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Performance Evaluation of Solid Lubricants under MQL in Hard Turning of EN-31 Steel Using Coated Carbide Inserts

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Abstract: ***The present work studies the application of a solid lubricant mixture like Graphite in SAE 40 oil and Boric acid in SAE 40 oil under MQL in turning of EN-31 steel. Boric acid and Graphite are mixed with SAE 40 oil separately and sonicated thoroughly. The prepared mixtures are used at the cutting zone for determining surface roughness and tool wear and in order to assess performance of the cutting fluid at the corresponding cutting conditions The experiments are conducted using design of experiments based on Taguchi method and analysis of results is carried out by ANOVA to find which of the process parameters has significant effect on Surface roughness and Tool wear Principal Component analysis integrated Taguchi method is used to obtain the optimal combination of input process parameters and their corresponding responses for both the conditions. It is observed that performance of Boric acid is better than Graphite in reducing Surface roughness and Tool wear of the machined surface.***

Keywords: Solid lubricant mixture, Graphite, Boric acid, SAE 40 oil, MQL, Turning, Principal Component Analysis, Surface roughness and Tool wear

1. Introduction

During metal removal process high temperature are generated. Due to this high cutting temperature tool life and surface roughness are affected so to remove heat generated in the machining zone cutting fluids are used. Cutting fluids which acts as coolant and lubricant takeaway the heat and reduces friction between moving surfaces. previous research says that conventional cutting fluid is hazardous to ecological balance, operators health and environment .So cryogenic cooling, minimum quantity lubrication (MQL), solid lubrication, solid lubrication with mineral oil are alternatives to conventional cutting fluid. solid lubricants like Boric acid, Graphite, Calcium fluoride, Molybdenum disulfide have drawn the attention of researchers. This is due to their layer lattice structure, low coefficient of friction ,spreading action. Micro lubrication is technique in which micro particles are mixed with base oils. Micro particles have good thermo physical properties like thermal conductivity and viscosity. These mixed mixture with oils carry away the heat and reduces coefficient of friction. Mineral oils are environment friendly, safe to operator, easily available in market and low cost .so it can be used with solid lubricants. mineral oils like Naphthenic oils SAE-20,40 can be used at the cutting zone.MQL or near dry machining is considered as effective lubrication at the cutting zone thus considering advantages of mineral oils, solid lubricants, micro particles and MQL. mineral oils with micro solid lubricants are used as cutting fluid in this experiment

2. Literature Review

Uttara R. Salunke et al [1] paper deals effects of cutting parameters on surface roughness while machining hardened AISI D2 cold work tool steel (60 HRC).paper suggests that dry machining eliminates cutting fluid with Development hard tool inserts. A.S. Varadarajan et al [2] shows overall performance during minimal cutting fluid application is found to be superior to that during dry turning and conventional wet turning on the basis of cutting force, tool life, surface finish, cutting ratio

N. R. Dhar et al [3] observed that high-pressure jet of soluble oil when applied at chip-tool interface, could reduce cutting temperature and improve tool life to some extent. The results indicated that performance of MQL machining is better than that of dry machining.

S. Paul, N.R dhar, A.B chatopadhyaya [4] work suggest cryogenic cooling by liquid nitrogen jet provided reduced tool wear and surface roughness compared to dry and and wet. This may be attributed to mainly reduction in cutting zone temperature and favourable change in the chip tool interaction.

Pratik l. Nagalwade, A. V. Kale [5] suggested TiN coated carbide tool produce better surface roughness and tool flank wear compared to uncoated carbide

APS Gaur, Sanjay Agarwal [6] have shown that there is considerable reduction in the cutting forces, average tool flank wear, and the surface roughness of the machined surface with Boric acid assisted machining compared to dry and wet machining

Abhang and Hameedullah [7] paper reports on the effect of lubricant environment when EN-31 steel alloy is machined with tungsten carbide inserts. The effect minimum quantity lubrication with respect to the surface roughness of machined parts. It is found that MQL condition will be a very good alternative other conditions.

