MACHINING PARAMETER OPTIMIZATION OF TITANIUM TI-6AL-4V USING MQL

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Abstract - Manufacturing by mechanical machining has historically benefited from the use of cutting fluid. Cutting fluids help to reduce temperature, friction, flush away chips, and hence improve machining performance. However, uncontrolled use of cutting fluid raises concern in respect of cost and environmental burden. For these reasons, dry machining is used in conjunction with high speed machining to reduce cycle times and simultaneously deliver a greener process. However, for some work piece materials full implementation of dry machining is not economically viable due to the absence of the essential cooling and lubricating functions delivered by cutting fluids. The most feasible bridging technology is minimum quantity lubrication (MQL) where a very small flow rate of coolant/lubricant is delivered to the cutting zones. This project is to study the effect of Minimum Quantity Lubrication (MQL) by conducting experiments in CNC milling of Titanium alloy material (Ti-6Al-4V) with two distinct cutting fluids and to compare and optimize the machining parameters obtained respectively

***Key Words*:** MQL, S/N, DF, R^2, MS, P, VC, F

1. INTRODUCTION

1.1 RESEARCH BACKGROUND

The most credible bridging technology is minimum quantity lubrication (MQL). Avoiding sudden temperature reduction as in MQL reduces the chances for thermal cracks, which is predominantly caused by rapid cooling due to the use of flood coolant.the small quantity of cutting fluid delivered to contact zones at high cutting speeds cannot guarantee a sufficient temperature reduction. Meanwhile, the research into MQL attempted to reduce the quantity of cutting fluid delivered as low as possible. Therefore, the optimisation of MQL is necessary in attempting to gain more merit for MQL.

1.2 AIM AND OBJECTIVES

- Aim of this project is to study the key process variable in vertical CNC milling machine and the MQL optimize process.
- To study the change in temperature and to optimize ideal cutting temperature based on variable. machining parameter under different cutting fluids
- To study and identify optimum surface roughness based on variable machining parameter under different cutting fluids.
- To identify the material removal rate (MRR) based on variable machining parameter under different cutting fluids.

1.3APPLICATION OF THE PROJECT IN INDUSTRIAL FIELD

The die and mould cavity industry is a significant player in the manufacturing base. Fabrication of the die and mould tools could be very time consuming, costly, as well as requiring high precision processes. This industry already uses high speed machining to rapidly make dies of advanced and higher quality. The wastage of cutting fluids due to high amount of heat generation while machining a product is minimized by introducing MQL setup, better quality dies and moulds with ideal surface finish is obtained at low cost.

2. LITERATURE REVIEW

Fratila and Caizar (2012a) investigated the influence of process parameters and cooling method on the surface quality of AISI-1045 during turning. Their results show that the minimal level of depth of cut, the maximum cutting speed, and the maximum lubricant flow rate resulted in a better quality of machined surface

Bhattacharya et al. (2009) have investigated an experimental study to investigate the effects of cutting parameters on surface finish and power consumption by employing Taguchi techniques. Their results showed a significant effect of cutting speed on the surface roughness and power consumption.

Sharma *et al.* (2015) observed that in a proper cooling MQL system, the film layer of lubricant is developed at the tool-chip interface and this makes a cushion between tool-chip interfaces and facilitates the slipping of chips over tool.

2.1 SUMMARY

It has been identified from the literature review that: Application of minimum quantity lubrication (MQL) is favourable in situations where dry machining application cannot be fully utilised due to limited capability of cutting tools. Some reports even found that MQL application is more superior in comparison to flood cooling. Thus, they tried to use the smallest amount of cutting fluid as possible to supply the cutting zones without considering the optimum flow rate that might be suitable for given work piece material. Therefore, a systematic investigation is needed to find the interaction between machining variables and MQL parameters, especially the effect of using different flow rates. Hence, the optimum setting for MQL and machining variables can be used to improve the machining performance for given work piece material.

3. MATERIALS & PROPERTIES

3.1. TITANIUM TI-6AL-4V

Ti-6Al-also sometimes called TC4, Ti64, or ASTM Grade 5, is an alpha-beta titanium alloy with a high strength-to-weight ratio and excellent corrosion resistance. It is one of the most commonly used titanium alloys and is applied in a wide range of applications where low density and excellent corrosion resistance are necessary such as e.g. aerospace industry and biomechanical applications (implants and prostheses).

