International Journal of Advance Research in Science and Engineering
Volume No.07, Special Issue No.01, March 2018
www.ijarse.com
IJARSE
ISSN: 2319-8354

Application and Comparative Performance Evaluation of Minimum Quantity Lubrication with and Without Additive in Turning of Alloy Steel EN8K

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ABSTRACT

Conventionally the flood lubrication system is used for cooling the tool and work interface to attain maximum surface finish, close dimensional tolerance and better tool life. This method has disadvantages that the chips get mixed with the coolant , more over coolant has minimum shelf life and hence has to be replaced frequently and flood lubrication has tendency to wet the workplace area making it dirty slippery and unsafe for working hence the conventional process needs to be replaced by new one which is minimum quantity lubrication.

Research work has been carried out to apply the MQL system in solitary manner during turning of steel EN8k where in the coolant will be applied to the tool -work interface as a air-lubricant (cutting oil) mist. Here machine parameters like speed, feed and depth of cut will be varied and measured parameters will be dimensional value of work piece, machining time have been done. Taguchi method has been used for Design of experiment and one way annova technique has been used to determine the optimized parameters of speed feed and depth of cut for optimized value of surface finish for wok piece. The test was also carried out after addition additive to the coolant and similar results were plotted. Comparative analysis and recommendations are made for both cases i.e., MQL with and without additives in machining of EN8K

Keywords- Minimum quantity lubrication, EN8K, Surface finish, additives, Taguchi

I. INTRODUCTION

Minimum quantity lubrication (MQL) has increasingly found its way into the area of metal cutting machining and in many areas has already been established as an alternative to conventional wet processing. In contrast to flood lubrication, minimum quantity lubrication uses only a few drops of lubrication (approx. 5 ml to 50 ml per hour) in machining. Today, the enormous cost-saving potential resulting from doing almost entirely without metalworking fluids in machining production is recognized and implemented by many companies, primarily in the automotive industry. While in the early 1990s small applications (sawing, drilling) were done “dry”, today we are able to produce cylinder heads, crankcases, camshafts and numerous other components made of common materials – such as steel, cast iron and aluminium – using MQL in the framework of highly automated large volume production.

The advantages of this new technology are clear. With respect to occupational safety, MQL offers numerous advantages over water-mixed metalworking fluids. A major advantage is the substantially better compatibility concerning skin care. Minimum quantity lubrication is a total-loss lubrication method rather than the circulated lubrication method used with emulsions. This means using new, clean lubricants that are fatty-alcohol or ester based. Additives against pollution, e.g. biocides and fungicides, are not necessary at all, since microbial growth is possible only in an aqueous phase. The extreme reduction of lubrication quantities results in nearly dry work pieces and chips. This greatly reduces health hazards caused by emissions of metalworking fluids in breathed-in air and on the skin of employees at their workplaces. Metalworking fluids do not spread throughout the area around the machine, thus making for a cleaner workplace. Costs generated by conventional flood lubrication (e.g. maintenance, inspection, preparation and disposal of metalworking fluids) are no longer an issue with minimum quantity lubrication

II. EXPERIMENTAL SETUP

In following sections experimental details are described:-

This can be divided methodically into three main parts namely

1. Work piece – material and geometry selection
2. Cutting tool geometry selection …this can be further categorized as
3. Machine tool selection for implementation of the experiment

2.1 System Description

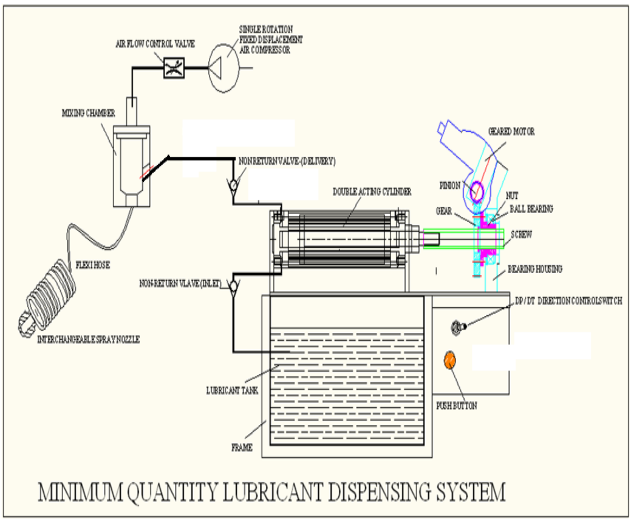

Figure 2.1: MQL setup

The system comprises of the following three subsystems:

1 Lubricant storage system

2 Dispensing mechanism

3 Mixing and coolant application mechanism

2.2 Construction

The MQL system comprises of following parts

a) Lubricant tank & frame: These are fabricated structural components of the MQL with primary functions of tank to hold the MQL lubricant and the frame to support the entire assembly of the MQL system

b) Dispenser actuator: The dispenser actuator is a double acting hydraulic cylinder with 20 mm bore and 50 mm stroke, thus the dispenser volume is 16 cc i.e. in one stroke of the dispenser it is possible to dispense 16 ml of MQL lubricant. The rate of displacement of the dispenser piston is thus important to determine the minimum quantity of oil dispensed per min.

c) Dispenser Actuator driving mechanism: The forward stroke of the displacer piston is used for the dispensing activity where as the return stoke charges the dispenser. The to and fro motion of the piston is achieved using a power screw and nut arrangement. The power screw is held in a nut supported in ball bearing in a bearing housing. The nut carries an spur gear driven by an spur pinion mounted on the geared motor.

d) Inlet circuit to dispenser: The inlet circuit to the dispenser uses a non-return valve opening into the cylinder side and closing on the tank side. This allows lubricant flow from the lubricant tank to the cylinder during suction stroke where as prevents reverse flow from the cylinder to tank during dispensing stroke.

e) Dispensing Circuit: Dispensing circuit connects the outlet of cylinder to the mixing chamber. The circuit comprises the an non-return valve opening into the mixing chamber side and closing on the cylinder side. This allows lubricant flow from the cylinder to mixing chamber during dispensing stroke where as prevents reverse air flow from the mixing chamber to cylinder during suction stroke.

f) Mixing chamber: Mixing chamber is the device that mixes the MQL lubricant and the compressed air to create lubricant mist to be directed onto the cutting action area to serve a threefold purpose:

i) Lubricate the tool tip and job contact area during cutting to minimize the friction between them, thereby reducing the heat produce. Misty nature of the lubricant ensures effective application of lubricant and better heat extraction.

ii) The second advantage of using compressed air mist that, it helps chip evacuation from the cutting area which is one of the major reasons of development of ‘built-up-edges ‘ on tool tip leading to reduced tool life and improper surface finish on job.

iii) The compressed air offer other advantage that fumes that are likely to be developed due to burning of the lubricant are not developed due to the high velocity of the lubricant particles (they do not reach flash point).

g) Flex hose with interchangeable nozzle: The flex hose connects the mixing chamber and the nozzle, two set of spray nozzle with tip diameters1.5 and 2.0 mm are provided for spraying.

2.3 Working

A) DISPENSER CHARGING CYCLE:

Motor is rotated in clockwise direction that rotates the nut in counter clockwise direction due to spur gearing , nut rotate and screw is constrained to translate hence it moves back thereby moving the piston in backward direction thereby effecting the suction stroke. The inlet circuit to the dispenser uses a non-return valve opening into the cylinder side and closing on the tank side. This allows lubricant flow from the lubricant tank to the cylinder during suction stroke where as prevents reverse flow from the cylinder to tank during dispensing stroke.