Uma Maheshwera Reddy Paturia [8] demonstrated that, surface quality of machined work material during WS2 solid lubricant assisted MQL machining showed a much improvement on the finish quality of work material by on average about 35% when compared to MQL machining alone. N. Suresh Kumar Reddy and P. Venkateswara Rao [9] found that there is a considerable improvement in the performance of milling using Graphite as a solid lubricant when compared with machining using cutting fluids in terms of specific energy requirements, cutting force, and surface finish

A. Venu Gopala , P. Venkateswara Rao[10] Results indicate that there is a considerable improvement in the performance of grinding SiC using Graphite as a solid lubricant when compared with dry grinding in terms of specific energy requirements, surface roughness, and damage. R Padmini, G Krishna Mohana Rao [11] have shown nMoS2 suspensions in CC at 0.5% npi have shown reduction in cutting forces, cutting temperatures, tool flank wear, and surface roughness respectively when compared to nBA counter parts in CC and SS at all npi

Vamsi et al. [12] reported that solid lubricants such as Graphite, calcium fluoride, molybdenum disulfide, and Boric acid are alternative to cutting fluids during machining. The use of solid lubricants during machining helps in reduction of the coefficient of friction, cutting forces and tool wear more than cutting fluids

Damera and Pasam [13] studied that surface quality was improved with Boric acid as a solid lubricant during machining compared to a dry condition. It is due to layer lattice structure, low coefficient of which helps in reducing the cutting forces and temperature at the cutting zone

Kumar et al [14] studied the effects of cutting environments (dry wet and solid lubricant) on surface quality. The superior surface quality was observed with the use of hBN solid lubricant when compared to wet and dry conditions

3. Experimental Details

3.1 Work Piece Material and Tool Insert

The work-piece material used is EN-31steel of 100mm length and 32 mm diameter, is a excellent high carbon alloy steel which offers a high measure of hardness with compressive strength and abrasion resistance. CNMG 432 TN 2000is used as CVD coated tungsten carbide (WC) tool insert..Tool holder used in holding of insert is PCLNR 2525M/12 tool holder. The cutting edge length of the insert is 12 mm, insert thickness is 4 mm, nose radius is 0.8 mm, shape is rhombus. The composition of EN-31 is given in Table 1and mechanical properties of EN-31 are listed in Table 2

Table 1: Chemical composition of EN-31steel

Element	% Weight
Carbon	1.5
Manganese	0.52
Silicon	0.22
Chromium	1.3
Sulphur	0.05
Phosphorous	1.3

Table 2: Mechanical properties of EN-31

Tensile strength	750N/mm^2
Yield stress	450N/mm^2
% of elongation	30
Modulus of elasticity	215Gpa
Density	7800kg/m^3
Hardness	63HRC

3.2 Preparation of cutting fluid

The individual micro particles of Boric acid and Graphite are chosen. Two different mixtures are obtained by mixing of micro particles of Boric acid and Graphite are mixedwith SAE-40oil separately in the required proportions, that is, 0.5% by weight [11] and manual mixing is done using stirrer subjected to thorough manual stirring. Then thus forming two different mixtures. The mixture which prepared is placed in an ultra sonicator. Sonication of each mixture carried out for1 hour. The micro particles were first mixed manually and then sonicated on a trial basis for 20min if uniform distribution of particles takes place then further sonication is not necessary. Thus to avoid settling of particles sonication time has been extended to 1hour .The micro fluids are used as cutting fluids in machining immediately after the sonication process

3.3 MQL Set Up

The setup used for applying minimum quantity lubrication in machining operations is commercially called as an 'oil mist lubricator'. The working of an oil mist lubricator is as follows

Highly compressed air with typical air pressure of 5 *bar* is supplied into the air filter via a solenoid valve. In the mean time cutting fluid from the oil reservoir is supplied to the mixing chamber via an oil control valve. Oil control valve helps to control the flow rate of oil to be supplied. In the mixing chamber, the compressed air from the filter via air control valve and the cutting fluid get mixed to form an aerosol known as oil-mist.

This oil mist is then supplied to the cutting zone through a very small hole (< 2 *mm*) nozzle. The cutting fluids used under MQL machining are Boric acid mixture and Graphite mixture. The flow rate of lubricant was adjusted as 300 *ml/hr* with the help of lubricator as shown in the figure

Figure 1: Photographic view of MQL setup

3.4 Process parameters and their levels

The input process parameters are cutting speed, feed rate and depth of cut. Output responses are surface roughness and tool wear. The factors and levels are given in the Table 3 below. Based on Taguchi method The design of experiments table is developed from the L9 orthogonal array and is shown in the Table 4 below.

