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EXPERIMENTAL INVESTIGATION ON EFFECT OF CUTTING PARAMETERS ON SURFACE ROUGHNESS AND MACHINING TIME IN TURNING EN31 HARDENED STEEL UNDER FLOODED AND MQL CONDITIONS

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Abstract —Hard turning is a turning process done on materials with a Rockwell C hardness greater than 45. It is typically performed after the work piece is heat treated. The process is intended to replace or limit traditional grinding operations. Hard turning can be applied for purely stock removal purpose or finishing purpose. Hard turning when applied for surface finish purpose can competes favorably with rough grinding (Ra = 0.5-0.8 μm). In Hard turning cutting velocity (Vc) is high i.e. machining time (Tm) is low due to which high amount of heat is generated at the chip-tool interface which not only increase the tool wear but also deteriorates the job quality in terms of surface finish. Therefore large amount of cutting fluid is used to increase the performance of hard turning operation due to which it becomes easier to keep tight tolerances but on the other hand use of cutting fluid has become more problematic in terms of cost, disposal, wastage and environmental pollution. Minimum quantity lubrication (MQL) is a good alternative to this flooded lubrication. This study investigates the performance of MQL with flooded lubrication in turning EN-31 by using Response Surface Methodology (RSM). ANOVA was used to find out the significant parameters. The results indicated that when range of cutting parameters (cutting velocity, feed & D.O.C) was low to medium turning with MQL provides some favorable results in terms of surface finish but with increase in the level of cutting parameters specially Vc and feed the surface finish obtained under MQL was less as compared to flooded lubrication, it means that MQL fails to reduce friction at the work–tool interface there by restricting the use of MQL to low range of cutting parameter only.

Keywords: Hard turning, MQL, flooded, machining time (Tm), Surface finish, RSM

I. INTRODUCTION

Increasing the productivity and the quality of the machined parts are the main challenges of metal cutting industries. Turning is the most widely used among all the machining processes. The growing demands for high productivity and quality of turned parts in terms of surface finish and less time for machining need use of high cutting velocity. Such machining inherently produces high cutting temperature, which not only reduces tool life but also impairs the product quality. Metal cutting fluids changes the performance of machining operations because of their lubrication, cooling, and chip flushing functions also the use of cutting fluid generally causes economy of tools and it becomes easier to keep tight tolerances, and to maintain work piece surface properties without damages but on the other hand use of cutting fluid has become more problematic in terms of both employee health and environmental pollution also the wastage disposal and cost related to this large quantity of cutting fluid is becoming problematic .Due to these problems, the alternative has been sought to minimize the use of cutting fluid in turning operations and this alternative is machining with minimum quantity lubrication (MQL). In MQL assisted machining fluid supplied is consumed at once so there is no need of fluid monitoring and disposal. The minimization of cutting fluid also leads to economical benefits by saving lubricant costs and work piece/tool/machine cleaning cycle time and reduction in use of water by 90%.MQL also known as near dry machining (NDM), refers to the use of cutting fluids of very small amount typically of a flow rate of 50 to 500 ml/hour which is very less than the amount commonly used in flood cooling condition .The MQL technique consists of a mixture of drops of cutting fluids (neat oils or emulsions) in a flow of compressed air, generating a “spray” called as aerosols (mists) which is impinged with high velocity on the cutting zone through the nozzle as shown on figure 1.

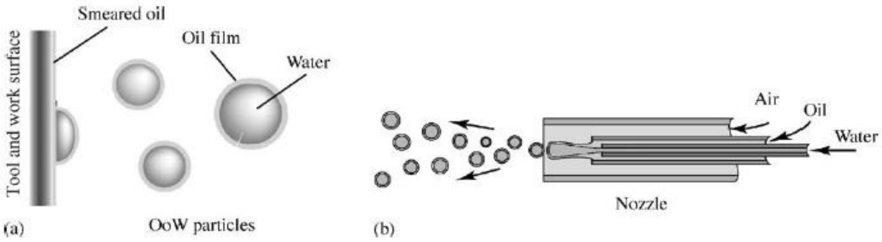


Fig.1: schematic view of coolant partials

The Manner of lubricant supply is as important as total amount of lubricant supplied. That means the amount which actually reaches in the work-tool or chip-tool interface to reduce friction.

