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Influence of different conditions on Surface Roughness in Hard Turning of AISI4340 Steel

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Abstract: In the present study, an attempt has been made to investigate the effect of different conditions (dry condition, wet and solid lubricant condition) on surface roughness in finish hard turning of AISI 4340 steel with hardness 60HRC using CBN tool. Its applications have been found in making dies and mould, roller and ball bearings, automobile and aircraft parts. Water based lubricant used as wet lubricant and boric acid in powder form is used as a solid lubricant. Three factors speed, feed and depth of cut were taken at three levels low, medium and high. The machining experiments were conducted based on RSM (Response Surface Methodology) and sequential approach using face CCD (Central Composite Design).The result indicated that there is significant improvements in a surface finish with the use of solid lubricants.

Keywords: Cutting Conditions, Hard Turning, Response Surface Methodology, Solid Lubricants, Surface Roughness.

I. INTRODUCTION

Industries around the world constantly strive for lower cost solutions with better surface quality in order to maintain their competitiveness [1-2]. Hardened steels are widely used in the traditional method of machining; hardened materials includes rough turning, heat treatment, and then grinding process. However, hard turning eliminates some of the unnecessary steps involved in the machining of hard materials and hence results in the increase of productivity rate [3-4]. Hard turning is the process of machining hardened ferrous material with a hardness value more than 45HRC in order to obtain finished work pieces directly from hardened parts [5]. The acceptance of this process of machining these steels (with high hardness) demands special machines and cutting tools with high rigidity and accuracy [6].

The various advantages of hard tuning are higher productivity, reduced set up times, surface finish closer to grinding and ability to machine the complex parts. Nowadays, hard turning is being employed in industries as a substitute for grinding process. This has become possible due to the development of new cutting tool materials such as CBN and mixed ceramics [7].

Due to the strict regulations and their enforcement regarding the use of the cutting fluids in industries, the researchers have started exploring the alterative methodologies. One of the solutions is to use the solid lubricants in order to reduce the tool wear and to improve the overall performance of the machining process. In the present study, the effect of different cutting conditions *(dry condition, wet and solid lubricant condition)* on the surface finish in the hard turning of the AISI4340 steel with the CBN tools was studied and their comparison has been made.

II. REVIEW OF LITRATURE

Singh and Rao [8] discussed about surface finish, and it was found that it varies when the cutting parameters varies. Statistical analysis of the experiment processed using ANOVA (analysis of variance). Surface roughness increases with the increase of feed rate and depth of cut and decreases with the increase of cutting speed.

Krishna et al. [9] studied the tool wear and surface roughness when solid lubricants were applied and compare with dry and wet machining. Graphite and boric acid in proportions of 5%, 10%, 20% and 30% by weight are mixed with SAE 40 oil. EN8 steel having hardness 30±2 HRC with carbide tool used. It was found that surface finish has been improved as compared to dry machining.

Reddy et al. developed surface roughness model for machining of aluminium alloys. Carbide cutting tool used with CNC machine is used for machining aluminium alloys for a wide range of machining conditions. The surface roughness was measure during the experimental work. RSM was used to optimize the experimental work. Results revealed that surface roughness increased with depth of cut.

H-J Hu and Huang [10] studied the tool wears and compare the tool materials like common ceramic and ultra-fine grained ceramic tools for better hard turning results with the help of different techniques. FEM (finite element modeling) approaches & lagrangian increment method were used for 3D metal turning. DEFORM -3D V6.0 software for simulate the turning process. Flank wear measured by scanning electron microscope (SEM) JSM 6460 LV. Wear rate calculated by using Archard empirical wear mode. As turning proceeds the amount of wears increases gradually for common ceramic tool and ultrafine-grained ceramic tool. The wear depths of common ceramic tool are bigger than that of ultrafine-grained ceramic tool.

B. Varaprasad et al. [11] studied the effect of machining parameters (feed, speed, depth of cut) on tool wear (flank wear), during hard turning of AISI D3 steel having hardness 62HRc with mixed ceramic insert (CC6050). It was found that the excessive temperature directly influences the temperatures of tool face and tool flank, and this leads to thermal damage of machined surface.

Revel et al. [12] used AISI 52100 bearing steel rings thermally treated to average hardness of 61±1 HRC to study the surface roughness and residual stresses. Full factorial experimental design was performed to analyze the effect of cutting parameters. Surface roughness strongly affected by feed rate and it was found that when feed rate decreases surface roughness decreases and with the increase in cutting speed the surface finish increases.

