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Performance evaluation of uncoated carbide inserts during turning of hardened steel

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Abstract
MQL is also known as near to dry machining (NDM) which is an alternative to conventional cooling/lubrication. MQL extremely reduce the consumption of cutting fluids and reduction in temperature at cutting zone by cooling effect of the compressed air and partially evaporation of the oil mist when it meets hot tool-chip interface. The minimization of cutting fluid also leads to economical, industrial hygiene & environmental benefits [17, 18]. One of the most significant issues in cutting technology is to improve cutting tool life and prevent tool damages including tool wear and chip adhesion which leads to tool failure. Especially in machining of steel materials and nickel alloys the increase in demand for high efficiency machining and the decrease of product cost requires the investigation of tool life in recent years.

Keywords: dry machining, minimum quantity lubrication (MQL)

Introduction
Experimental set up
Minimum quantity Lubrication also known as near dry machining machining (NDM) which is an alternative to conventional cooling/lubrication. MQL extremely reduce the consumption of cutting fluids and reduction in temperature at cutting zone by cooling effect of the compressed air and partially evaporation of the oil mist when it meets hot tool-chip interface. The minimization of cutting fluid also leads to economical, industrial hygiene & environmental benefits [17, 18]. One of the most significant issues in cutting technology is to improve cutting tool life and prevent tool damages including tool wear and chip adhesion which leads to tool failure. Especially in machining of steel materials and nickel alloys the increase in demand for high efficiency machining and the decrease of product cost requires the investigation of tool life in recent years. In this research lubrication oil used in MQL was soybean oil as it is eco-friendly and easy to dispose off. Fig 1. (a), (b) shows the MQL setup used with Lathe machine. In the present study groundnut oil is used as lubricant at the flow rate of 50ml/hr.

(a) (b)

Fig 1: (a) Nozzle used in MQL setup, (b) MQL setup used with lathe machine

Work Piece Material Selection & Preparation
Introduction: - AISI 4340 Steel rods of Diameter 24 mm and length 240 mm were selected as it is used in Heavy-duty axles, shafts, heavy-duty gears, spindles, pins, studs, collets, bolts, couplings, sprockets, pinions, torsion bars, connecting rods, crow bars, conveyor parts etc. Round bar was cut in length of 240 mm.

Table 1: Chemical Properties of AISI-4340.

Chemical Composition	C	Si	Mn	P	S	Cr	Mo	Ni	Fe
(%)	.370-.430	.150-.300	.600 - . 800	.0350	.0400	.700 -. 900	.200 - . 300	1.65 – 2.0	95.195 – 96.33

Work piece preparation: The work piece was cut to required length with the help of power hacksaw after which sizing and centring is done by maintaining L/D ratio as per ISO 3685 standards.

Sizing & Centring operation: - In this outer layer of the piece were removed using carbide tools. This was done to remove the oxidation layer before the start of the heat treatment the length of the piece was controlled as 200 mm during sizing & centring operation.

(a) (b)

Fig 2: AISI 4340 Steel rod (a) Unfinished (b) Finished

Heat treatment of Workpieces

1. The solid bars were through hardened by first preheating at 560 to 600 deg C for 1 hr followed by second preheating from 830 to 880 deg C. The heated Workpieces were than quenched in hot salt bath maintained at 500 deg C to obtain the hardness of 45 HRC ± 0.5
2. The reduction in hardness of 1 HRC within a distance of 2 to 3 mm was observed while moving outer surface towards the centre of workpiece. The hardening was followed by two tempering cycles of 500 deg C for 2 hrs in order to improve ductility.

Tool Insert

The uncoated carbide inserts are considered as commonly used tools for machining medium to hard cut materials. Thus, in this study uncoated carbide inserts of triangular shape with 0.8 mm nose radius were procured from WIDIA having specification TNMA 160408-THMF, as the cost of these tools is also less as compared to other tooling material used to machine hard to cut materials.