II. LITERATURE REVIEW

Khan and Dhar [1] investigated the role of MQL (Air: 7 bar; Flow rate: 60ml/h through external nozzle) using vegetable oil (food-grade, Viscosity: 84 centipoise at 20 °C) as compared to dry machining in turning AISI-1060 steel having hardness 245BHN at industrial speed-feed combinations. Results include significant reduction in tool wear rate, surface roughness by MQL mainly through reduction in the cutting zone temperature.

Panda. et al. [2] has done study on hard turning of EN 31 steel (55HRC) under varying process parameters such as cutting speed, feed and depth of cut with respect to surface roughness using TiN/TiCN/Al_2O_3 multilayer coated carbide inserts through Taguchi L16 orthogonal array design by investigating Ra under dry environment. The machining time was fixed as 3 minute for each run. From the study feed is found to be the most dominant parameter for affecting the surface roughness and the surface quality appeared better with increase in cutting speed. An increase of feed deteriorated the surface finish therefore feed is noted as highly significant from ANOVA study.

Katgeri and Kulkarni [3] investigated the influence of speed, feed and DOC on surface roughness in Turning of EN-24 and EN-31 under Dry and Wet Conditions. In the mathematical model developed it was observed that the predicted values and measured values are fairly close which indicates that the developed surface roughness prediction models can be effectively used to predict the surface roughness from the cutting process with 95% confident intervals for both case (dry and wet). Discarded (used) Petrol engine oil of (SAE-40) was used as a lubricant and it was observed that it improve the surface finish of materials as compared to dry machining. In machining EN-24 & EN-31 steels under (dry and wet) it was observed that surface roughness decreases as the speed increases, increases as the feed increases and surface roughness decreases when DOC is low and increases when it is high.

Hwang and Lee [4] investigated the performance of MQL and wet lubrication in turning of AISI 1045 work material with the objective of suggesting the experimental model in order to predict the cutting force and surface roughness, to select the optimal cutting parameters. The process parameters selected were cutting speed, feed rate depth of cut and nozzle diameter. Central composite design was used for the experiment plan. The measured data was analyzed and optimization was done using Response surface methodology. From the experimental results obtained, the MQL turning process showed better surface roughness compared with the general wet turning process.

III. EXPERIMENTAL CONDITION AND PROCEDURE

Experiments were carried out to experimentally investigate the effect of cutting parameters on surface roughness (R_a) and machining time (Tm) under flooded and MQL conditions by plain turning of 38 mm diameter and 75 mm long rod of EN-31steel using a powerful and rigid semi-automatic geared lathe (Pioneer 250-PL, Rajkot, India) at different cutting velocities (*V*c) and feed rates (*S*o) and depth of cut (t) combination each at three different levels using Response surface methodology. For each experimental run new cutting edge was used. The experimental condition is given in table. 1. External MQL set up was design and used having a flow rate of 480 ml/hr. at 4 bar pressure impinged at cutting zone so that the aerosol (air + coolant) reaches as close to the chip-tool and the work-tool interfaces as possible. The photographic view of the MQL set-up is shown in Fig.2.a, b& c and the effect diagram is shown in figure 3.