The chemical composition of grade 5 Ti-6Al-4V alloy is outlined in the following table

ELEMENT	CONTENT
Titanium, Ti	87.6 - 91
Aluminum, Al	5.5 - 6.75
Vanadium, V	3.5 - 4.5
Iron, Fe	$\leq$ 0.40
Oxygen, O	$\leq$ 0.20
Carbon, C	$\leq$ 0.080
Nitrogen, N	$\leq$ 0.050
Hydrogen, H	$\leq$ 0.015

Table 3.1 Chemical composition of TI6AL4V

3.2 CEMENTED CARBIDE

Cemented carbide is a hard material used extensively as cutting tool material, as well as other industrial applications. It consists of fine particles of carbide cemented into a composite by a binder metal. Cemented carbides commonly use tungsten carbide (WC), titanium carbide (TiC), or tantalum carbide (TaC) as the aggregate. Mentions of "carbide" or "tungsten carbide" in industrial contexts usually refer to these cemented composites.

Fig 3.1 Cemented Carbide Cutting Tool

3.3 CASTOR OIL

Castor oil has long been used commercially as a highly renewable resource for the chemical industry. It is a vegetable oil obtained by pressing the seeds of the castor oil plant.

Physical properties of castor oil is tabulated below

Viscosity (centistokes)	889.3
Density (g/mL)	0.959
Thermal conductivity (W/m°C)	4.727
Specific heat (kJ/kg/K)	0.089
Flash point (°C)	145
Pour point (°C)	2.7
Melting point (°C)	-2 to -5
Refractive index	1.480

Table 3.2 Physical Properties of Castor Oil

3.4 CNC Coolant Oil

It is a mineral oil, chlorine and nitrite free, synthetic metal working coolant, specially designed for grinding and light to medium duty machining of cast iron, ferrous alloys, aluminium alloys and copper alloys

4. MINIMUM QUANTITY LUBRICATION

In minimum quantity lubrication, a small volume of cutting fluid is transported to the cutting zone assisted by air and converted via orifices into small particles (atomization). These small particles are delivered to the cutting zone in the form of air borne particles, a gaseous suspension of liquid particles. An idealized condition of MQL can be seen in However, the ideal concept, is hard to achieve due to the air pressure accelerating the small particles and creating a mist.

Fig 4.1 Lubricant sprayed in tip of the tool

4.1 EFFECT OF MQL OVER MACHINING PARAMETERS

4.1.1 CUTTING TEMPERATURE

Cutting temperature is an important machinability index as it affects the cutting forces, surface roughness, chip morphology and tool wear. The tool wear mechanisms such as abrasion, adhesion, diffusion, chemical action are also temperature dependent. As a result excessive cutting temperature softens the tool material and increases the tool wear rate. So, it should be reduced to an acceptable level to reduce the detrimental effects associated with high cutting temperatures

4.1.2 SURFACE ROUGHNESS

Machined surfaces are not smooth due to feed marks of tool, vibration of machining system, wear of cutting edge and in some cases due to formation of built up edge. Surface finish is generally improved by reducing the feed rate, increasing the cutting speed and using a cutting fluid. However, use of cutting fluid in flooded condition does not provide desirable results, as it is not able to reach the cutting zone. On the other hand, better surface finish is obtained with application of MQL in machining operations due to better penetration of cutting fluid in cutting zone.

5. MACHINING PARAMETERS AND THEIR RESPONSES

5.1 MACHINING PARAMETERS

For any machining or metal cutting operation, three relative motions between the work piece and cutting tool are indispensably necessary for gradual removal of material from the work piece. In fact, the simultaneous action of all three relative motions causes advancement of cutting tool towards work material along the intended path generating a finished surface with intended shape, size and tolerance.

These three relative motions are called Cutting Parameters.