B) DISPENSER DELIVERY CYCLE:

Motor is rotated in counter-clockwise direction that rotates the nut in clockwise direction due to spur gearing nut rotates and screw is constrained to translate hence it moves forward thereby moving the piston in forward direction thereby effecting the delivery stroke. Dispensing circuit connects the outlet of cylinder to the mixing chamber. The circuit comprises the an non-return valve opening into the mixing chamber side and closing on the cylinder side. This allows lubricant flow from the cylinder to mixing chamber during dispensing stroke where as prevents reverse air flow from the mixing chamber to cylinder during suction stroke. Circuit also has flow control valve for fine adjustments of flow rate of lubricant to mixing chamber, and pressure gage indicates the pressure in the delivery line.

III. WORKPIECE MATERIAL

The term Mild Steel applies to all low carbon Steel that does not contain any alloying elements in its makeup and has a carbon content that does not exceed 0.25%. The term “Mild” is used to cover a wide range of specifications and forms for a variety of Steel. Mild Steel is used in mechanical engineering applications for parts that will not be subject to high stress.

EN8K: unalloyed medium carbon Steel (BS 970 080m40) has high strength levels compared to normal bright Mild Steel, due to thermo mechanical rolling. EN8K is suitable for all round engineering purposes that may require a Steel of greater strength.

Table 3.1 Chemical Composition of EN8K steel

	C	Mn	Si	P	S
Min	0.35	0.60	0.05	0.015	0.015
Max	0.45	1.00	0.35	0.06	0.6

IV. MACHINE USED

Figure 4.1: Machine used for Experimentation

Product details:

Four speed

Length of Bed 7 Feet

Width of Bed: 15 Inch

Height of Center : 12 Inch

Spindle Bore: 80 MM

Distance Of Between Center 1000 MM

V. CUTTING OIL USED

SAE10

Cutting oil SAE 10 have a slightly complicated relationship to machine tools. Straight-weight non-detergent motor oils are usable, and in fact SAE 10 oils used to be the recommended spindle and way oils (respectively) on manual machine tools decades ago, although nowadays dedicated way oil formulas prevail in commercial machining. While nearly all motor oils can act as adequate cutting fluids in terms of their cutting performance alone, modern multi-weight motor oils with detergents and other additives are best avoided. These additives can present a copper-corrosion concern to brass and bronze, which machine tools often have in their bearings and lead screw nuts (especially older or manual machine tools).

Kinematic viscosity at 40 °C and 100 °C - low-shear viscosity - determined according to ASTM D445, where the alternative method according to ASTM D7042 delivers comparable results.High-shear viscosity (10/s) at high temperature of 150 °C - HSHT viscosity - determined according to ASTM D4683, CEC L-36-A-90 (ASTM D 4741) or ASTM DS481.

International Journal of Advance Research in Science and Engineering
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www.ijarse.com
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Table 4.3 Viscosity of SAE10 cutting oil

SAE Viscosity Grade[°C	Min.Viscosity [mm²/s] at 100 °C	Max.Viscosity [mm²/s] at 100 °C	High Shear Rate Viscosity [mPa.s] at 150 °C
10W	4.1	-	-

VI.ADDITIVE USED

Ether based n-Nonyl Additive

Table 6 .1 Characteristics of Ether based n-Nonyl Additive

Ethers	pH	Rust inhibition test Duration (h) 24 48 72	Friction Coefficient	Surface tension 10-3 N/m	Intial seizure load MPa	Antimicrobial properties (d) 1 2 3
PE-61 monoether n-Nonyl	10.2	10 10 10	0.25	36	0.78	+++ +++ +++

6.1 Reason to Select Additive

Ether based n-Nonyl additive deliver long-lasting system stability, with minimal maintenance and no compromise on quality. They're ideal for machining cast iron and low alloy steel – and suitable for large central systems and single sump machines. Cutting fluids for ferrous metals have needed particular care and attention to keep them in good working condition – avoiding poor sump life, increased additive usage, bacterial or fungal infections, bad odours and unpleasant working environments and, ultimately, high rejection rates. To achieve this, traditional cutting fluids contain boron and formaldehyde-releasing agents. But using these chemicals is increasingly at odds with health and safety regulation. Formulated using unique resilient additive technology, this innovative solution maintains pH at a constant level, assuring consistent productivity for longer than other standard cutting fluids. Ether based n-Nonyl additive is also boron and biocide free, which can help improve your health and safety profile in itself. Ether based n-Nonyl additive Long Lasting fluids for System Stability

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with minimal maintenance and no compromise on quality. It is ideal for machining cast Iron and Low- Medium alloy steel. It is suitable for large central systems and single sump machines.