Table: 1 Experimental Condition

Particulars	**Description**
Material	EN31(C:1.02 Si:0.26 Mg:0.42 Cr:1.25 Ni:0.14 Mo:0.025 S:0.022 P: 0.01),Hardness 55 to 57 HRC
Cutting Tool & tool geometry	(Coated carbide insert SNMG 120404) Tool Holder PSBNR 2525M 12, Tool geometry -6°,-6°,6°,15°,75°,0.4 mm
Measuring Instruments	Surface roughness Tester (Taylor Hobson Surtronic 3)
Input parameters	(Vc-59.69, 92.519, 143.256 m/min, So - 0.1,0.15,0.23 mm/rev and t -0.5, 0.8, 1.0 mm)
MQL Parameters	Supply pressure (4 bar), flow rate 480 ml/hr , aerosol jet velocity 75.26 mm/s, nozzle diameter 1.5mm , nozzle distance 15 mm above chip tool interface , nozzle position vertically downward ,
Environment	(Flooded - water to oil ratio 1: 10 and for MQL 1: 5) cutting fluid-water soluble

The figure clearly show the basic parts of the MQL set up. The set up of MQL is based on External supply i.e. coolant and compressed air is flown separately, firstly flow control valve is open due to which the stored coolant in the sump will flow vertically downward (passing from inner pipe) up to coolant pipe, at the end of coolant pipe the inner pipe is extended and nozzle is attached so as to increase the velocity and then compressed air is blown (passing from outer pipe) up to coolant pipe at the end compressed air will transmits its energy to the coolant/liquid jet and the jet will break into mist or aerosol (air + coolant).This aerosol is then supplied at the cutting zone.