- Feed Rate
- Spindle Speed
- Depth Of cut

5.2 RESPONSES

During machining process because of three relative motions some factors are relatively change. They are

- Temperature of the cutting tool
- Surface roughness of the work piece

6. OPTIMIZING MACHINING PAPAMETER USING TAGUCHI METHOD

6.1 ORTHOGONAL ARRAY

Taguchi Orthogonal Array (OA) design is a type of general fractional factorial design. It is a highly fractional orthogonal design that is based on a design matrix proposed by Dr. Genichi Taguchi and allows you to consider a selected subset of combinations of multiple factors at multiple levels. Taguchi Orthogonal arrays are balanced to ensure that all levels of all factors are considered equally.

6.2EXPERIMENTAL PROCEDURE

6.2.1 EXPERIMENTAL DESIGN

The objectives of the experiment to minimize the surface roughness of the work piece and temperature of the cutting tool and to determine the optimum condition leads to minimum surface roughness and temperature rise. The cutting speed, the feed rate and depth of cut is consider as shown below

Parameters	Level 1	Level 2	Level 3	Level 4
Feed rate (mm/min)	100	200	300	400
Spindle speed (rpm)	2000	3000	4000	5000
Depth of cut(mm)	0.05	0.1	0.15	0.2

Table 6.1 Levels of cutting parameters

The L16 orthogonal array obtained by TAGUCHI method using Minitab 19 software is listed below

TRIALS	FEED RATE(MM/MIN)	SPINDLE SPEED (RPM)	DEPTH OF CUT(MM)
1	100	2000	0.05
2	100	3000	0.10
3	100	4000	0.15
4	100	5000	0.20
5	200	2000	0.10
6	200	3000	0.05
7	200	4000	0.20
8	200	5000	0.15
9	300	2000	0.15
10	300	3000	0.20
11	300	4000	0.05
12	300	5000	0.10
13	400	2000	0.20
14	400	3000	0.15
15	400	4000	0.10
16	400	5000	0.05

Table 6.2 L16 orthogonal array obtained by TAGUCHI method

According to the parameters defined in Table 6.1 are evaluated with four different levels. Therefore, the orthogonal arrangement of Taguchi to be used is an L16 array. This means that sixteen combinations of parameters are required, as shown in Table.

6.2.2 CASTOR OIL USED IN MQL SETUP

Feeding 2 litre of castor oil as cutting fluid into the MQL setup and spraying at the flow rate of 100 ml/hr. at a pressure of 5 bar before commencing the milling operation.

6.2.3 SYTHETIC COOLANT USED IN MQL SETUP

Feeding 2 litre of synthetic cutting oil as cutting fluid into the MQL setup and spraying at the flow rate of 100 ml/hr at a pressure of 5 bar before commencing the milling operation

6.3 FEEDING OF PROGRAM CODE TO CNC MACHINE

The 16 shortlisted machining parameter obtained from Minitab software by Taguchi method is fed into the CNC machine with help of CIMATRON, it generates control codes for performing CNC operations. In this operation the cut of 10mm width is performed at regular distance of 2mm with castor oil as cutting fluid. Similarly the same 16 machining parameter is performed with CNC cutting oil as cutting fluid. The cutting temperature of 32 trials is observed with the help of infrared thermometer, the surface roughness is measured with MITECH SURFACE TESTER MR200.and the MRR calculated for each trail respectively.

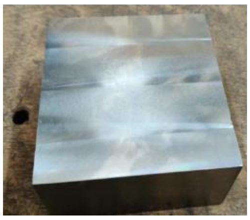

Fig 6.1 before Machining Operation

Fig 6.2 after Machining Operation

6.4 MQL SPECIFICATION

MQL TYPE	External Jet Mist Spray
Reservoir Capacity	3.5 Liters
Tank Type	Non-Pressurized
Operating Source	Compressed air supply
Working Pressure	1 to 10 bar
Solenoid Valve	230vac to 240vac
Nozzle diameter	2.3mm

Table 6.3 MQL specification

CONSTANT PARAMETERS

Flow rate	**150ml/hr**
pressure	**1 bar**

Table 6.4 Constant parameters

7. ANALYSIS AND OPTIMIZATIONS

In this work, Taguchi L16 experimental design was applied to shortlist a machining trials, the test was performed with three independent variable at four different levels as shown in table 6.2. Optimal experimental conditions were determined by calculated signal-to-noise ratios. The optimal machining parameter were obtained by the Taguchi method and regression analysis. Linear regression was applied to fit the experimental data and optimize the machining parameter

