey relational grade (GRG) is predicted for the optimal combination of parameters (V1-F1-D1) Applying this relation, predicted values of GRG, Temp. and Ra at the optimum conditions are calculated as:

	Vegetable oil & MQL	**Nanofluids & MQL**
GRG	0.9662	0.9682
Ra	0.261	0.2127
Temp.	40.667	37.45

Table 10: Predicted Values of GRG, Ra & Temp.

VI. CONCLUSIONS

The present work has successfully demonstrated Synthesis and Preparation of Al_2 O_3 Nano fluid and its applications in CNC turning on EN353 using Minimum Quantity Lubrication.

The surface roughness (Ra) and Temperature were measured under different cutting conditions for diverse combinations of machining parameters. The final conclusions arrived, at the end of this work are as follows:

1) There is a reduction of 7 to 8% in surfaceroughness using (3 % Al2O3) Nano fluids MQL compared to MQL Vegetable oil.
2) (3 % Al2O3) Nano fluids reduce cutting temperature by 11 to 13 % compared to MQL Vegetable oil.These experiments show that Surface Roughness and Temperature can be reduced significantly by machining EN353 using Nanofluids (i.e. 3 Vol.% of Al2O3 Nano fluid) as compared to MQL Vegetable oil.
3) From this analysis, it is revealed that feed rate Seed are prominent factors which affect the turning of EN353 case hardened steel. The feed rate (C= 45.09%) is the most influencing factor in determining the multiple performance characteristics or grey relational grade (GRG) followed by cutting speed (C =37.94%) and depth of cut (C = 15.75%).
4) The percentage of error between the predicted and experimental values of the multiple performance characteristics during the confirmation experiments is Less than 5 % as it is within limit.
5) The value of multiple performance characteristics obtained from confirmation experiment is within the 91% to 91.30% confidence interval of the predicted optimum condition.

Hence it is concluded that feed rate has significant effect on surface roughness & Temperature.

REFERENCES

[1] Anselmo Eduardo Diniz, Ricardo Micaroni,(2002) "Cutting conditions for finish turning process aiming: the use of dry Cutting" International Journal of Machine Tools & Manufacture 42,899-904
[2] Buongiorno, J. (March 2006). "Convective Transport in Nanofluids". Journal of Heat Transfer (American Society Of Mechanical Engineers) 128 (3): 240. Retrieved 27 March 2010.
[3] Douglas C. Montgomery (2009), Design and Analysis of Experiments, 7th edition Wiley.
[4] E.O. Ezugwua,R.B. Da Silvaa,J. Bonneya, Á.R. Machadob, (2005) "International Journal of Machine Tools and Manufacture", Volume 45, Issue 9, Pages 1009–1014.
[5] EmelKuram, Babur Ozcelik and ErhanDemirbas (2013), "Environmentally Friendly Machining: Vegetable Based Cutting Fluids", Green Manufacturing Processes and Systems, Materials Forming, Machining and Tribology, 23-29
[6] Eastman J A, Phillpot S R, Choi S U S, and Keblinski P, (2004) "Thermal transport in nanofluids", A Rev. Mater. Res., 34, 219-230.
[7] FundaKahraman,(2009) "The use of Response Surface Methodology for Prediction and Analysis of Surface Roughness of AISI 4140 Steel"Materiali in tehnologije / Materials and technology, 267–270.
[8] Jung Soo Nam, Pil-Ho Lee and Sang Won Lee (2011), "A Study on Machining and Environmental Characteristics of Micro-Drilling Process Using Nanofluid Minimum Quantity Lubrication" ASME 2011 International Manufacturing Science andEngineering Conference, Volume 2 Corvallis, Oregon, USA, June 13–17.
[9] M. M. A. Khan (2009), "Effects of minimum quantitylubrication on turning AISI 9310 alloy steel usingvegetable oil-based cutting fluid" Journal of MaterialsProcessing Technology 209, 5573–5583.
[10] Malkin, S. and Sridharan, U., (2009) "Effect of minimum quantity lubrication with nanofluids on grinding behavior and thermal distortion", Trans. NAMRI/SME, 37, 629-636.

[11] Pil-Ho Lee, Jung Soo Nam, Sang Won Lee,(2012)“An Experimental Study on Micro Grinding Processwith Nano Fluid Minimum Quantity Lubrication”, I.Jou. Precision Engineering and Manufacturing, Vol. 13, no. 3, pp. 331-338.
[12] Yigit Kazancoglu, Ugur Esme, Melih Bayramoglu, “Multi-Objective Optimization of the Cutting Forces in Turning Operations Using the Grey-Based Taguchi Method” UDK 621.9.025.5:669.14 ISSN 1580-2949, Original scientific article, MTAEC9, 45(2)105(2011)
[13] Nikhil Aggarwal and Sushil Kumar Sharma, “Optimization of Machining Parameters in End Milling of AISI H11 Steel Alloy by Taguchi based Grey Relational Analysis” International Journal of Current Engineering and Technology E-ISSN 2277 – 4106, P-ISSN 2347 - 5161 ©2014 INPRESSCO
[14] K.C Chang and M-F, Yeh, Grey-relational analysis based approach for data clustering, IEEE Proc,_Vis. Image Signal Process., Vol.152,No,2, April 2005, pp165-172.
[15] Rao DN, Srikant RR (2006) Influence of emulsifier content on cutting fluid properties.ProcInstMechEng, Part B: EngManuf 220:1803–1806
[16] Rahman, MM, Khan, M M A, and Dhar, N R, (2009) “An experimental investigation into the effect of minimum quantity lubrication on cutting temperature for machinability of AISI 9310 steel alloy”, Eur. J Sci. Res.,29(4), 502-508.
[17] S. Khandekar, M. Ravi Sankar, V. Agnihotri, J Ramkumar (2012), “Nano Cutting fluid for enhancement of Metal Cutting Performance”, Material and Manufacturing Processses, 27:9, 963- 967