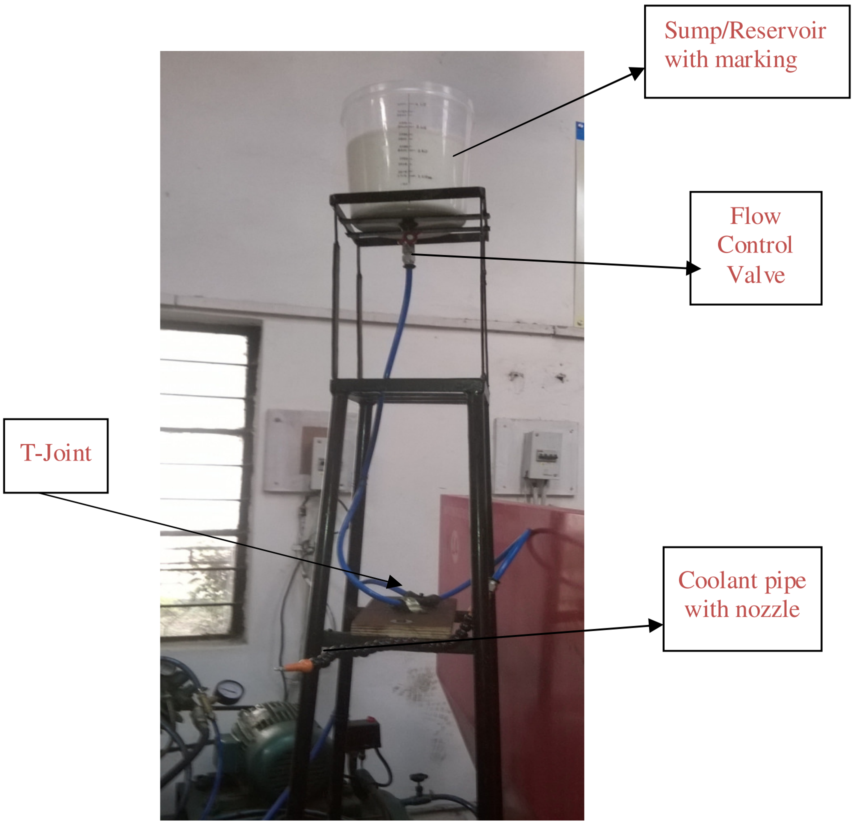


Fig.2.a: Photographic view of External MQL Set- up

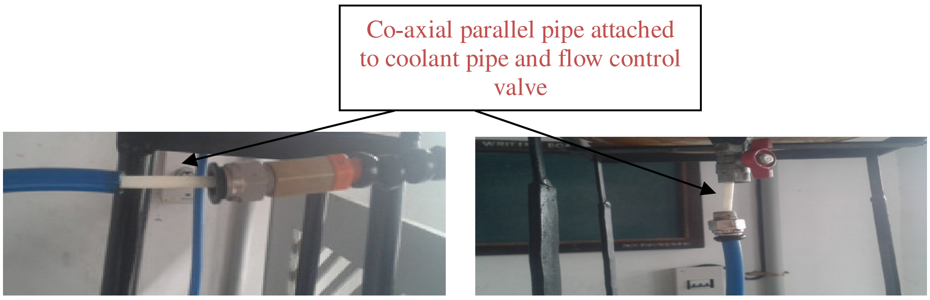


Fig.2.b: Co-axial parallel pipe (inner & outer) attached to coolant pipe and flow control valve.

Fig.2.c: MQL Nozzle supplying mist

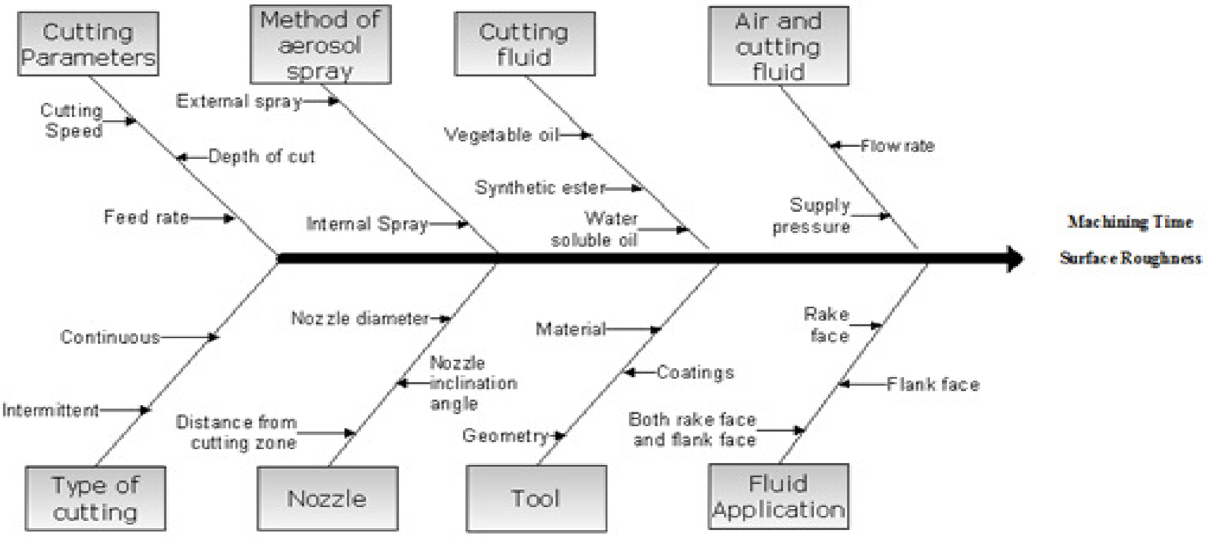
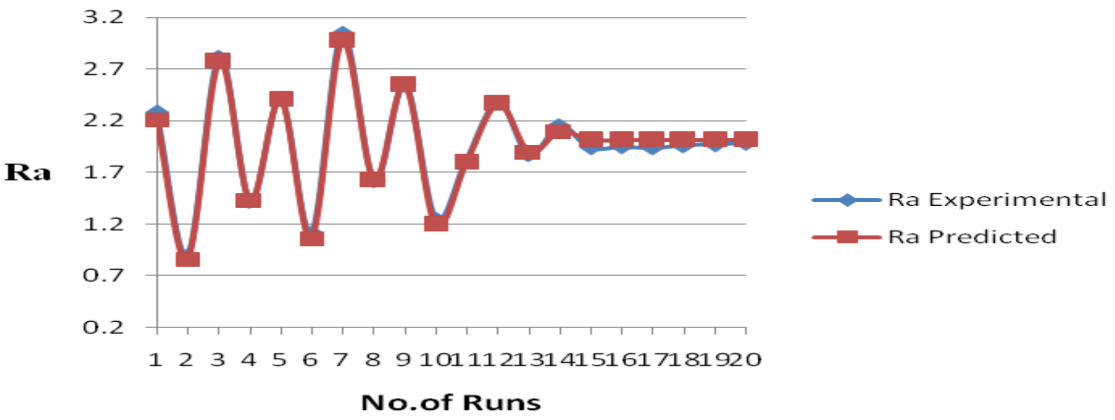