7.1 L16 ORTHOGONAL ARRAY AND EXPERIMENTAL DATA

7.1.1 CASTOR OIL

The following machining outcomes were obtained through castor oil as cutting fluids in MQL arrangements under three independent variable at four different levels as shown

FEED RATE (mm/min)	SPINDLE SPEED (rpm)	DEPTH OF CUT (µm)	TEMPERATURE (degree Celsius)	SURFACE ROUGHNESS (µm)	MATERIAL REMOVAL RATE (mm^3/min)
100	2000	50	32.2	0.367	50
100	3000	100	31.8	0.245	100
100	4000	150	32.1	0.144	150
100	5000	200	32.2	0.152	200
200	2000	100	32.3	0.181	200
200	3000	50	32.7	0.144	100
200	4000	200	32.5	0.195	400
200	5000	150	32.7	0.114	300
300	2000	150	32.8	0.230	450
300	3000	200	33.0	0.334	600
300	4000	50	32.8	0.196	150
300	5000	100	33.1	0.224	300
400	2000	200	33.4	0.329	800
400	3000	150	33.0	0.279	600
400	4000	100	32.9	0.361	400
400	5000	50	33.0	0.312	200

Table 7.1 Machining parameters and its responses under castor oil

7.1.2 CNC CUTTING FLUID

The following machining outcomes were obtained through synthetic oil as cutting fluids in MQL arrangements under three independent variable at four different levels as shown

FEED RATE (mm/min)	SPINDLE SPEED (rpm)	DEPTH OF CUT (µm)	TEMPERATURE (degree Celsius)	SURFACE ROUGHNESS (µm)	MATERIAL REMOVAL RATE (mm^3/min)
100	2000	50	31.9	0.188	50
100	3000	100	31.8	0.173	100
100	4000	150	32.0	0.206	150
100	5000	200	32.1	0.118	200
200	2000	100	31.8	0.342	200
200	3000	50	31.8	0.172	100
200	4000	200	31.7	0.222	400
200	5000	150	31.7	0.142	300
300	2000	150	32.2	0.342	450
300	3000	200	32.3	0.309	600
300	4000	50	32.1	0.192	150
300	5000	100	32.2	0.207	300
400	2000	200	32.2	0.442	800
400	3000	150	32.2	0.247	600
400	4000	100	32.0	0.281	400
400	500	50	31.9	0.261	200

Table 7.2 Machining parameters and its responses under CNC oil

7.2 REGRESSION

7.2.1 REGRESSION EQUATION FOR TEMPERATURE WITH CASTOR OIL AS CUTTING FLUID

Temperature = 31.645+0.003375feed Rate+0.000018spindle Speed +0.000850 Depth of Cut

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	31.645	0.233	136.10	0.000	
FEED RATE	0.003375	0.000456	7.40	0.000	1.00
SPINDLE SPEED	0.000018	0.000046	0.38	0.708	1.00
DEPTH OF CUT	0.000850	0.000912	0.93	0.370	1.00

Table 7.3 Regression analysis of temperature under castor oil

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.203920	82.30%	77.88%	69.03%

Table 7.4

7.2.2 REGRESSION EQUATION FOR SURFACE ROUGHNESS WITH CASTOR OIL AS CUTTING FLUID

Surface roughness = 0.2524+0.000367feed rate-0.000026 spindle speed - 0.000135 depth of cut

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.2524	0.0827	3.05	0.010	
FEED RATE	0.000367	0.000162	2.26	0.043	1.00
SPINDLE SPEED	- 0.000026	0.000016	-1.57	0.141	1.00
DEPTH OF CUT	- 0.000135	0.000324	-0.42	0.683	1.00

Table 7.5 Regression analysis of surface roughness under castor oil

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0725235	39.33%	24.17%	0.00%

Table 7.6

7.2.3 REGRESSION EQUATION FOR MATERIAL REMOVAL RATE WITH CASTOR OIL AS CUTTING FLUID

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Material removal rate = -155.0+1.2500feed rate-0.04500 Spindle speed+2.500depth of cut