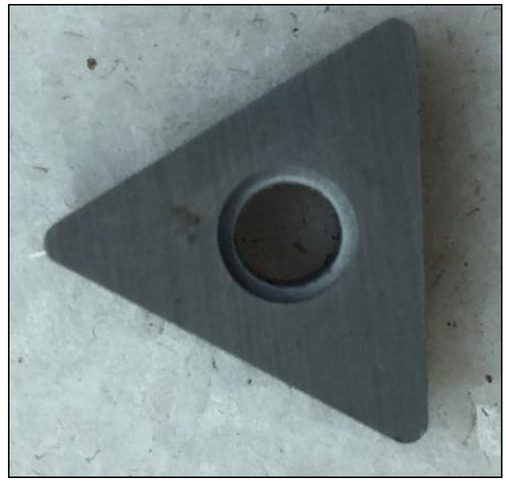


Fig 3: Tool Insert TNMA 160408-THMF (WIDIA)

MQL – Soybean Oil

Lubrication oil used in MQL was soybean oil as it is eco-friendly and easy to dispose off.

Table 2: Chemical Properties of Soybean oil.

Relative density (gm/cm^3)	Refractive index (nd40°C)	Viscosity (Kinematic at 20°C, mm^2/sec)	Cold test (15 hrs at 4°C)	Moisture content	Thermal conductivity (W/m° K)
0.917	1.4736	78.3	Passed	13.2	0.192-0.198

Experiment Parameters

Investigation on finished turning of AISI-4340 Steel

Literature reveals that for finished turning of AISI 4340 Steel it is preferable to use carbide tool below 50 HRC [21]. But in order to explore the possibilities of working of carbide tool above 50 HRC preliminary experimentation at 50 and 55 HRC were conducted at fixed speed (200 m/min), feed (.25 mm/sec) and DoC (.1 mm). Literature indicates that most significant parameters are speed, feed and DoC which affects the overall performance of turning operation (paper reference). Results indicated that at 55 HRC tool underwent catastrophic failure below 1 min of machining time as shown in Fig (4) and at 50 HRC under the tested conditions the machining time was only 2.2 minutes as the tool reaches V_{Bmax} value of 200 Micron. Based on above tested facts it was decided to conduct the experimentation at 45 HRC.

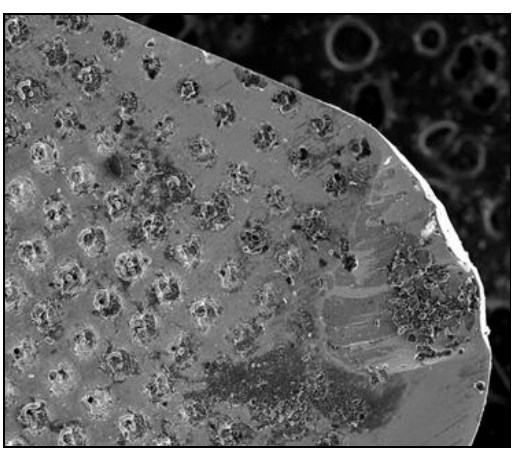


Fig 4: Failure of tool at 55 HRC

After deciding the workpiece hardness the second set of preliminary experiments were conducted to decide the maximum value of speed and feed during experimentation. In order to explore the suitability of higher values of speed and feed preliminary investigations were carried out at speed V1=200m/min and V2 = 250 m/min with feed of F1=. 25 mm/rev and F2= 0.3 mm/rev.

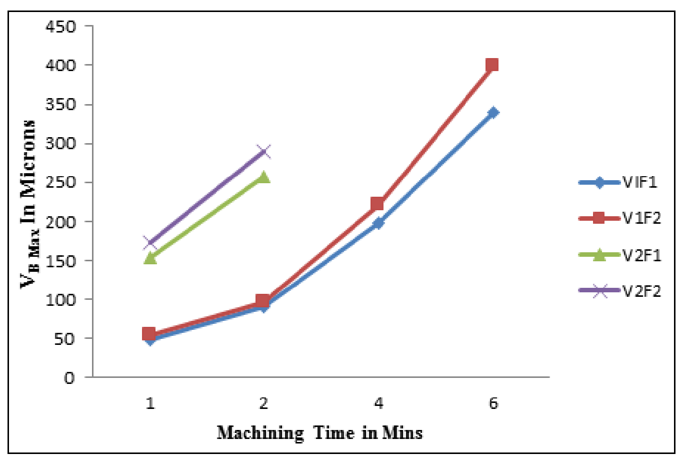


Fig 5: Flank wear

The detailed experimentation results were plotted in Figure-5. In this flank wear of inserts was measured w.r.t different machining time. At highest speed and feed after 1 min of machining time a sudden increase in noise during machining was observed and at 2 min of machining time the measured value of flank wear was 290 microns similarly at higher speed and feed of. 25 mm/rev the total machining time was less than 2 mins as the inserts crosses 200 micron limit. Thus it was clear not to opt cutting speed of 250 m/min for the experimentation as indicated in fig-1.at 200m/min speed and both the feed the machining time was only 4 mins and even less than that. Thus it was finally decided to keep the cutting speed for detailed experimentation below 200 micron and feed also below. 25 mm/rev.