Fig.3: Effect diagram for MQL

Table 2: Design of Experiments with observed response i.e. machining time (Tm) & Surface Roughness (R_a) under flooded and MQL Conditions. Using RSM's Central Composite Design

Exp. Run	Vc (m/min)	So (mm/rev)	t (mm)	Tm (min)	R_{aM} (µm) Exp.	R_{aM} Predicted	Error for $R_{aM} \leq$ 5%	R_{aF} (µm) Exp.	R_{aF} Predicted	Error for $R_{aF} \leq$ 5%
1	59.69	0.1	0.5	0.948	1.93	1.976186	2.393	2.28	2.208325	3.2456
2	143.256	0.1	0.5	0.402	1.09	1.102921	1.1854	0.89	0.85957	3.5401
3	59.69	0.23	0.5	0.783	2.38	2.446767	2.8053	2.82	2.777026	1.5474
4	143.256	0.23	0.5	0.226	1.57	1.573503	0.2231	1.42	1.428271	0.5824
5	59.69	0.1	1.0	0.975	2.19	2.237646	2.1756	2.41	2.407275	0.1131
6	143.256	0.1	1.0	0.409	1.35	1.364381	1.0652	1.11	1.05852	4.8633
7	59.69	0.23	1.0	0.792	2.68	2.708227	1.0532	3.04	2.975976	2.1513
8	143.256	0.23	1.0	0.233	1.76	1.834963	4.2592	1.62	1.627221	0.4457
9	59.69	0.15	0.8	0.856	2.29	2.314055	1.0504	2.55	2.546426	0.1364
10	143.256	0.15	0.8	0.331	1.41	1.44079	2.1773	1.25	1.197671	4.3692
11	92.519	0.1	0.8	0.712	1.84	1.789998	2.7934	1.81	1.797835	0.6766
12	92.519	0.23	0.8	0.539	2.39	2.26058	5.725	2.38	2.366536	0.5689
13	92.519	0.15	0.5	0.676	1.89	1.814115	4.183	1.87	1.897196	1.4543
14	92.519	0.15	1.0	0.632	2.16	2.075575	4.0675	2.15	2.096146	2.5691
15	92.519	0.15	0.8	0.644	1.95	1.970991	1.0764	1.94	2.016566	3.9467
16	92.519	0.15	0.8	0.644	1.96	1.970991	0.5607	1.95	2.016566	1.0341
17	92.519	0.15	0.8	0.644	1.97	1.970991	0.0503	1.94	2.016566	3.9467
18	92.519	0.15	0.8	0.644	1.99	1.970991	0.9644	1.96	2.016566	2.886
19	92.519	0.15	0.8	0.644	1.98	1.970991	0.457	1.97	2.016566	2.3637
20	92.519	0.15	0.8	0.644	1.99	1.970991	0.9644	1.98	2.016566	1.8467



Graph 1: Predicted vs. Experimental Runs of Surface Roughness under flooded lubrication

IV. RESULT AND DISCUSSION

The Analysis of variance (ANOVA) is a necessary test which is performed in most of the optimization process due to its accuracy in prediction of P-values. If the p-value is lower than 0.05 then the factor is significant.