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-155.0	48.8	-3.17	0.008	
FEED RATE	1.2500	0.0957	13.06	0.000	1.00
SPINDLE SPEED	-0.04500	0.00957	-4.70	0.001	1.00
DEPTH OF CUT	2.500	0.191	13.06	0.000	1.00

Table 7.7 Regression analysis of MRR under castor oil

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
42.8174	96.80%	96.00%	93.57%

Table 7.8

7.2.4 REGRESSION EQUATION FOR TEMPERATURE WITH CNC CUTTING OIL AS CUTTING FLUID

Temperature =31.735+0.000825 feed rate -0.000023 spindle speed+0.001050 depth of cut

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	31.735	0.205	154.79	0.000	
FEED RATE	0.000825	0.000402	2.05	0.063	1.00
SPINDLE SPEED	-0.000023	0.000040	-0.56	0.586	1.00
DEPTH OF CUT	0.001050	0.000804	1.31	0.216	1.00

Table 7.9 Regression analysis of temperature under CNC oil

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.179815	34.17%	17.71%	0.00%

Table 7.10

7.2.5 REGRESSION EQUATION FOR SURFACE ROUGHNESS WITH CNC CUTTING OIL AS CUTTING FLUID

Surface roughness =0.2330+0.000452feed rate-0.000044spindle speed+0.000384depth of cut

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.2330	0.0497	4.69	0.001	
FEED RATE	0.000452	0.000097	4.65	0.001	1.00
SPINDLE SPEED	-0.000044	0.000010	-4.51	0.001	1.00
DEPTH OF CUT	0.000384	0.000195	1.97	0.072	1.00

Table 7.11 regression analysis of surface roughness under CNC oil

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0435554	79.25%	74.07%	62.53%

Table 7.12

7.2.6 REGRESSION EQUATION FOR MATERIAL REMOVAL RATE WITH CNC CUTTING OIL AS CUTTING FLUID

Material removal rate =-155.0+1.2500feedrate-0.04500spindle speed+2.500depth of cut

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-155.0	48.8	-3.17	0.008	
FEED RATE	1.2500	0.0957	13.06	0.000	1.00
SPINDLE SPEED	-0.04500	0.00957	-4.70	0.001	1.00
DEPTH OF CUT	2.500	0.191	13.06	0.000	1.00

Table 7.13 regression analysis of MRR under CNC oil

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
42.8174	96.80%	96.00%	93.57%

7.3 FITS AND DIAGNOSTICS FOR ALL OBSERVATIONS

In general, a model fits the data well if the differences between the observed values and the model's predicted values are small and unbiased. The standard error of the fits (SE of fits) estimates the variation in the estimated mean response for a specified set of predictor values, factor levels, or components and is used to generate the confidence interval for the prediction. The smaller the standard error, the more precise the estimated mean response

RESIDUAL

A residual is the vertical distance between a data point and the regression line. In other words, the residual is the error that isn't explained by the regression line. The residual (e) can also be expressed with an equation. The e is the difference between the predicted value (ŷ) and the observed value

$$e_i = y_i - \hat{y}_i$$

7.3.1 Castor Oil

Trial	Temperature	Fit	Resid	Std Resid
1	32.200	32.060	0.140	0.89
2	31.800	32.120	-0.320	-1.75
3	32.100	32.180	-0.080	-0.44
4	32.200	32.240	-0.040	-0.25
5	32.300	32.440	-0.140	-0.77
6	32.700	32.415	0.285	1.56
7	32.500	32.560	-0.060	-0.33
8	32.700	32.535	0.165	0.90
9	32.800	32.820	-0.020	-0.11
10	33.000	32.880	0.120	0.66
11	32.800	32.770	0.030	0.16
12	33.100	32.830	0.270	1.48
13	33.400	33.200	0.200	1.27
14	33.000	33.175	-0.175	-0.96
15	32.900	33.150	-0.250	-1.37
16	33.000	33.125	-0.125	-0.79