III. PROBLEM FORMULATION

It has been seen in the literature review that different authors have studied different cutting parameters, tool geometry on different materials like AISI 52100, AISI 1045, 41Cr4 under different conditions like using cryogenics, solid lubricants, wet lubricants etc. but it has been found that no previous literature was available to see the effect of different conditions (Dry, Wet lubricant & Solid lubricant condition) on surface roughness in hard turning of AISI 4340 steel.

IV. OBJECTIVES

The main objectives of this work are given below:

(i) To determine the surface roughness (Ra) under different conditions.

(ii) To compare the different conditions to find best suitable condition for surface roughness (Ra).

V. EXPERIMENTAL SETUP AND METHODOLOGY

5.1 Work Material:

The material AISI 4340 steel is chosen for experimentation, based on its wide applications in die and mould steel, roller and ball bearings, manufacturing material for steel balls for shot peening, blasting, barrel cleaning etc. This variety of steel can possess hardness up to 60 HRC when heat treated as against a hardness of 23 HRC in its raw form.

Table 1: Details of Work Piece

Work material	Hardness	Length	Diameter
AISI 4340 steel	60 HRC	120 mm	50 mm

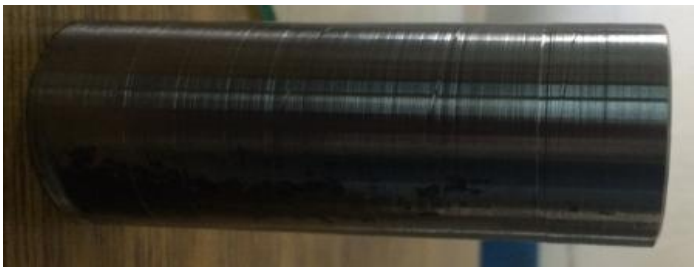

Figure 1: Work materials AISI 4340 steel

5.2 Chemical Composition of Work Material:

Table 2: Chemical Composition of Work Material

Item	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%	Co%	Hardness
Steel Bar (Round)	0.402	0.235	0.592	0.0190	0.0225	1.00	0.200	1.41	0.0088	135-144 BHN

5.3 Cutting Tool Details:

CBN insert was used for this experimental work. Tool was selected according to the tool holder and material requirement. To machine work material of 60 HRC; CBN insert is recommended because of its high hardness properties, wear resistance and thermal stability. Tool specification is given in table 3.

Table 3: Details of Cutting Tool

Insert Type	Insert Shape	Insert Specification	Nose Radius
CBN (Cubic Born Nitride)	Rhombic	CCMT09	0.8 mm

5.4 Surface Roughness Tester:

Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. The most commonly used surface roughness parameters are Ra (arithmetic mean deviation).

Table 4: Details of Surface Roughness Tester

Make	Roughness Parameter	Filter	Probe Tip Radius	Measuring Speed
SJ-301, Mitotoyo	Ra, Rz, Rq	Gaussian	0.002 mm	0.25 mm/s

5.5 Cutting Parameters and Methodology:

The experiments have been designed by Center Composite Design defined by Response Surface Methodology using Design Expert software (Version 8.0.). Analysis of variance (ANOVA) was employed to find out the most significant input parameters, and their interactions, in terms of their significant effect on different cutting parameters and cutting condition. To check the cutting parameter and cutting conditions performance, sequential F-test, lack of fit test and other adequacy measures were used. Trial experiments were conducted in order to find out best suited cutting parameters for evaluation of machining variables of work materials. While selecting cutting parameters, capability of the machine as well as the cutting tool were also taken into account. The cutting parameters used in the experiments are given in table no, 5. The total numbers of experiments conducted for each case was twenty including fourteen base experiments and six repeat experiments.

Table 5: Cutting Parameters for Experimentation

Approaching Angle (degree)	Cutting Speed (m/min)	Feed rate (mm/rev)	Depth of Cut (mm)
90	100, 125 , 150	0.4 , 0.8 , 0.12	0.1 , 0.2 , 0.3

VI. RESULTS AND DISCUSSION

The effects of selected cutting parameters such as cutting speed, feed and depth of cut with dry cutting condition, wet lubricant cutting condition and solid lubricant cutting condition have been discussed. Table 5.1 presents the experimental design matrix and collected data for surface roughness (Ra) with different conditions.