Finally the value of cutting speed and feed and conditions were selected on the bases of literature [7] and preliminary experimentation as indicated in table 3.

Table 3: Parameters decided for actual experimentation for Dry Lubrication

Sample No	Symbol	feed (mm/rev)	cutting speed (m/min)	DOC (mm)
1	F1V1	0.07	70	0.1
2	F1V2	0.07	120	0.1
3	F1V3	0.07	190	0.1
4	F2V1	0.15	70	0.1
5	F2V2	0.15	120	0.1
6	F2V3	0.15	190	0.1
7	F3V1	0.22	70	0.1
8	F3V2	0.22	120	0.1
9	F3V3	0.22	190	0.1

Table 4: Parameters decided for actual experimentation for MQL

Sample No	Symbol	feed (mm/rev)	cutting speed (m/min)	DOC (mm)
1	F1V1	0.07	70	0.1
2	F1V2	0.07	120	0.1
3	F1V3	0.07	190	0.1
4	F2V1	0.15	70	0.1
5	F2V2	0.15	120	0.1
6	F2V3	0.15	190	0.1
7	F3V1	0.22	70	0.1
8	F3V2	0.22	120	0.1
9	F3V3	0.22	190	0.1

Result

The results of the experiments for Machining time, surface roughness and cutting forces carried out using textured uncoated carbide tools and the work piece material made of AISI-4340 hardened steel (45±1 HRC) under different lubricating conditions are given in Table 5

The values of response parameters measured corresponding to flank wear V_{Bmax} of 200 µ and depth of cut (DoC) of 0.1 mm

Table 5: Response for Machining Time & Surface roughness.

	Condition	F1V1	F1V2	F1V3	F2V1	F2V2	F2V3	F3V1	F3V2	F3V3
	Cutting Speed	70	120	190	70	120	190	70	120	190
M/C TIME (Minutes)	Dry Lubrication	9.5	8	6.5	9.3	8.4	6.9	8.8	6.2	5.1
	MQL	10.2	9.9	8.8	10	9.5	8	9.4	7.1	5.7
Surface Roughness R_A (µm)	Dry Lubrication	0.42	0.39	0.5	0.4	0.42	0.53	0.56	0.58	0.6
	MQL	0.38	0.35	0.46	0.36	0.38	0.49	0.54	0.56	0.58

Analyses of Tool Wear: In this study tool wear was measured in term of $V_{B\ max.}$ The criteria for stopping the experiment was V_B max ≥ 200 micron and Ra ≥ 1.5 micron as standard criterion and for checking the same SEM images were taken at regular intervals of time.

Analyses of tool wear for Tool under Dry conditions at various feed rates: Figure 6 shows machining time for turning AISI 4340 steel with dimple tool under dry conditions at feed rates 0.07, 0.15, 0.22 mm/rev and speed 70,120, 190 m/min respectively. Depth of cut was kept constant at 0.1 mm.

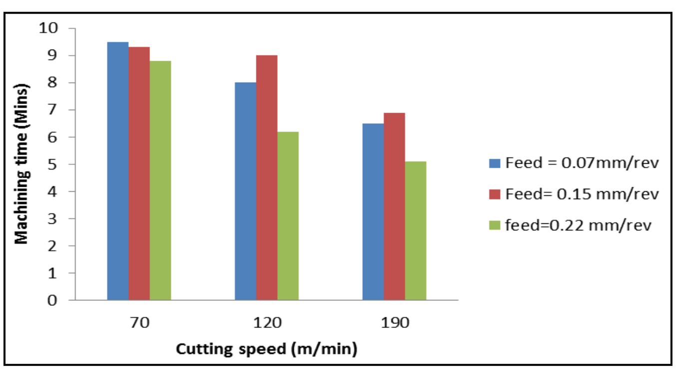


Fig 6: Machining time for tool under dry conditions

It is observed that at speed 70 m/min there was no significant decrease in machining time under selected feed rates, also the same is observed when speed is 120 m/min and feed is. 07 and 0.15 mm/rev but there was significant decrease in machining time when feed is increased to 0.22 mm/rev. When cutting speed is increased to 190 m/min, a drastic reduction in machining time of AISI 4340 steel was observed for various feed rates taken, which may be due to lack of lubrication and more friction at high speeds.