Table 3: Parameters and their Levels

Factor/level	1	2	3
Speed (S) (rpm)	1000	1200	1400
Feed(F) (mm/rev)	0.05	0.1	0.15
Depth of cut(D) (mm)	0.1	0.2	0.3

Table 4: Design of Experiments

Trail No.	S	F	D
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3

3.5 Experimental Procedure

Experiments have been carried out by turning a 32 *mm* diameter and 100*mm* length rod of EN 31 steel on a CNC lathe machine with different parameters and environmental conditions as mentioned. The machinability characteristics of the work material mainly in respect of tool wear and surface roughness have been investigated to study the role of MQL with solid lubricant mixtures. The experimental conditions are given in the table 4

Figure 2: Hardinge CNC lathe

Boric acid mixture and Graphite mixture as a lubricant. The lubricant mixes with the air and comes out of the nozzle of the lubricator in the form of spray which is arranged near the tool and work piece zone with a flow rate of 300 *ml/hr*. The work piece and tool is set into CNC turning and turning operation is performed on 9 work pieces according to design of experiments combination table. The required amount of mixture is used according to number of work pieces to be machined from 250 ml solid lubrication mixture which is present in MQL GUN .The tools wear readings and surface roughness readings after each machined part are measured by toolmaker's microscope and surface roughness tester. The values obtained are tabulated and are shown in the Table

Table 5: Responses of tool wear and Ra with boric acid under MQL Condition

Ex No	Ra 1 (µm)	TW1(mm)
1	0.441	0.04
2	0.878	0.103
3	0.733	0.06
4	0.66	0.07
5	0.98	0.08
6	0.808	0.051
7	0.571	0.03
8	0.98	0.06
9	1.008	0.08

Table 4: Responses of tool wear and Ra with Graphite under MQL Condition

Ex No	Ra 2(µm)	TW2(mm)
1	1.1467	0.05
2	1.233	0.045
3	1.99	0.02
4	0.627	0.06
5	1	0.02
6	1.911	0.01
7	0.71	0.09
8	0.89	0.08
9	1.67	0.1

4. Results and Discussion

Analysis of Variance (ANOVA)
ANOVA analysis is done on the experimental data to check the significance of the model and to determine the most contributing factor for output responses

Table 6: ANOVA Analysis of Surface Roughness for Boric acid under MQL Condition

Source	DF	SeqSS	F	P	% of contribution
S	2	0.047354	9.23	0.098	14.92
F	2	0.245801	47.9	0.020	77.44
D	2	0.019129	3.73	0.211	6.03
Error	2	0.005131			1.62
Total	8	0.317414			100.00

From the Table 6 the P-value of feed is <0.05. Hence it is the most
Significant parameter affecting surface roughness.
Speed and Depth of cut has no any significant effect on surface roughness
R-sq= 98.38%,R-sq(adj)=93.53%
R^2=98.38% is which close to 100% which indicates the model has a variance of 1.62% and hence it is within the acceptable limit

Table 7: ANOVA Analysis of Tool wear for Boric acid under MQL Condition

Source	DF	SeqSS	F	P	%of contribution
S	2	0.000228	5.24	0.160	5.70
F	2	0.001768	40.6	0.024	44.19
D	2	0.001962	45.04	0.022	49.02
Error	2	0.000044			1.09
Total	8	0.004002			100.00

From the Table 6 the P-value of depth of Cut and feed are <0.05. Hence are the most significant parameter affecting Tool Wear. Cutting speed has no significant effect on tool wear

R-sq=98.91% , R-sq(adj)=95.65%

R^2=98.91% which is close to 100% indicates the model has a variance of 1.09% and hence it is within the acceptable limits

Table 8: ANOVA Analysis of Surface Roughness for Graphite under MQL Condition

Source	DF	SeqSS	F	P	% of contribution
S	2	0.21921	9.06	0.099	10.73
F	2	1.77031	73.18	0.013	86.65
D	2	0.02941	1.22	0.451	1.44
Error	2	0.02419			1.18
Total	8	2.04313			100.00

From the Table 8 the P-value of feed is <0.05. Hence is the most significant parameter affecting Surface roughness Speed and Depth of cut has no significant effect on surface roughness