Table 6: Experimental results of Surface Roughness (Ra), with Dry, Wet and Solid Lubricant Conditions

Sr. No.	Cutting Speed	Feed	D.O.C	Ra, Dry Condition	Ra, Wet Lubricant	Ra, Solid Lubricant
1	100.00	0.12	0.10	0.45	0.51	0.41
2	150.00	0.04	0.10	0.18	0.19	0.19
3*	125.00	0.08	0.20	0.39	0.47	0.33
4*	125.00	0.08	0.20	0.39	0.46	0.33
5	150.00	0.12	0.30	0.71	0.78	0.66
6*	125.00	0.08	0.20	0.39	0.47	0.33

7	125.00	0.04	0.20	0.32	0.38	0.28
8	100.00	0.04	0.10	0.22	0.25	0.21
9	100.00	0.04	0.30	0.57	0.66	0.5
10	100.00	0.12	0.30	0.88	1.1	0.68
11	150.00	0.12	0.10	0.35	0.44	0.28
12	125.00	0.08	0.30	0.58	0.66	0.52
13	125.00	0.12	0.20	0.62	0.71	0.55
14*	125.00	0.08	0.20	0.39	0.47	0.33
15*	125.00	0.08	0.20	0.39	0.47	0.33
16	150.00	0.08	0.20	0.37	0.44	0.32
17	125.00	0.08	0.10	0.25	0.3	0.22
18	150.00	0.04	0.30	0.49	0.56	0.44
19*	125.00	0.08	0.20	0.39	0.47	0.33
20	100.00	0.08	0.20	0.44	0.52	0.38

6.1 Surface Roughness (Dry Condition) = $1.60 + 0.079A - 0.23B - 0.34C - 1.085E - 003AB - 0.025AC + 0.10BC - 0.012\,A^2 - 0.069\,B^2 + 0.068C^2$ -- (i)
where A is cutting speed, B is feed, C is D.O.C., AB is the interaction factor between cutting speed and feed, AC is the interaction factor between cutting speed and D.O.C., BC is the interaction factor between feed and D.O.C., Negative sign in front of each term represents antagonistic effect, while synergistic effect is represented by positive sign.