Analyses of tool wear for Tool under use of Minimum quantity Lubrication conditions at various feed rates

Figure 7 shows machining time for turning AISI 4340 steel with dimple texture tool under use of solid lubricant and Minimum quantity lubrication at Feed 0.07, 0.15 and 0.22 mm/rev and speed 70,120 and 190 m/min respectively, depth of cut was kept constant at 0.1 mm.

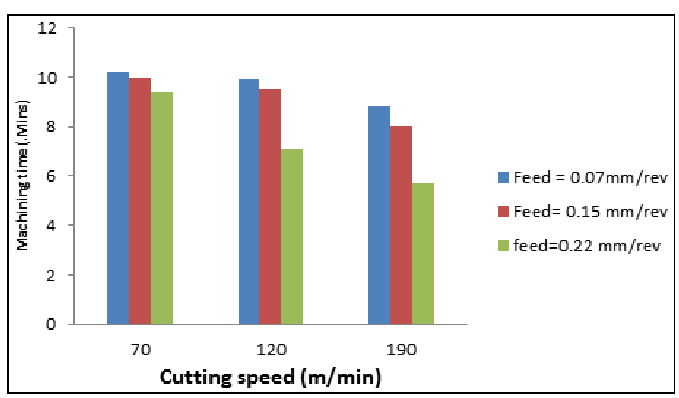


Fig 7: Machining time for tool using minimum quantity lubrication.

Same pattern is also observed in other conditions viz using solid lubrication and use of minimum quantity lubrication in contrast was only one thing that at speed 190 m/min the machining time at feed 0.07 and 0.15 mm/rev was almost same as indicated in the figure 5.2.

It was also observed that under different value of feed the machining time with lowest feed was high in comparison to other feeds; it was also observed that the difference in machining time with low and medium feed was marginal which indicated that the feed can be varied from 0.7 to 0.15 mm/rev without hindering the surface finish of work piece and other turning parameters. But in contrast at high feed the machining time was significantly low than other two feed particularly in high speed feed combination.

This was mainly due to the fact that with increase in speed the temperature at the cutting zone increases and resulted in more irregular flank wear along with chipping of rake surface near the cutting edge as shown in fig 8 which is taken when feed is 0.22 rev/mm and speed 190 m/min under dry condition.

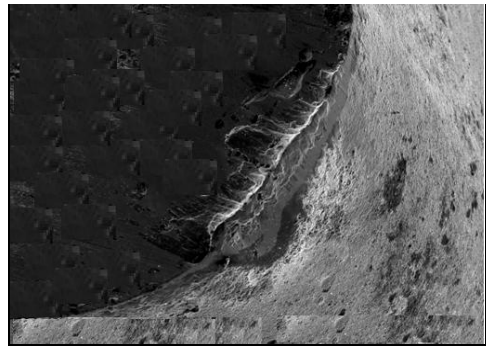
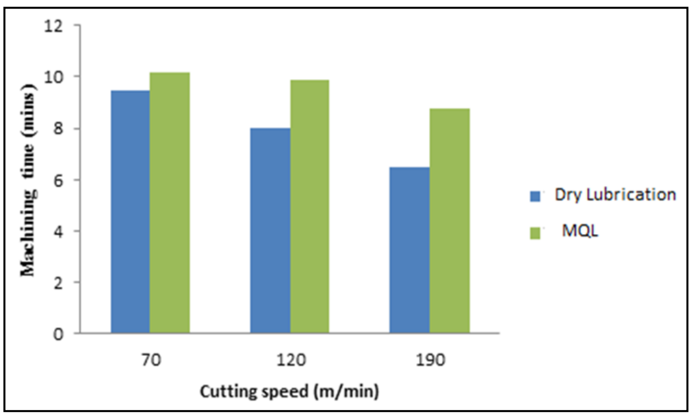