4.1 Adequacy and ANOVA of the Model for Ra_F (surface roughness under flooded)

The analysis was done using uncoded units

Surface Roughness (R_{aF}) = 2.53531 – 0.01614 Vc + 4.37462 So+ 0.39790 t

Table 3: Coefficient Table for Surface Roughness

Term	Coef	SE Coef	T	P
Constant	2.53531	0.076546	33.122	0.000
Vc	-0.01614	0.000394	-40.957	0.000
So	4.37462	0.252894	17.298	0.000
t	0.39790	0.065964	6.032	0.000
S = 0.0526592 PRESS= 0.0686632 R-Sq = 99.21% R-Sq(pred.) = 98.77% R-Sq(adj.) = 99.06%				

Table 4: ANOVA Table for input parameters

Source	**DF**	**Seq SS**	**AdjSS**	**MS**	**F**	**P**	**% of Contribution**	
Vc	1	4.61375	4.65163	4.65163	1677.48	0.000	83.32%	Most Significant
So	1	0.82220	0.82976	0.82976	299.23	0.000	14.86%	Significant
t	1	0.10090	0.10090	0.1009	36.39	0.000	1.80%	Least Significant
Total	19							

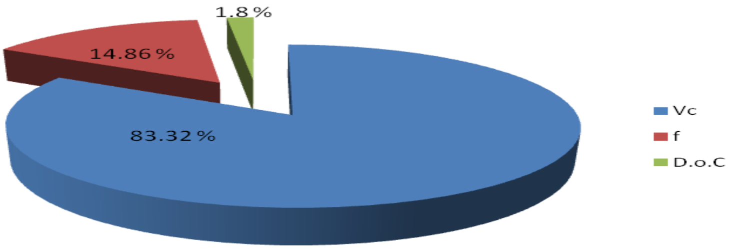
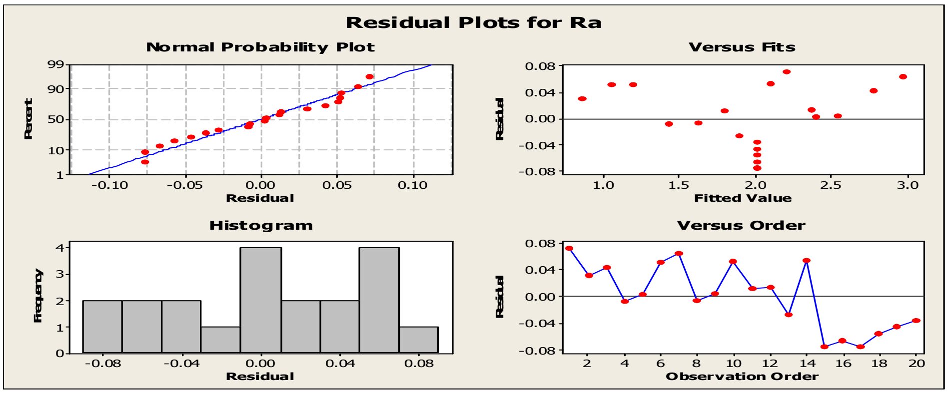


Chart 1: Percentage of Contribution for Surface Roughness (R_{aF})



Graph 2: Residual Plot for Surface Roughness (R_{aF}) under flooded condition.

