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Optimization Of Process Parameters In Turning 817M40T Steel At Minimum Quantity Lubrication (MQL) Condition

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ABSTRACT

This research conducts optimization of cutting parameters on surface roughness during turning of 817M40T steel under dry and minimum quantity lubrication (MQL) conditions. The cutting parameters such as spindle speed, feed rate and depth of cut were the parameters taken as input variables for the investigation of the surface roughness quality. The experimental design adopted in this work was a three-factors-three-levels of L9 Orthogonal Array of Taguchi Robust Design Technique. Fifty four samples were experimented in a CNC Turning in dry and MQL environment and surface roughness measured using profilometer instrument. The optimal surface roughness value for MQL condition was found to be 1.9853µm. The result of ANOVA has the spindle speed contributing 71.5 %, followed by feed rate 14.10% and depth of cut has least effect of 7.80%.

In dry condition, the result of ANOVA has spindle speed with 55.78% contribution followed by feed rate of 35.7% while depth of cut has least effect of 5.52%. In dry condition, the optimum value of surface roughness is 2.7096µm.

MQL cutting condition was found to be better and more reliable because it is environmentally friendly and gives better surface finish. With the obtained optimum input parameters for surface roughness, production machining operations will be enhanced.

Key words: Surface roughness, Machining, Minimum quantity lubrication (MQL), CNC turning, 817M40T Steel

1. INTRODUCTION

Turning is most widely employed machining process for producing rotating parts. Surface roughness in CNC Turning has been recognized as quality characteristics of the machining operations. In the manufacturing industries, various manufacturing processes are adopted to remove the material from workpiece. Out of those processes, turning is the first most common method of metal cutting because of its ability to remove materials faster with a reasonable good surface quality [8]. In recent time, the technology of CNC turning machine tools have been improved significantly to meet the advanced requirements in various manufacturing fields, especially in the precision metal cutting industry. It is widely used in a variety of manufacturing industries. The quality of the surface plays a very important role in the performance of the mechanical part and good-quality surface significantly improves fatigue strength, corrosion resistance, or creep life [17].

Surface finish is one of the most important quality characteristics which influence product appearance, function, reliability as well as production cost in manufacturing industries, [6]. As a result, it is important to maintain consistent tolerances and surface finish. In recent times, modern industries are trying to achieve the high quality products in a very short time with less operator input with the use of the computer Numerically Controlled (CNC) machine tools. These machine tools have automated and flexible manufacturing systems.

Metal is cut by removal of chips which may be in the form of continuous ribbon or discontinuous chips composed of individual segments, which depends on the work material and cutting conditions. There is no flow of metal at right angles to the direction of chip flow. Flow lines are evident on the side and back of a chip, which suggests that cutting involves a shearing mechanism. A lot of heat is generated in the process of cutting due to friction between the chip and tool. The friction can be reduced by having sharp cutting edge and better tool finish, increased sliding speed, and improved tool geometry use of low friction work or tool materials, and use of a cutting fluid [15] The temperature of the cutting tool reaches a high value when taking a heavy cut at high speed. Sometimes, a built-up edge is formed at the tip of the tool and it significantly alters the cutting process. It deteriorates the surface finish and rate of tool wear is increased. Various studies have considered the behavior of tool wear under different tool-work-piece material combinations and experiments, such as the effect of flood coolant, and dry machining [12],[19] [10], [16].

The turning operation is governed by geometry factors and machining factors. Among them, the three primary adjustable/controllable machining factors or parameters in a basic turning operation are cutting speed, feed rate, and depth of cut. Material removal is obtained by the combination of these three parameters [7].

Cutting Speed: Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it tells their rotating speed. But the important feature for a particular turning operation is the surface speed, or the speed at which the work piece material is moving past the cutting tool [3]. Cutting speed can be obtained from the spindle speed. The spindle speed is the speed at which the spindle, and hence, the workpiece rotates. Cutting speed is usually between 3 and 200m/min. the rotational speed (RPM) of the spindle is usually constant during a single operation, so that when cutting a complex from the cutting speed varies with the diameter being cut at any instant. At the nose of the tool the speed is always lower than at the outer surface. The best possible cutting speed for a given job depends on the hardness of the material being machined, the material of the tool bit and how much feed and depth of the cut is required [11].

It is simply the product of the rotating speed times the circumference of the work piece before the cut is started. It is expressed in meter per minute (m/min), and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same.

Feed Rate: Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev[13].

Feed rate is dependent on the kind of tool, surface finish desired, power obtained at the spindle, characteristics of the machine being cut, tooling set up, strength of the workpiece and the rigidity of the workpiece.

Depth of Cut: Depth of cut is practically the thickness of the layer being removed (in a single pass) from the workpiece. Also, it is the distance from the uncut surface of the work to the cut surface, expressed in mm. It is also referred to as chip width thickness in turning. It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work due to the rotation of the work. Very low depth of cut increases machining time while excessive depth of cut increases tool cutting force, and tool temperature increases also, [1].