R-sq=98.82%, R-sq(adj)=95.26%

R^2=98.82% which is close to 100% indicates that the model has a variance of 1.18% and hence it is within the acceptable limits

Table 9: ANOVA Analysis of Tool Wear for Graphite Under MQL Condition

Source	DF	SeqSS	F	P	% of contribution
S	2	0.006339	60.05	0.016	74.97
F	2	0.000906	8.58	0.104	10.71
D	2	0.001106	10.47	0.087	13.07
Error	2	0.000106			1.25
Total	8	0.008456			100.00

From the Table 9 the P-value of speed is <0.05 .hence is the most significant parameter affecting Tool Wear. Feed and depth of cut has no significant effect on tool wear

R-sq=98.75%, R-sq(adj)=95.01%

R^2=98.75% which is close to 100% indicates that the model has a variance of 1.25% and hence it is with in the acceptable limits

4.1 Main Effect Plots

Main effect plots of surface roughness and tool wear for boric acid under MQL condition are shown below

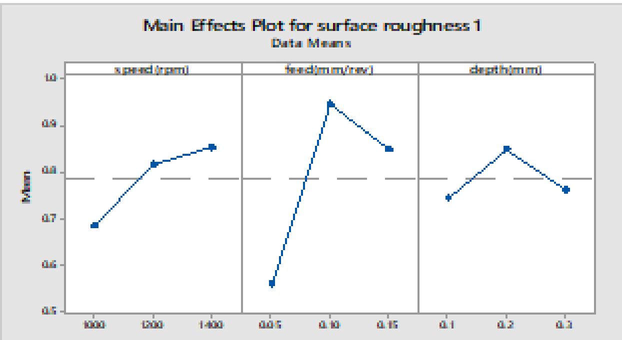

Figure 3: Main effect plots of surface roughness for boric acid

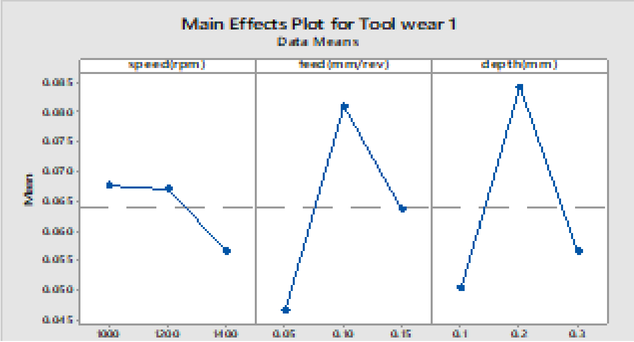

Figure 4: Main effect plot of tool wear for boric acid

Main effect plots of surface roughness and tool wear for Graphite under MQL condition are shown below

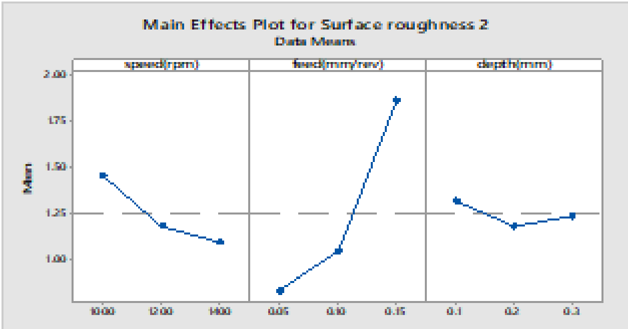

Figure 5: Main effect plots of surface roughness for Graphite

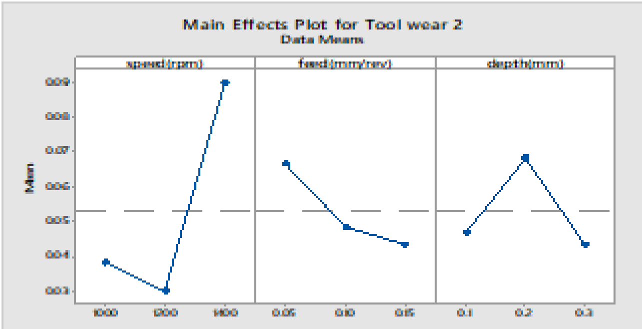

Figure 6: Main effect plots of Tool wear for Graphite

4.2 Regression model

The relationship between input process parameters and corresponding output Responses is obtained by regression analysis Speed,feed and depth of cut are input process parameters. Surface Roughness (Ra 1)and Tool wear (TW 1)are output responses for Boric acid