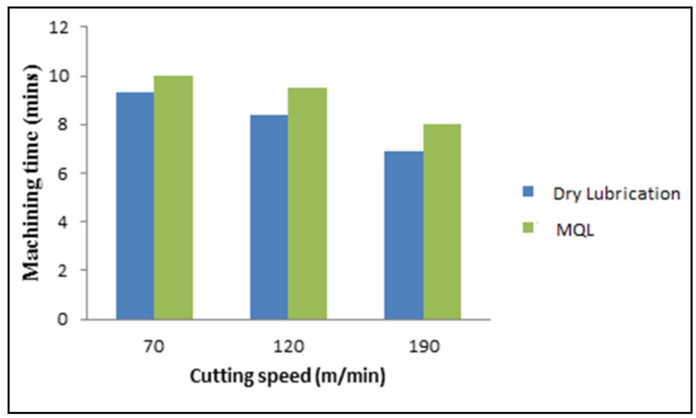
Fig 8: SEM Image of tool Insert at speed 190 m/min and feed 0.22 rev/min under dry condition

Comparison of machining time under various Lubrication conditions

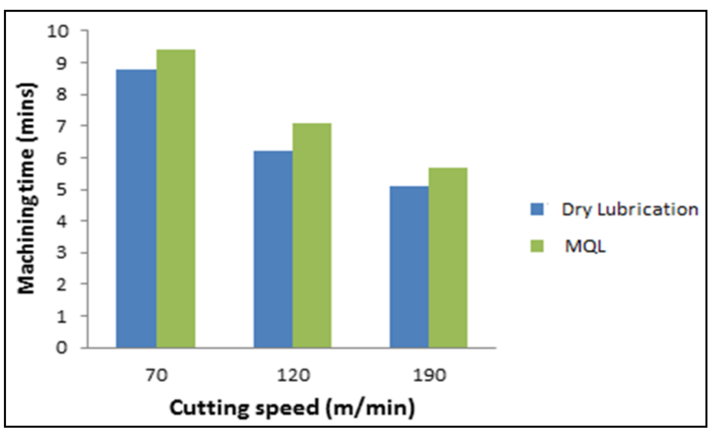
Figure 9 shows machining time for turning AISI 4340 steel with tool under dry condition and minimum quantity lubrication for different cutting speeds at different feed rates.



(a)



(b)



(c)

Fig 9: Machining time when feed rate is (a) 0.07 mm/rev (b) 0. 15 mm/rev and (c) 0.22 mm/rev

It was observed that for all cutting conditions the lowest value of machining time was obtained under the condition of only tool i.e. without use of any lubricant. This was mainly because of absence of any lubrication under the tool.

Similarly for all cutting conditions the highest value of machining time was obtained with tool under MQL. This is mainly due to precise flow of air oil mixture at flank face and near nose of the tool insert which helps in reducing the friction between the work piece and tool insert.

No doubt use of lubricant helps in effective lubrication of rake surface and resulted in reduced friction between chip and rake face but at the same time it does not improve any lubrication quality at flank face of the tool which can be effectively done by precise application of lubricant at nose, flank face of the tool insert with the help of nozzle used in minimum quantity lubrication and led to improvement in tool life. Therefore from above discussions it is clear that MQL improves the tool life and also it is an eco-friendly option.

Analyses of Surface Roughness

In this study using surface roughness analyser (SZ=301) Ra values were measured at regular intervals along with tool wear. The quantification of surface roughness (Ra) was carried out to observe the effect of different lubricating conditions. It was observed that under the influence of MQL the value of Ra was low in comparison to dry condition.

The comparison of effects of different feed on Ra was plotted as shown in figure 10. It was observed that with increase in feed the value of Ra rises which is mainly due to increase in cutting force and chattering and vibrations produced by lathe machine that agrees well with the previous findings [21].