6.2Proportions

Additive used is 6 % by volume of the cutting fluid.

6.3 Method of Preparation

The Ether based n-Nonyl additive have tendency to evaporate at elevated temperature, thus they are mixed with the oil as per proportion by adding the oil and additive in a closed container and then mixture was added to the coolant tank for dispensing. As the dispenser is a closed circuit and the NRV guarding the fluid motion, the mixture is only exposed to air and elevated temperature in the mixing chamber.

6.4 Effect of Additive

SAE 10 oil is low viscosity oil with excellent lubricant properties and also a low boiling point helps the oil to extract the heat at faster rate when it comes in contact with the tool interface at elevated temperature. The additive when mixed with the SAE 10, the n-Nonylmonoether accelerate the dispersion process in the mixing chamber where air at close to 3-bar pressure is introduced. The Action of high pressure and the additive together makes the atomization of the oil and an appropriate mist is created and thus applied to the tool interface using a 0.8 mm nozzle.

VII. TESTING EQUIPMENT'S

7.1 Digital Tachometer

7.2 Portable Roughness Tester

Portable Surface Roughness Tester Surftest SJ-210

Figure 7.1: Surface Roughness Tester Surftest SJ-210

VIII. RESULT ANALYSIS AND DISCUSSIONS

8.1 Optimization of Process Parameters for Surface Finish in Plain MQL

Table No. 8.1.1 Results of experiment with MQL plain for surface finish

Sr no	Speed	Feed	DoC	Ra_P
1.	750	0.2	1.5	0.897938
2.	750	0.18	1.2	0.874235
3.	750	0.16	0.9	0.756669
4.	750	0.14	0.6	0.73107
5.	500	0.2	1.2	0.878975
6.	500	0.18	1.5	0.827777
7.	500	0.16	0.6	0.819244
8.	500	0.14	0.9	0.809763
9.	350	0.2	0.9	0.842947
10.	350	0.18	0.6	0.833466
11.	350	0.16	1.5	0.874235
12.	350	0.14	1.2	0.815452
13.	275	0.2	0.6	0.889405
14.	275	0.18	0.9	0.880872
15.	275	0.16	1.2	0.872339
16.	275	0.14	1.5	0.86665

8.1.2 Taguchi Design for Plain MQL

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Welcome to Minitab, press F1 for help.

Taguchi Design

Taguchi Orthogonal Array Design

L16(4^3)

Factors: 3Runs: 16

Columns of L16(4^5) Array

1 2 3

Taguchi Analysis: Ra_P versus Speed, Feed, Doc

Response Table for Signal to Noise Ratios

Smaller is better

Level	speed	feed	doc
1	7.186	8.817	7.414
2	7.938	8.235	7.547
3	8.111	7.672	8.410
4	8.684	7.194	8.548
Delta	1.499	1.623	1.134
Rank	2	1	3

Response Table for Means

Level	speed	feed	doc
1	0.4373	0.3657	0.4266
2	0.4015	0.3906	0.4203
3	0.3939	0.4141	0.3826
4	0.3750	0.4373	0.3783
Delta	0.0623	0.0716	0.0484
Rank	2	1	3