Surface Roughness (Ra 2) and Tool wear (TW 2) are output responses for Graphite

Ra1 (µm) = -0.033+0.000422xspeed (rpm)+2.92xfeed (mm/rev)+0.092xdepth (mm) (1)

TW 1(mm = 0.0734-0.000028xspeed (rpm) +0.170xfeed (mm/rev) +0.032xdepth (mm) (2)

Ra 2(µm) = 1.395-0.000916xspeed (rpm) +10.29xfeed (mm/rev)-0.413xdepth (mm) (3)

TW 2(mm) = -0.0756+0.000129xspeed (rpm)-0.233xfeed (mm/rev)-0.017xdepth (mm) (4)

4.3 Principal Component Analysis (PCA) Integrated Taguchi Analysis

PCA is an optimisation tool which converts several multiple correlated responses data into several uncorrelated quality indices. It maximizes the variability of the data while minimizing the dimensionality of the data. The following steps are involved in the process.

4.3.1 Normalisation of data

The normalized values are calculated using the equation given below.

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \qquad (5)$$

Where y denotes the experimental data and x denotes the normalized data

Table 10: Normalized Experimental Data for Boric acid under MQL Condition

Ex No.	Ra 1 (µm)	TW 1 (mm)
1	1	0.863014
2	0.229277	0
3	0.485009	0.589041
4	0.613757	0.452055
5	0.049383	0.315068
6	0.352734	0.712329
7	0.770723	1
8	0.049383	0.589041
9	0	0.315068

Table 11: Eigen Values and Eigen Vectors for boric acid

	PC1	PC2
Eigen vectors	0.707	0.707
	0.707	-0.707
Eigen values	1.6797	0.5239
Accountability Proportion (AP)	0.84	0.16
Cumulative AP	0.84	1.000

4.3.2Calculating Principal Components (PC)

Composite Principal Components (CPC) and S/N values

$$PC\ 1= 0.707xRa+0.707xTW \qquad (6)$$

$$PC2 = 0.707xRa-0.707xTW \qquad (7)$$

$$CPC = (PC_1^{\,2}+PC_2^{\,2}+PC_3^{\,2})^{1/\text{No. of Responses}} \qquad (8)$$

$$CPC= (PC^2+PC^2)^{0.5} \qquad (9)$$

$$\eta = -10\ln_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \qquad (10)$$

Where η is S/N Value and y is CPC Value

Table12: Principal Components

Ex No.	PC1	PC2
1	1.317151	0.096849
2	0.162099	0.162099
3	0.759353	-0.07355
4	0.753529	0.114323
5	0.257667	-0.18784
6	0.752999	-0.25423
7	1.251901	-0.1621
8	0.451366	-0.38154
9	0.222753	-0.22275

Table 13: CPC and S/N Values

Ex No.	CPC	SN Low
1	1.320707	-2.41613
2	0.229242	12.79411
3	0.762907	2.350568
4	0.762152	2.359171
5	0.318867	9.927812
6	0.794759	1.995286
7	1.262352	-2.02361
8	0.591018	4.567983
9	0.315021	10.03321