4.2 Adequacy and ANOVA of the Model for R_{aM} (surface roughness under MQL)

The analysis was done using uncoded units

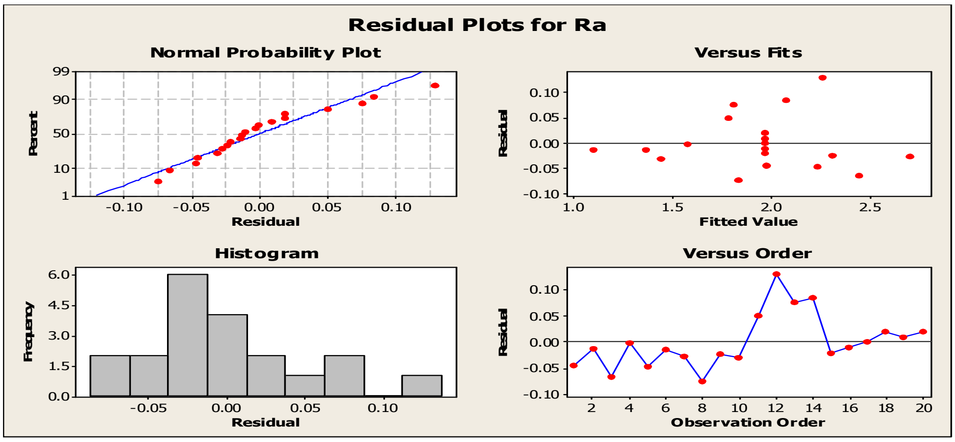
Surface roughness (R_{aM}) = 1.97650-0.01045Vc + 3.61986 So + 0.52292 t

Table 5: Coefficient Table for Material Removal Rate

Term	Coef	SE Coef	T	P
Constant	1.97650	0.081818	24.157	0.000
Vc	0.01045	0.000421	-24.801	0.000
So	3.61986	0.270314	13.391	0.000
t	0.52292	0.070508	7.417	0.000
S = 0.0562865 PRESS= 0.0866742 R-Sq = 98.14% R-Sq(pred) = 96.81 % R-Sq(adj) = 97.79%				

Table 6: ANOVA Table for input parameters

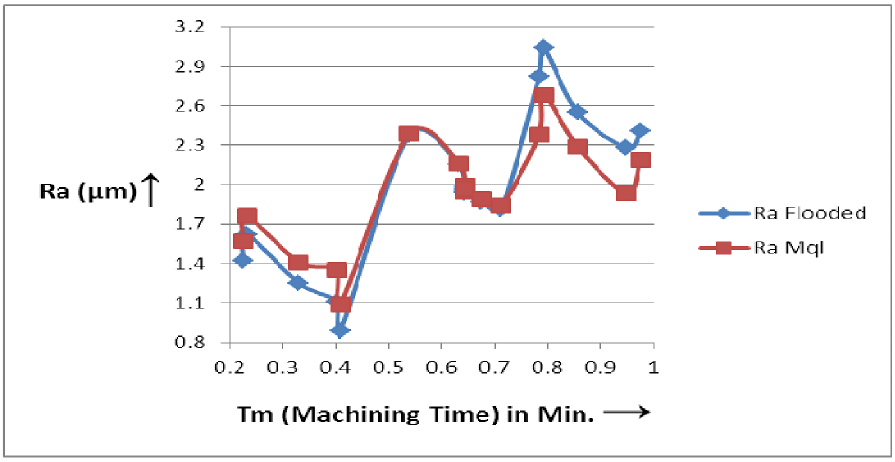
Source	**DF**	**Seq SS**	**Adj SS**	**MS**	**F**	**P**	**% of Contribution**	
Vc	1	1.93363	1.94870	1.94870	615.09	0.000	72.41	Most Significant
So	1	0.55987	0.56814	0.56814	179.33	0.000	21.11	Significant
t	1	0.17426	0.17426	0.17426	55.00	0.000	6.47	Least Significant
Total	19							