Main Effects Plot for Means

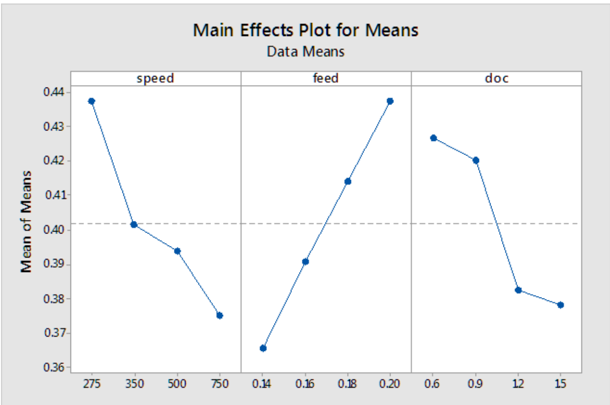

Figure 8.1.1: Main Effects Plot for Means-Ra

Main Effects Plot for SN ratios

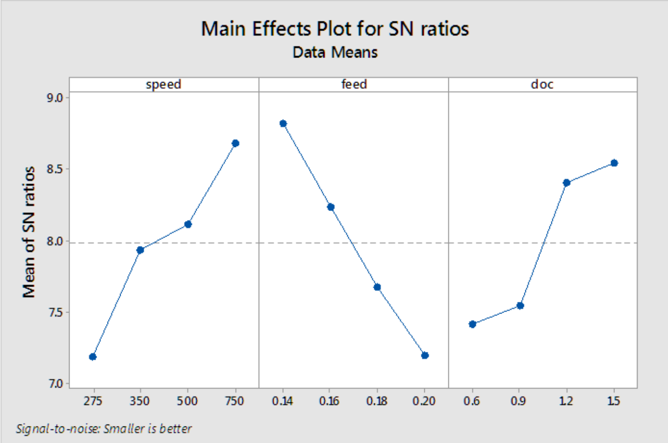

Figure 8.1.2: Main Effects Plot for SN ratios-Ra

Selection of Optimum Level of Parameters

The least variation and the optimal design are obtained by means of the S/N ratio. Higher the S/N ratio, more stable the achievable quality (Tosun et al., 2004). Figure 8.1.2 shows the S/N ratio plots for MRR. It is clear from Figure8.1.2, highest S/N ratio first level of SPEED (750), fourthlevel of FEED (0.14 mm/rev), first level of DOC (1.5mm)Therefore, the optimal setting of process parameters which yield maximum surface finish is $\mathbf{A_1B_4C_1}$

8.2 Optimization of Process Parameters for Surface Finish in MQL+ Additive

Table No. 8.2.1Results of experiment with MQL for surface finish

Sr no.	Speed	Feed	DoC	Ra_W
1.	750	0.2	1.5	0.457938
2.	750	0.18	1.2	0.434235
3.	750	0.16	0.9	0.316669
4.	750	0.14	0.6	0.29107
5.	500	0.2	1.2	0.438975
6.	500	0.18	1.5	0.387777
7.	500	0.16	0.6	0.379244
8.	500	0.14	0.9	0.369763

International Journal of Advance Research in Science and Engineering
Volume No.07, Special Issue No.01, March 2018
www.ijarse.com
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9.	350	0.2	0.9	0.402947
10.	350	0.18	0.6	0.393466
11.	350	0.16	1.5	0.434235
12.	350	0.14	1.2	0.375452
13.	275	0.2	0.6	0.449405
14.	275	0.18	0.9	0.440872
15.	275	0.16	1.2	0.432339
16.	275	0.14	1.5	0.42665

Taguchi Design for MQL + Additive

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Taguchi Design

Taguchi Orthogonal Array Design

L16(4^3)

Factors: 3

Runs: 16

Columns of L16(4^5) Array

1 2 3

Taguchi Analysis: Ra_W versus speed, feed, doc

Response Table for Signal to Noise Ratios

Smaller is better

Level speed feed doc

1 7.186 7.194 7.414

2 7.938 7.672 7.547

3 8.111 8.235 8.410

4 8.684 8.817 8.548

Delta 1.499 1.623 1.134

Rank 2 1 3

Response Table for Means

Level	speed	feed	doc
1	0.4373	0.4373	0.4267
2	0.4015	0.4141	0.4203
3	0.3939	0.3906	0.3826
4	0.3750	0.3657	0.3783
Delta	0.0623	0.0716	0.0484
Rank	2	1	3