From the above analysis the mean of S/N ratios plot is obtained

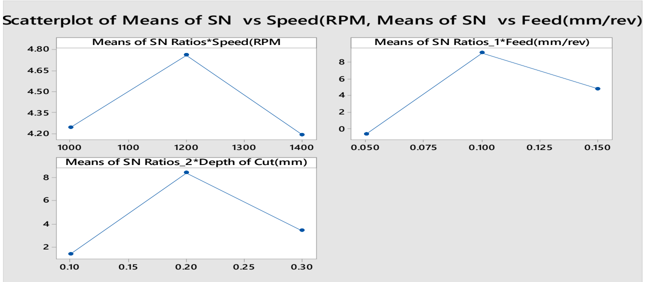

Figure 7: Main effect plot of S/N ratios for boric acid under MQL

- The optimized input parameters for Boric acid under MQL cutting condition were speed=1200rpmfeed=0.1 mm/rev, depth of cut=0.2 mm. Corresponding output responses are Tool wear(TW 1) = **0.07 mm** Surface Roughness (Ra 1) = **0.86 µm**
- While in Boric acid under MQL with increase in speed there was first decrease from 1000 rpm to 1200 rpm then there was gradual increase from 1200 rpm to 1400 rpm and with increase in feed there was decrease from 0.05mm/rev to 0.1mm/rev then there was gradual increase from 0.1mm/rev to 0.15 mm/rev.
- The decrease in case of Boric acid may be attributed to its early spreading action. The lubricating action of the Boric acid reduces the frictional forces between the tool and work piece, thereby reducing the temperatures developed and reducing tool wear, thus increasing tool life, resulting in surface quality improvement.
- At higher cutting speeds and feeds high temperatures are generated. Under high temperatures Boric acid melts creating a thin film there by reducing effective lubrication which results in higher surface roughness and tool wear.

Table 14: Normalised Data for Graphite under MQL

Ex No.	Ra 2(µm)	TW 2(mm)
1	0.618709	0.555556
2	0.555393	0.611111
3	0	0.888889
4	1	0.444444
5	0.726339	0.888889
6	0.05796	1
7	0.939105	0.111111
8	0.807043	0.222222
9	0.234776	0

Table 15: Eigen Values and Eigen Vectors for Graphite

	PC1	PC2
Eigen vectors	-0.707	-0.707
	0.707	-0.707
Eigen values	1.445	0.555
Accountability Proportion (AP)	0.722	0.278
Cumulative AP	0.722	1

$$PC1 = -0.707xRa+0.707xTW \quad (11)$$
$$PC\ 2 = -0.707xRa-0.707xTW \quad (12)$$

Table 16: Principal Components

Ex No	PC1	PC2
1	-0.04465	-0.8302
2	0.039393	-0.82472
3	0.628444	-0.62844
4	-0.39278	-1.02122
5	0.114923	-1.14197
6	0.666022	-0.74798
7	-0.58539	-0.7425
8	-0.41347	-0.72769
9	-0.16599	-0.16599

Table17: CPC and S/N Values

Ex No.	CPC	SN Low
1	0.831405	1.603751
2	0.825658	1.663993
3	0.888755	1.024362
4	1.094152	-0.78156
5	1.147734	-1.19683
6	1.001527	-0.01325
7	0.945512	0.486656
8	0.836953	1.545981
9	0.234741	-12.5882

From the above analysis the mean of S/N ratio values plot is obtained

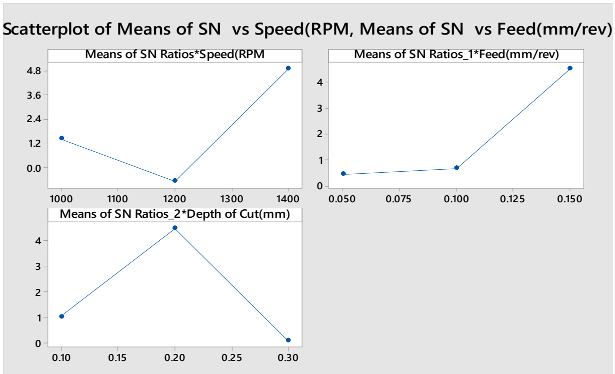

Figure 8: Main effect plot of means for Graphite under MQL

- The Optimized input parameters for Graphite under MQL Cutting Condition were Speed= 1400 RPM, feed= 0.15mm/rev, depth of cut =0.2mm. Corresponding output Responses are Tool Wear = **0.1mm** Surface Roughness= **1.67µm**
- While in Graphite under MQL with increase in speed there was first increase from 1000 rpm to 1200 rpm then there was gradual decrease from 1200 rpm to 1400 rpm and with increase in feed there was increase from 0.05mm/rev to 0.1mm/rev. then there was gradual decrease from 0.1mm/rev to 0.15 mm/rev
- At lower speeds and feed it shows abrasive action Due to this abrasive action surface roughness and tool wear are higher. but at higher speeds and feed high temperature are generated .under such high temperature Graphite melts creating a thin film which reduces the frictional forces between the tool and work piece, thereby reducing the temperatures developed and finally preventing tool wear, thus increasing tool life, resulting in surface quality improvement

5. Conclusions

Based on the experimental investigation on EN-31 work piece with coated carbide inserts the following conclusions are drawn