Table 7.14 Fit and diagnostics for Temperature under castor oil

Trial	Surface Roughness	Fit	Resid	Std Resid
1	0.3670	0.2313	0.1357	2.42
2	0.2450	0.1990	0.0460	0.71
3	0.1440	0.1667	-0.0227	-0.35
4	0.1520	0.1344	0.0176	0.31
5	0.1810	0.2612	-0.0802	-1.24
6	0.1440	0.2425	-0.0985	-1.52
7	0.1950	0.1966	-0.0016	-0.03
8	0.1140	0.1779	-0.0639	-0.99
9	0.2300	0.2912	-0.0612	-0.94
10	0.3340	0.2589	0.0751	1.16
11	0.1960	0.2537	-0.0577	-0.89
12	0.2240	0.2214	0.0026	0.04
13	0.3290	0.3212	0.0078	0.14
14	0.2790	0.3024	-0.0234	-0.36
15	0.3610	0.2837	0.0773	1.19
16	0.3120	0.2649	0.0471	0.84

Table 7.15 Fit and diagnostics for surface roughness under castor oil

Trial	Material Removal Rate	Fit	Resid	Std Resid
1	50.0	5.0	45.0	1.36
2	100.0	85.0	15.0	0.39
3	150.0	165.0	-15.0	-0.39
4	200.0	245.0	-45.0	-1.36
5	200.0	255.0	-55.0	-1.44
6	100.0	85.0	15.0	0.39
7	400.0	415.0	-15.0	-0.39
8	300.0	245.0	55.0	1.44
9	450.0	505.0	-55.0	-1.44
10	600.0	585.0	15.0	0.39
11	150.0	165.0	-15.0	-0.39
12	300.0	245.0	55.0	1.44
13	800.0	755.0	45.0	1.36
14	600.0	585.0	15.0	0.39
15	400.0	415.0	-15.0	-0.39
16	200.0	245.0	-45.0	-1.36

Table 7.16 Fit and diagnostics for MRR under castor oil

7.3.2 CNC CUTTING OIL

Trial	Temperature	Fit	Resid	Std Resid
1	31.9000	31.8250	0.0750	0.54
2	31.8000	31.8550	-0.0550	-0.34
3	32.0000	31.8850	0.1150	0.72
4	32.1000	31.9150	0.1850	1.33
5	31.8000	31.9600	-0.1600	-0.99
6	31.8000	31.8850	-0.0850	-0.53
7	31.7000	32.0200	-0.3200	-1.99
8	31.7000	31.9450	-0.2450	-1.52
9	32.2000	32.0950	0.1050	0.65
10	32.3000	32.1250	0.1750	1.09
11	32.1000	31.9450	0.1550	0.96
12	32.2000	31.9750	0.2250	1.40
13	32.2000	32.2300	-0.0300	-0.22
14	32.2000	32.1550	0.0450	0.28
15	32.0000	32.0800	-0.0800	-0.50
16	31.9000	32.0050	-0.1050	-0.75

Table 7.17 Fit and diagnostics for Temperature under CNC oil

Trial	SURFACE ROUGHNESS	Fit	Resid	Std Resid
1	0.1880	0.2095	-0.0215	-0.64
2	0.1730	0.1848	-0.0118	-0.30
3	0.2060	0.1600	0.0460	1.18
4	0.1180	0.1352	-0.0172	-0.51
5	0.3420	0.2740	0.0680	1.75
6	0.1720	0.2108	-0.0388	-1.00
7	0.2220	0.2245	-0.0025	-0.06
8	0.1420	0.1613	-0.0193	-0.50
9	0.3420	0.3384	0.0036	0.09
10	0.3090	0.3136	-0.0046	-0.12
11	0.1920	0.2121	-0.0201	-0.52
12	0.2070	0.1874	0.0196	0.50
13	0.4420	0.4029	0.0391	1.16
14	0.2470	0.3397	-0.0927	-2.38
15	0.2810	0.2766	0.0045	0.11
16	0.2610	0.2134	0.0476	1.41