Main Effects Plot for Means

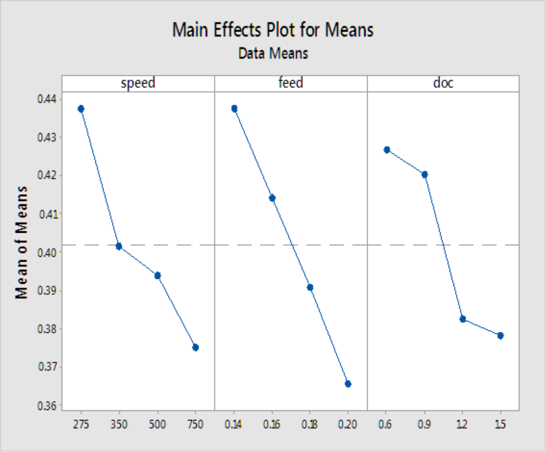

Figure 8.2.1: Main Effects Plot for Means-Ra

Main Effects Plot for SN ratios

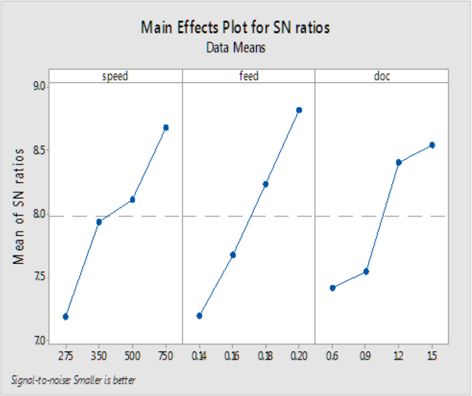

Figure 8.2.2: Main Effects Plot for SN ratios-Ra

International Journal of Advance Research in Science and Engineering
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Selection of Optimum Level of Parameters

The least variation and the optimal design are obtained by means of the S/N ratio. Higher the S/N ratio, more stable the achievable quality (Tosun et al., 2004). Figure 8.2.2 shows the S/N ratio plots for MRR. It is clear from Figure 8.2.2, highest S/N ratio first level of SPEED (750), first level of FEED (0.2 mm/rev), first level of DOC (1.5mm)Therefore, the optimal setting of process parameters which yield maximum surface finish is $\mathbf{A_1B_1C1}$

8.3 Observation for Plain MQL-Tolerance and Machining Time

Table No. 8.3.1 Results of experiment with MQL for tolerance and machining time

Sr no.	Speed	Feed	DoC	Tolerance	Machining time (sec)
1.	750	0.2	1.5	0.11	41
2.	500	0.2	1.5	0.09	50
3.	350	0.2	1.5	0.13	62
4.	275	0.2	1.5	0.14	83

Graph of Tolerance Zone Vs. Speed

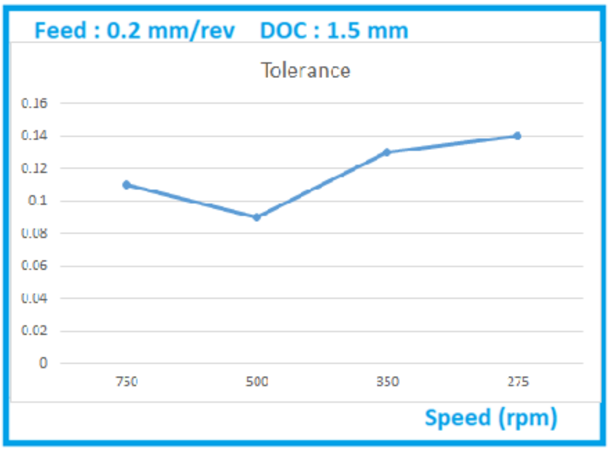

Figure 8.3.1: Graph of Tolerance Zone vs. Speed

International Journal of Advance Research in Science and Engineering
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The graph of tolerance zone vs. Speed for maximum feed and maximum depth of cut, it is observed that the speeds of 750 rpm and 500 rpm are in the optimal range and the recommended speed for better precision is 500 rpm