- Boric acid mixture under MQL is better at medium speed, medium feed, medium depth
- Graphite mixture under MQL is better at higher speed ,higher feed, medium depth
- From analysis of variance (ANOVA) analysis it is observed that model is significant
- Principal component analysis has given optimal combination of input process parameters and their corresponding responses for Boric acid Speed at level 2(1200 rpm), Feed at level 2(0.1 mm/rev) Depth at level 2 (0.2 mm) and Graphite Speed at level 3(1400 rpm), Feed at level 3 (0.15 mm/rev) Depth at level 2 (0.2 mm)
- Boric acid under MQL shows less Tool wear and Surface roughness compared to Graphite under MQL
- MQL with solid lubricants is far better process than Wet or flooded system as it is economical, environment friendly and a faster machining process

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References

[1] Uttara R. Salunke, M. G. Rathi , optimization of hard turning process parameters of AISI D2 under dry cutting conditions, international journal of scientific & engineering research, volume 6, issue 3, march-2015

[2] A.S. Varadarajan, P.K. Philip, B. Ramamoorthy, investigations on hard turning with minimal cutting fluid application (HTMF) and its comparison with dry and wet turning international journal of machine tools & manufacture 42 (2002) 193–200

[3] N. R. Dhar, M. T. Ahmed, S. Islam An Experimental Investigation on Effect of Minimum Quantity Lubrication in Machining AISI 1040 Steel, International Journal of Machine Tools & Manufacture, Vol. 47, 2007, pp. 748-753.

[4] S. Paul, N.R dhar, A.B chatopadhyaya, beneficial effects of cryogenic cooling on tool wear, dimensional accuracy and surface finish in turning aisi1040 and E4340C steels, wear249(2002) 932-942.

[5] Pratik l. Nagalwade, A. V. Kale Performance evaluation of tin coated and uncoated carbide tools in turning aisi 4140 steel, 5th international & 26th all india manufacturing technology, design and research

conference (AIMTDR 2014) december 12th–14th, 2014

[6] APS gaur, sanjay agarwal, an experimental investigation into the applicability ofBoric acid as solid lubricant in turning AISI 4340 steel, 5th international & 26th all india manufacturing technology, design and research conference (AIMTDR 2014) december 12th–14th, 2014

[7] Lb abhang and m hamedullah, optimisation of machining parameters in steel turning operation using taguchi method ,procedia engineering 38 (2012) 40 – 48

[8] Uma Maheshwera Reddy Paturia,*, Yesu Ratnam Maddua, Ramalinga Reddy Maruria, Suresh Kumar Reddy Narala Measurement and analysis of surface roughness in WS2 solid lubricant assisted minimum quantity lubrication (MQL) turning of Inconel 718, Procedia CIRP 40 (2016) 138 –143

[9] N. Suresh Kumar Reddy , P. Venkateswara Rao (2005) Performance Improvement of End Milling Using Graphite as a Solid Lubricant, Materials and Manufacturing Processes, 20:4,673-686

[10] Venu Gopal, A., and P. Venkateswara Rao. "Performance improvement of grinding of SiC using Graphite as a solid lubricant." Materials and manufacturing processes 19, no. 2 (2004): 177-186.

[11] R Padmini1, P Vamsi Krishna2 and G Krishna Mohana Rao3 Experimental evaluation of nano-molybdenum disulphide and nano-Boric acid suspensions in vegetable oils as prospective cutting fluids during turning of AISI 1040 steel, Engineering Tribology 0(0) 1–13 ! IMechE 2015

[12] Patil Deepak Kumar h, Dr. M. Sadaiah, "investigationson finish turning of AISI 4340 steel in different cutting environments by CBN insert

[13] Vamsi Krishna, P., R. R. Srikant, and D. Nageswara Rao. "Solid lubricants in machining." Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology 225, no. 4 (2011): 213-227.

[14] Damera, Nageswara Rao, and Vamsi Krishna Pasam. "Performance profiling of Boric acid as lubricant in machining." Journal of the Brazilian Society of Mechanical Sciences and Engineering 30, no. 3 (2008): 239-244.97.

[15] Kumar S, Singh D, Kalsi NS., 2017, Experimental investigation of the effect of environmental conditions during hard turning of AISI 4340 steel with CBN inserts. International Journal of Advanced Mechatronics and Robotics, 9(1), pp.111-115.