Table 7.18 Fit and diagnostics for surface roughness under CNC oil

Trial	MATERIAL REMOVAL RATE	Fit	Resid	Std Resid
1	50.0	5.0	45.0	1.36
2	100.0	85.0	15.0	0.39
3	150.0	165.0	-15.0	-0.39
4	200.0	245.0	-45.0	-1.36
5	200.0	255.0	-55.0	-1.44
6	100.0	85.0	15.0	0.39
7	400.0	415.0	-15.0	-0.39
8	300.0	245.0	55.0	1.44
9	450.0	505.0	-55.0	-1.44
10	600.0	585.0	15.0	0.39
11	150.0	165.0	-15.0	-0.39
12	300.0	245.0	55.0	1.44
13	800.0	755.0	45.0	1.36
14	600.0	585.0	15.0	0.39
15	400.0	415.0	-15.0	-0.39
16	200.0	245.0	-45.0	-1.36

Table Fit and diagnostics for MRR under CNC oil

7.4 NORMAL PROBABILITY PLOT

To calculate the total variance, you would subtract the average actual value from each of the actual values, square the results and sum them. From there, divide the first sum of errors (explained variance) by the second sum (total variance), subtract the result from one, and you have the R-squared
Residual plot is a graph that shows the residuals on the vertical axis and the independent variable on the horizontal axis. If the points in a residual plot are randomly dispersed around the horizontal axis, a linear regression model is appropriate for the data; otherwise, a nonlinear model is more appropriate