Graph of Machine Time vs. Speed

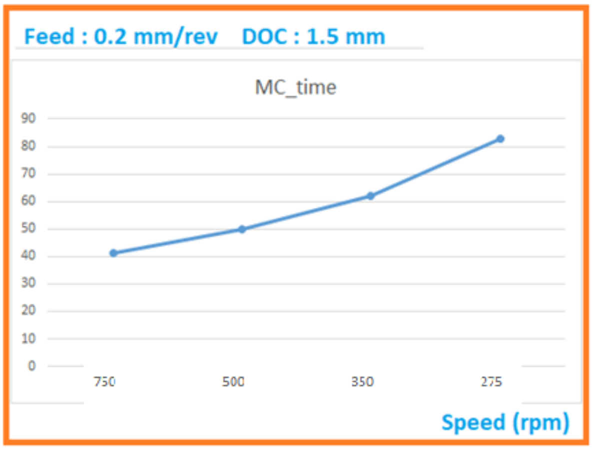

Figure 8.3.2: Graph of Machining time vs. Speed

The graph of Machine time Vs. Speed for maximum feed and maximum depth of cut, it is observed that the speeds of 750rpm and 500 rpm are in the optimal range and the recommended speed for better production rate is 750 rpm

8.4 Observation ForMQL+Additive-Tolerance And Machining Time

Table No. 8.4.1 Results of experiment with MQL+Additive for tolerance and machining time

Sr no.	Speed	Feed	DoC	Tolerance	Machining time (sec)
1.	750	0.2	1.5	0.08	38
2.	500	0.2	1.5	0.06	42
3.	350	0.2	1.5	0.09	56
4.	275	0.2	1.5	0.10	74

Graph of Tolerance Zone vs. Speed

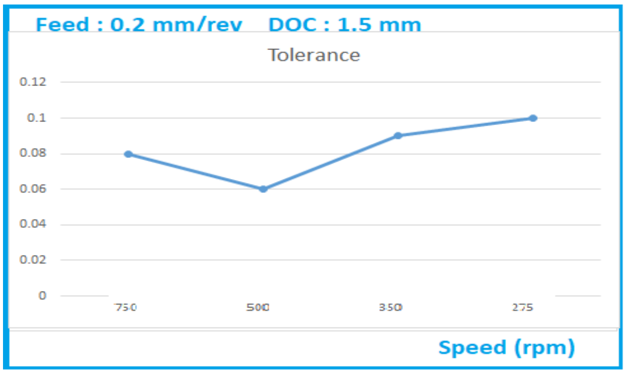

Figure8.4.1: Graph of Tolerance Zone vs. Speed

The graph of tolerance zone Vs. Speed for maximum feed and maximum depth of cut, it is observed that the speeds of 500 rpm and 750 rpm are in the optimal range and the recommended speed for better precision is 500 rpm

Graph of Tolerance Zone vs. Machining time

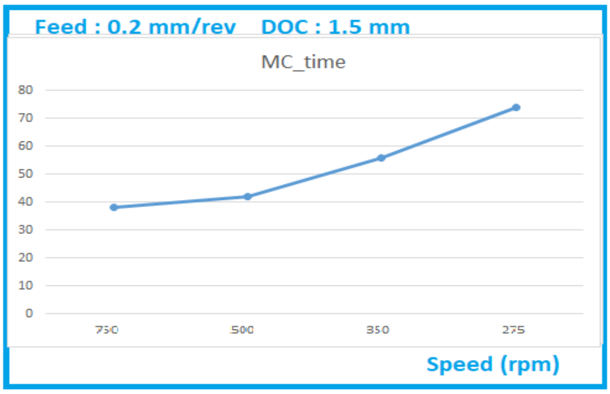

Figure 8.4.2: Graph of Machining time vs. Speed

The graph Machine time vs. Speed for maximum feed and maximum depth of cut , it is observed that the speeds of 500 rpm and 750 rpm are in the optimal range and the recommended speed for better production rate is 750 rpm