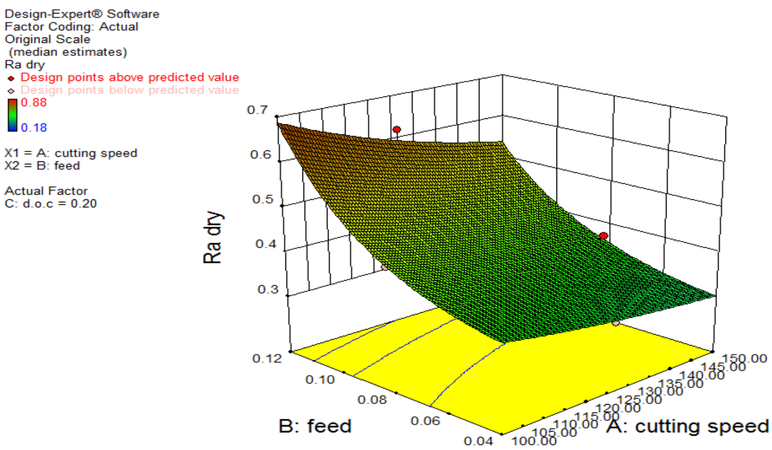

Figure 2: 3-D Plot between Cutting speed and Feed rate under dry conditions

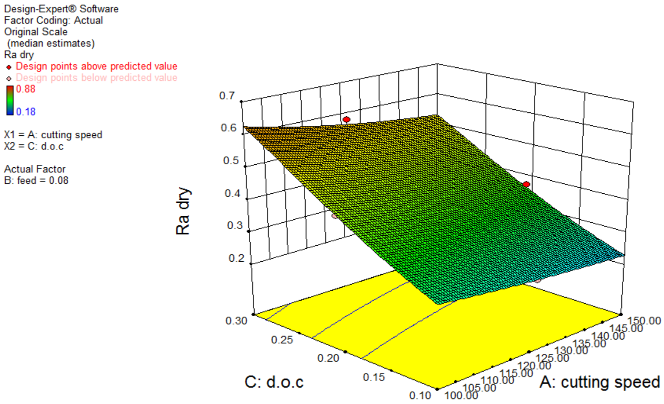

Figure 3: 3-D Plot between Cutting speed and Depth of cut under dry conditions

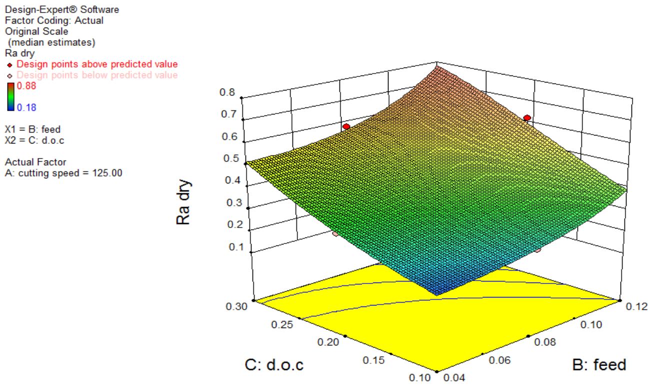

Figure 4: 3-D plot between Feed and Depth of cut under dry conditions

Maximum value of surface roughness was found to be 0.88 µm when the cutting speed was 100 mm/sec, feed 0.12 mm/rev. and depth of cut is 0.3 mm. The minimum value of surface roughness was 0.18µm at cutting speed 150 mm/s, feed rate 0.04 mm/rev. and depth of cut 0.1mm. This shows that surface roughness decreased with the higher cutting speed, lower feed and lower depth of cut.

6.2 Surface Roughness (Wet Condition) = -0.33 - 0.048A + 0.13B + 0.18C - 2.859E -003AB - 4.669E - 003AC - 0.039BC + 4.623E - 003A^2 + 0.040B^2 - 0.027C^2 -- (2)

where A is cutting speed, B is feed, C is D.O.C., AB is the interaction factor between cutting speed and feed, AC is the interaction factor between cutting speed and D.O.C., BC is the interaction factor between feed and D.O.C., Negative sign in front of each term represents antagonistic effect, while synergistic effect is represented by positive sign.