7.4.1 CASTOR OIL

a) TEMPERATURE

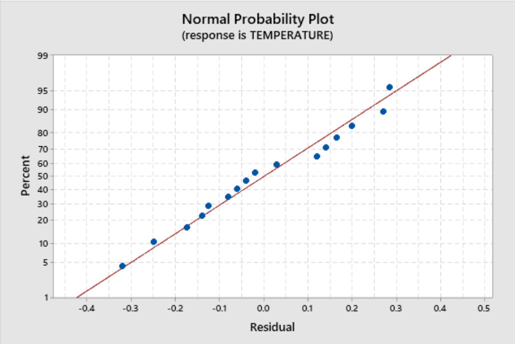

Fig 10.1 Normal Probability Plot for temperature under castor oil

b) SURFACE ROUGHNESS

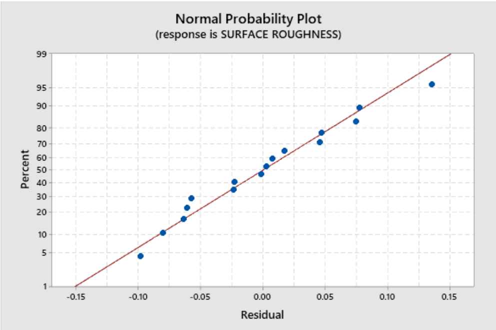

Fig 10.2 Normal Probability Plot for surface roughness under castor oil

c) MATERIAL REMOVAL RATE

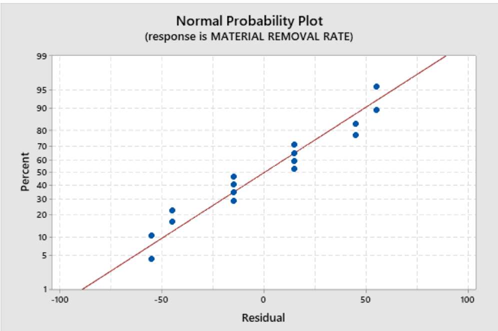

Fig 10.3 Normal Probability Plot for MRR under castor oil

7.4.2 CNC CUTTING OIL

a) TEMPERATURE

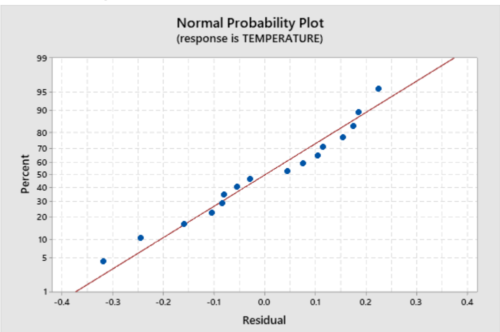

Fig 10.4 Normal Probability Plot for temperature under CNC oil

b) SURFACE ROUGHNESS

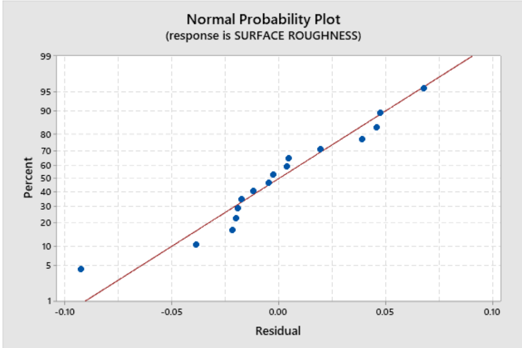

Fig 10.5 Normal Probability Plot for surface roughness under CNC oil

c) MATERIAL REMOVAL RATE

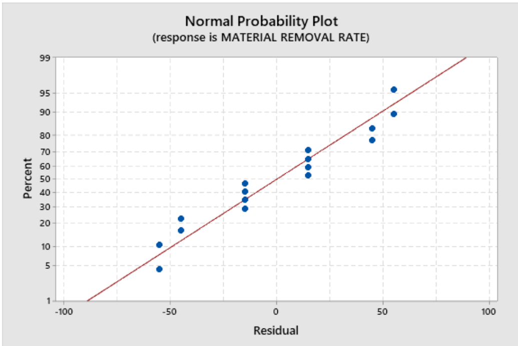

Fig 10.6 Normal Probability Plot for RR under CNC oil

8. RESULT & CONCLUSION

8.1 OPTIMIZING MACHINING PARAMETER

a) Temperature

The optimum temperature obtained through MQL machining using castor oil

Solution	Feed rate	Spindle speed	Depth of cut	Temperature fit	Composite desirability
1	100	2000	50	32.06	0.8375

Table 8.1 optimum temperature through castor oil

The optimum temperature obtained through MQL machining using CNC Cutting oil

Solution	Feed rate	Spindle speed	Depth of cut	Temperature fit	Composite desirability
1	100	5000	50	31.7575	0.904167

Table 8.2 optimum temperature through CNC oil

From the above tables the lower temperature is obtained when CNC cutting oil is used as cutting fluid and so it's considered to be the optimal temperature

b) Surface Roughness

The optimum surface roughness obtained through MQL machining using castor oil

Solution	Feed rate	Spindle speed	Depth of cut	Surface roughness fit	Composite desirability
1	100	5000	200	0.1344	0.919368

Table 8.3 optimum surface roughness through castor oil

The optimum surface roughness obtained through MQL machining using CNC cutting oil

Solution	Feed rate	Spindle speed	Depth of cut	Surface roughness fit	Composite desirability
1	100	5000	50	0.07765	1

Table 8.4 optimum surface roughness through CNC oil

From the above tables the lower surface roughness is obtained when CNC cutting oil is used as cutting fluid and so it's considered to be the optimal surface roughness

C) Material Removal Rate

The optimum material removal rate (MRR) obtained through MQL setup is

Solution	Feed rate	Spindle speed	Depth of cut	Material removal rate fit	Composite desirability
1	400	2000	200	755	0.94

Table 8.5 optimum MRR through both castor oil &CNC oil

11.2 OVERALL OPTIMIZED MACHINING PARAMETER

The overall optimized machining parameters for castor oil MQL machining on the basis of optimized temperature, surface roughness, material removal rate

Solution	Feed rate	Spindle speed	Depth of cut	Material removal rate fit	Surface roughness fit	Temperature fit	Composite desirability
1	100	2272.73	200	367.727	0.204014	32.1923	0.590597

Table 8.6 Overall Optimized Machining Parameter under castor oil

The overall optimized machining parameters for CNC cutting oil MQL machining on the basis of optimized temperature, surface roughness, material removal rate

Solution	Feed rate	Spindle speed	Depth of cut	Temperature fit	Material removal rate fit	Surface roughness fit	Composite desirability
1	178.788	5000	200	31.98	343.485	0.170902	0.558944

Table 8.7 Overall Optimized Machining Parameter under CNC oil

CONCLUSIONS

By comparing the above tables the overall optimized temperature with minimum lubricating wastage with an optimized surface finish at higher production rate is obtained under MQL with CNC oil as cutting fluid

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