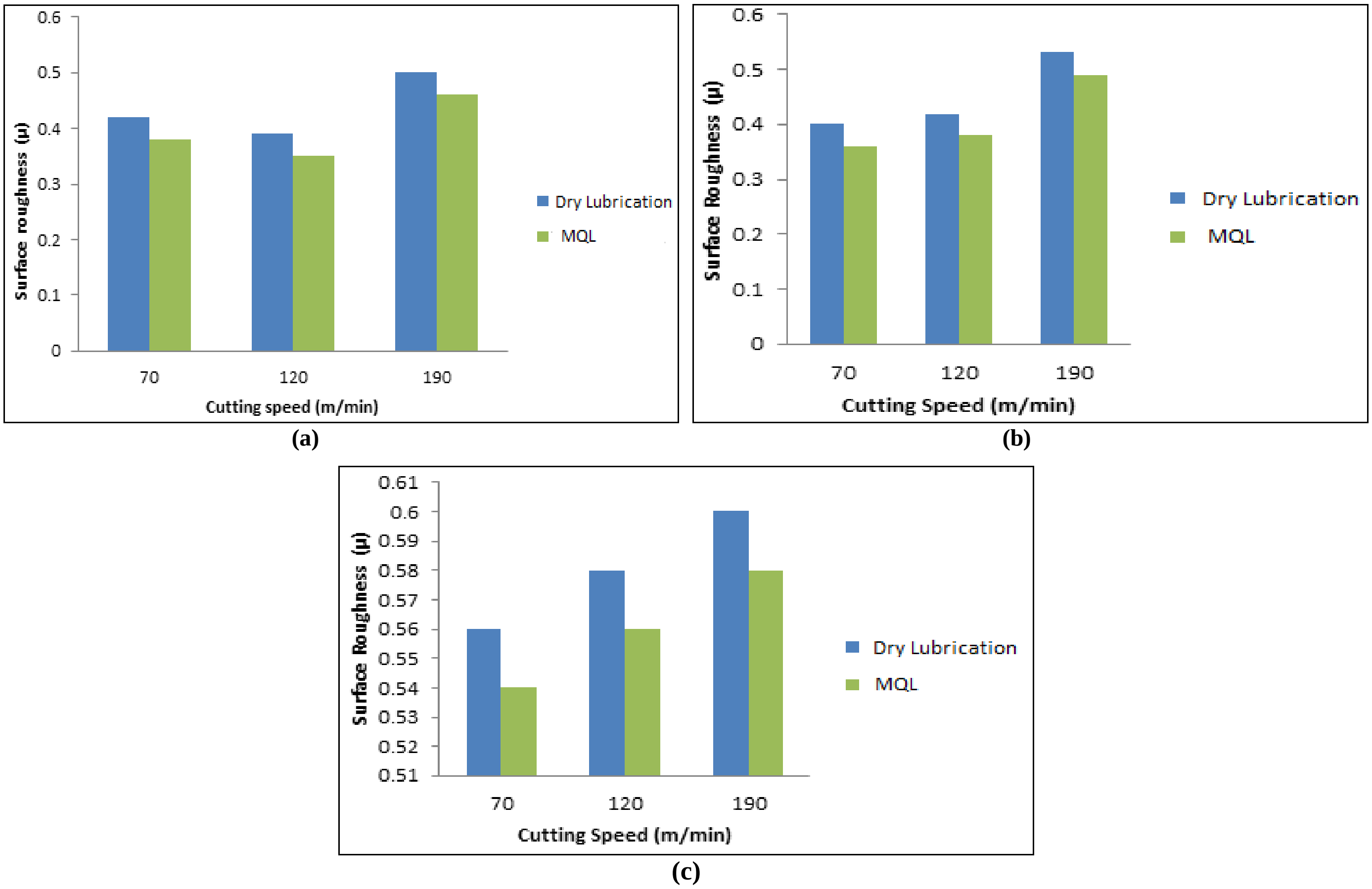


Fig 10: Surface Roughness feed is (a) 0.07 mm/rev (b) 0.15 mm/rev and (c) 0.22 mm/rev

Conclusion

In this study uncoated carbide tool inserts were used for turning of hardened steel AISI 4340. The performance of tool was evaluated under two lubricating conditions which are; dry conditions, minimum quantity lubrication using Soybean oil. Different values of Cutting speed and feed rates were taken for comparison by keeping depth of cut constant some of the major conclusions that were drawn after analysing the process parameters are as follows:

1. Apart from cutting speed, feed also played a vital role in affecting the tool life of the inserts. At highest feed and speed combination tool life was low. It was also observed that the Surface roughness was also affected by the variation in feed.
2. Lubrication conditions played a significant role in controlling the friction produced on the rake face of the tool. Under MQL and use of solid lubricant at all speed and feed combination the tool life was found high in comparison to tools used without lubricants (under dry conditions)
3. With the MQL technique, there can be a remarkable reduction in machining cost, quantity of lubricant used and surface roughness by properly orienting the nozzle on flank face of the tool. Further performance of MQL can be enhanced using chip evacuation system. From viewpoint of cost, health, safety and environment, performance of MQL technique is better with the use of vegetable oils as compared to mineral oils. The value of surface roughness on turned component was significantly affected by the use of lubricants as under MQL and Solid nano lubricant the value of Ra was low in comparison to dry conditions.

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