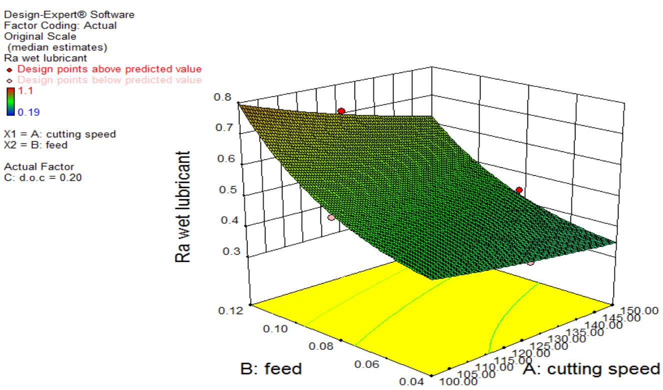

Figure 5: 3-D Plot between Cutting speed and Feed rate under wet conditions

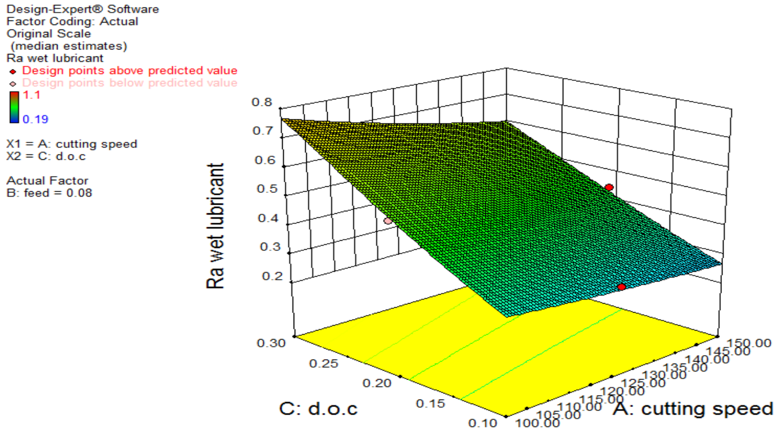

Figure 6: 3-D Plot between Cutting speed and Depth of cut under wet conditions

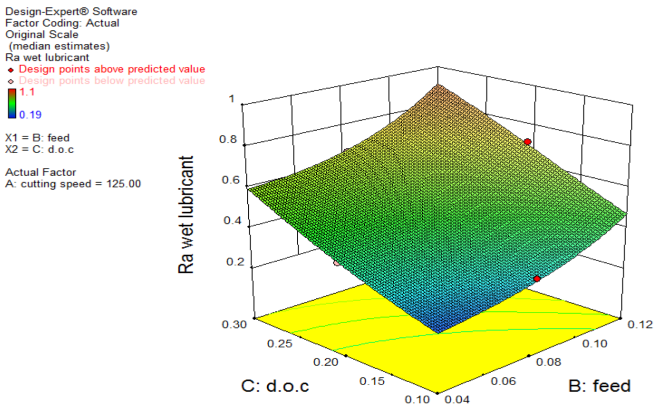

Figure 7: 3-D plot between Feed and Depth of cut under wet conditions

Maximum value of surface roughness was found to be 1.1 µm, when the cutting speed is 100 mm/sec, feed 0.12 mm/rev. and depth of cut is 0.3 mm. The minimum value of surface roughness was 0.19 µm at cutting speed 150 mm/sec., feed rate 0.04 mm/rev. and depth of cut 0.1mm. This shows that surface roughness decreased with the higher cutting speed, lower feed and lower depth of cut.

6.3 Surface Roughness (Solid Lubricant) = + 10.60 + 2.00A - 5.73B -9.02C + 0.069AB - 1.68AC + 4.37BC - 1.00A^2 - 1.27B^2 + 4.01C^2 --- (3)

where A is cutting speed, B is feed, C is D.O.C., AB is the interaction factor between cutting speed and feed, AC is the interaction factor between cutting speed and D.O.C., BC is the interaction factor between feed and D.O.C., Negative sign in front of each term represents antagonistic effect, while synergistic effect is represented by positive sign.