8.5 Comparison Graph of Tolerance Zone For Plain MQL &MQL+Additive

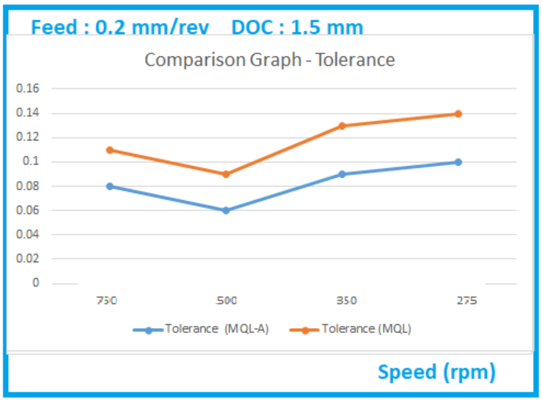

Figure 8.5.1:Comparison graph of tolerance zone vs. Speed

The comparison graph of tolerance zone vs. Speed for maximum feed and maximum depth of cut, it is observed that the speeds of 750 rpm and 500 rpm are in the optimal range and the recommended speed for better precision is 500 rpm in either cases but the MQL + additive shows a better tolerance zone as compared to the Plain MQL so much as to say that all speeds are recommendable when the additive is used.

8.6 Comparison Graph of Machining Time for Plain MQL &MQL+Additive

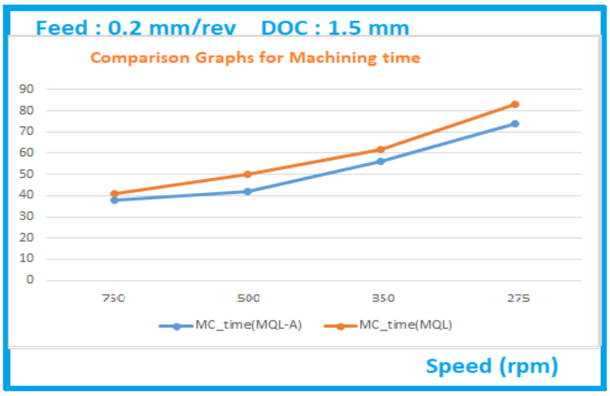

Figure 8.6.1: Comparison graph of machining time vs. Speed

The graph Machine time vs. Speed for maximum feed and maximum depth of cut , it is observed that the speeds of 750 rpm and 500 rpm are in the optimal range and the recommended speed for better production rate is 750 rpm , but a slightly reduced machining time is observed with the MQL + Additive arrangement.

IX. CONCLUSION

1. The MQL system was designed and fabricated to apply the MQL as a stand-alone system and as well as with the additive.
2. Design of Experiment using Taguchi method was done to optimize the parameters for best surface finish

3. The Surface finish is observed to improve with application of Additive with MQL System.
4. The optimal level of parameters are as follows for Plain MQL to obtain optimal surface finish first level of SPEED (750), fourthlevel of FEED (0.14 mm/rev), first level of DOC (1.5mm)
5. The optimal level of parameters are as follows for MQL+Additive first level of SPEED (750), first level of FEED (0.2 mm/rev), first level of DOC (1.5mm)
6. The comparison graph of tolerance zone Vs. Speed for maximum feed and maximum depth of cut ,it is observed that the speeds of 750 rpm and 500 rpm are in the optimal range and the recommended speed for better precision is 500 rpm in either cases but the MQL + additive shows a better tolerance zone as compared to the Plain MQL so much as to say that all speeds are recommendable when the additive is used
7. The graph Machine time Vs. Speed for maximum feed and maximum depth of cut , it is observed that the speeds of 750 rpm and 500 rpm are in the optimal range and the recommended speed for better production rate is 750 rpm but a slightly reduced machining time is observed with the MQL + Additive arrangement.
8. The MQL System with additive addition shows better overall results and it is recommended for use.

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