Graph 3: Residual Plot for Surface Roughness (R_{aM}) under MQL condition

4.3 Comparative analysis (Flooded vs.MQL)

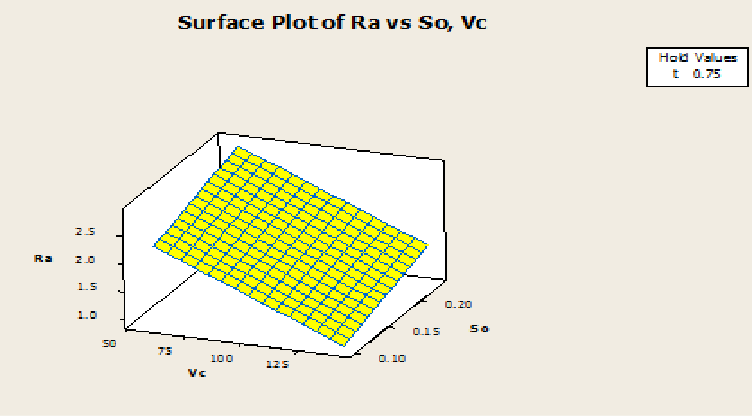
As shown in graph it was observed that surface roughness (R_a) increases with increase in machining time (i.e. machining time is mainly depended on cutting velocity followed by feed rate) further it was observed that minimum R_a value under both flooded and MQL condition (0.89 µm & 1.09 µm) was obtained when machining time is minimum (0.402 Min.) i.e. at high cutting velocity, low feed rate and low D.o.C. From graph it is clear that surface roughness decreases under flooded lubrication as compared to MQL when cutting velocity is medium to high, whereas at low cutting velocity the results provided by MQL in terms of surface roughness are better indicating that MQL can be used effectively at low cutting parameters (low Vc, low So & low D.o.C) where as at high cutting velocity flooded lubrication provides better results.



Graph 4: Surface roughness vs. Machining time under flooded and MQL conditions.

4.4 Effect of Process Variables on Surface Roughness

From graph .5 it is clear that the Surface Roughness has an increasing trend with the increase in feed rate and has decreasing trend with increase in cutting velocity, similarly Ra has increasing trend with increase in D.o.C. but to less extent as compared to cutting velocity and feed rate. The reason behind less effect of D.o.C as compared to cutting speed and feed rate on Surface Roughness might be the range (i.e. for finish cut small D.o.C is used in the range of 0.5 to 1.0mm).



Graph 5: Response Surface Plot of R_a vs. Vc, So

4.5 Optimized results

The process optimization was done using RSM's D-Optimal Test. The optimized value of input parameters for the response is shown in table below.

Table 7: Optimized results

Input parameters	Optimized value for **Flooded**	Predicted response for flooded	Optimized value for **MQL**	Predicted response for MQL
Vc (m/min)	137.2373	Ra_F =0.9565µm Tm=0.449 Min	89.2335	Ra_M = 1.6932µm Tm=0.737 Min.
So (mm/rev)	0.10		0.1070	
t (mm)	0.5		0.5	

V. CONCLUSION

From the analysis of surface roughness and machining time in flooded and MQL system following conclusion can be drawn:

1) By using MQL system very large amount of coolant can be saved, also at some runs (when cutting velocity & feed was low to medium) the performance of MQL in terms of surface finish was better but with increase in cutting velocity the value of surface finish obtained under flooded lubrication was found better as compared to MQL this indicates that for hard turning at high cutting velocity flooded provides better results as compared to MQL.

2) Machining time /Cycle time obtained under both Flooded and MQL conditions was found same because experimental run was same for both Flooded and MQL with use of new cutting edge for each experimental run.

3) MQL totally fails to reduce friction at the work–tool interface when cutting velocity increases indicated by less surface finish as compared to flooded , thereby restricting the application of MQL to a certain range of parameter only i.e. optimized value for MQL found was medium cutting velocity (89.2335 m/min) , Low feed (0.1070 mm/rev) and low D.o.C (0.5 mm) where as flooded lubrication permitting use of high cutting velocity which is required for hard turning i.e. optimized value for flooded found was high cutting velocity (137.2373m/min) , Low feed (0.10 mm/rev) and low D.o.C (0.5 mm).

It is clear that flooded lubrication performance was better as compared to MQL when cutting velocity is high which is needed for high production rate and good surface finish in hard turning.

VI. ACKNOWLEDGEMENT

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