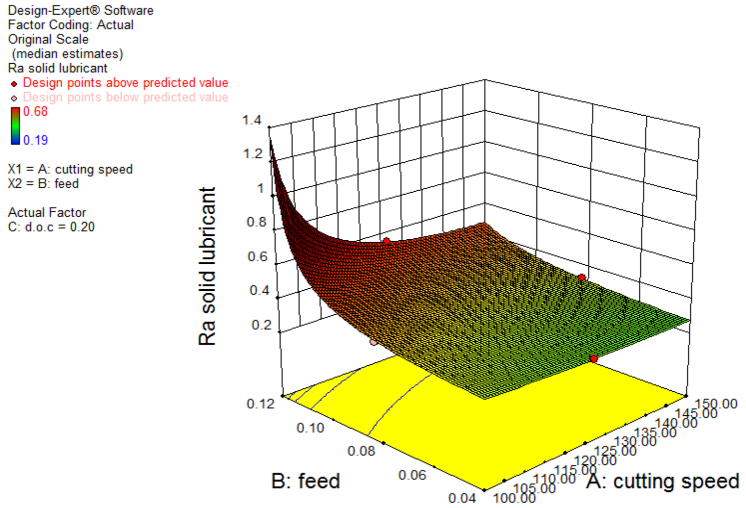

Figure 8: 3-D Plot between Cutting speed and Feed rate under solid conditions

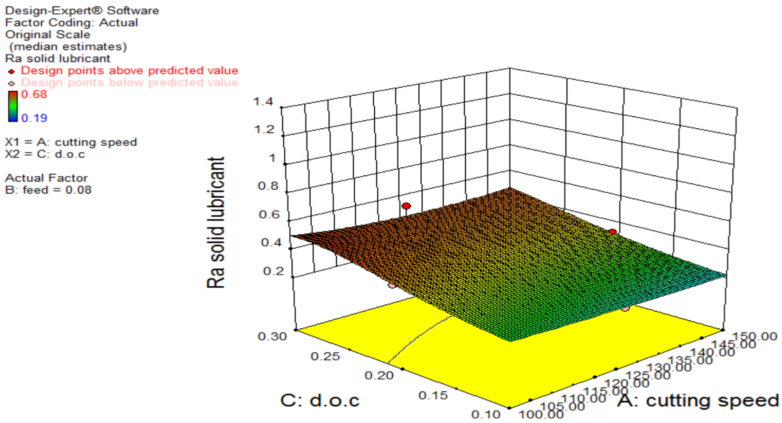

Figure 9: 3-D Plot between Cutting speed and Depth of cut under solid conditions

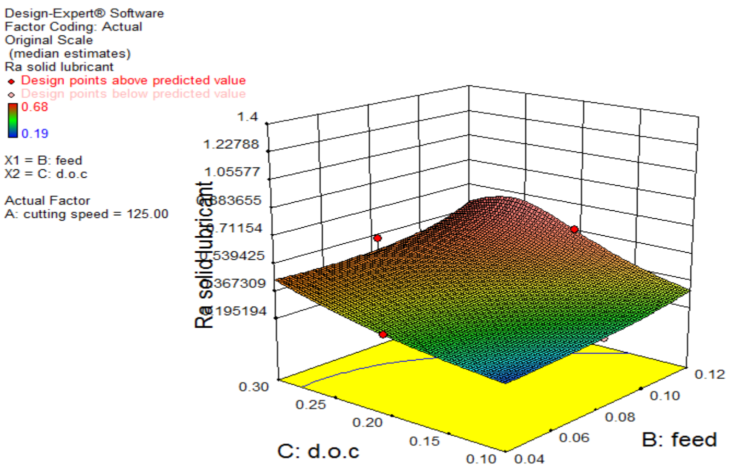

Figure 10: 3-D plot between Feed and Depth of cut under solid conditions

Maximum value of surface roughness was found to be 0.68 µm, when the cutting speed is 100 mm/s, feed 0.12 mm/rev. and depth of cut is 0.3 mm. The minimum value of surface roughness was 0.18 µm.

6.4 Comparison Plot for Surface Roughness with all Cutting Conditions

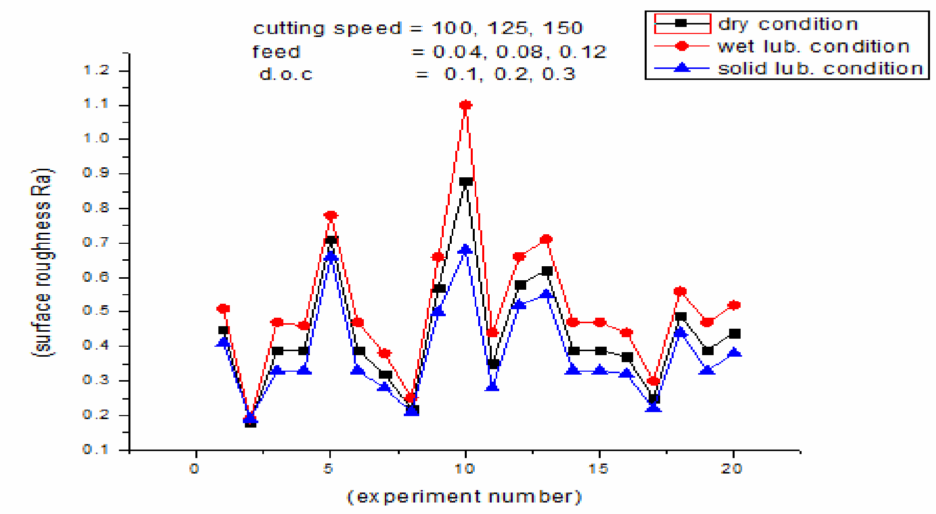

Figure 11: Comparison plot of Surface roughness (Ra) with all Cutting condition

The results of solid lubricant in hard turning of AISI 4340 steel with CBN insert are better as compared to other two conditions (wet lubricant condition & dry condition). The values of surface roughness (Ra) decreases in solid lubricant condition as compared to wet lubricant condition and dry condition because with the use of solid lubricant, frictional force between work piece and insert reduced as compared to dry condition and wet lubricant condition. Due to this, material removes smoothly in solid lubricant condition. In dry turning the friction between work material and insert is high as compared to solid lubricant condition and in wet lubricant condition surface roughness is increasing due to increase of hardness during turning.

VII. CONCLUSION

In this study, surface roughness were measured during turning of AISI 4340 Steel with CBN (Cubic Boron Nitride) insert under different cutting conditions.

(i) Maximum value of surface roughness in dry condition is **0.88 µm** when the cutting speed is 100 mm/s, feed 0.12 mm/rev. and depth of cut is 0.3 mm.
(ii) Maximum value of surface roughness in wet lubricant condition is **1.1 µm**, at same cutting speed, feed and depth of cut which are used in dry condition.
(iii) Maximum value of surface roughness in solid lubricant condition is **0.68 µm**, at same cutting parameters which are used in both dry condition and wet lubricant condition.
(iv) Minimum surface roughness was obtained under solid lubricant conditions compared to wet and dry conditions in all the process parameters.

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