The quality of machined surface is characterized by the accuracy of its surface finish besides the dimensions specified by the designer. Every machining operation leaves characteristic evidence on the machined surface. This evidence in the form of finely spaced micro irregularities left by the cutting tool. Each type of cutting tool leaves its own individual pattern which therefore can be identified. This pattern is known as surface finish or surface roughness and the smaller is the better, [9].

Surface finish is one of the most important quality characteristics which influence product appearance, function, reliability as well as production cost in manufacturing industries, [4]. As a result, it is important to maintain consistent tolerances and surface finish. In recent times, modern industries are trying to achieve the high quality products in a very short time with less operator input with the use of the computer Numerically Controlled (CNC) machine tools. These machine tools have automated and flexible manufacturing systems.

Also, the determination of the machinability of materials is done by the measure of surface finish. Surface roughness is an important measure of product quality since it greatly influences the performance of mechanical parts as well as production cost. The optimization of machining parameters increases the utility for machining economics and the product quality increases to a great extent as well [18]..

817M40T is a high quality, high tensile, alloy steel and it has high tensile strength, shock resistance, good ductility and resistance to wear. It is most suitable for the manufacture of parts such as heavy-duty axles and shafts, gears, bolts and studs. 817M40T is capable of retaining good impact values at low temperatures, [5].

Component of soluble cutting oil as coolant requires base oil mineral or petroleum oil; and coolant for turning operation has various properties viz:

- Good lubricating qualities.
- High thermal conductivity for cooling.
- High flash point.
- Non-toxic.
- Chemically inert.
- Must not produce a gummy or solid precipitate at ordinary working temperature

2. MATERIALS AND METHODS

The workpiece used for the work is 817M40T Alloy steel bars with nominal dimension of 100mm length and diameter of 50mm. Base oil mineral was used as cutting fluid (coolant) for lubrication. Carbide tool (P-30) was used as cutting tool. Cutting processes were orthogonal array procedure of 3-levels -3-factors design of Taguchi Experiment. The parameters for experiments were selected for minimum quantity lubrication condition. All experiments were performed using Profilometer for measurement of surface roughness.

Experimental investigation was done at the AMT/CNC Laboratory of National Engineering Design Development Institute, Nnewi Anambra state, Nigeria.

Table 1: Chemical Composition of 817M40T Alloy Steel.

Element	C	Ni	Cr	Mo
Weight %	0.4	1.5	1.0	0.23

Table 2: Mechanical Properties of the 817M40T Alloy Steel.

Yield Strength	Tensile Strength	Ductility
110 MPa	221 Mpa	(% EL 8.5 in 50mm

Figure 1: Experimental setup for MQL and dry conditions for the turning test

Table 3: The selected process parameters and their levels

Factors	Symbol	Level 1	Level 2	Level 3
Speed (rpm)	A	600	800	1000
Feed Rate (mm/rev.)	B	0.1	0.2	0.3
Depth of Cut (mm)	C	0.2	0.4	0.6

The turning operations and measurements of surface roughness were done on fifty-four (54) workpieces. The workpieces were turned by Carbide cutting tool. Experiments were designed with the help of Taguchi L9 orthogonal array. The software used for DOE (Design of experiment) is Minitab16. Fifty four samples were carried out in CNC turning and surface roughness was recorded one after the other.

The experiment ran as follows: the workpiece is first fixed in a three-jaw chuck of the CNC machine. The length of work piece is 100mm in which the 40mm was used for holding on the chuck. The remaining length 60mm was used for machining. The cutting tool was allowed to slightly touch the right side of the work piece of material and the coordinates of the start of the work piece are set on the CNC lathe. The cutting tool was then allowed to have contact with the surface of the work piece material lightly, and the diameter of the work piece was set in the CNC lathe. Then, machining was carried out in minimum quantity lubrication condition; there were 9 samples for each experiment following L9 Orthogonal Array Sequence. Three trials experiment were done making a total of 27 in each condition in order to ascertain average mean of surface roughness values. A total of 54 samples were used for both dry and MQL conditions.

Similarly, machining was carried out in all the workpieces. After machining, the surface roughness of the workpieces was measured using Mitutoyo SJ201 (profilometer).

This investigation outlines the Taguchi optimization methodology, which was applied to optimize cutting parameters for optimal surface quality in turning operation. The machining parameters evaluated were spindle speed, feed rate and depth of cut. The experiments conducted by using Taguchi L9 orthogonal array as suggested by Taguchi. Signal-to-Noise (S/N) ratio, Analysis of Mean(ANOM) and Analysis of Variance (ANOVA) were employed to analyze the effect of cutting parameters on surface quality.

3. RESULTS

Table 4.1.1: Effect of Process Parameter on the Mean Surface Roughness with S/N Ratio under MQL Condition

Speed (rpm)	**Feed rate (mm/rev.)**	**Depth of cut (mm)**	**Surface roughness (µm)**				**S/N Ratio**
			SR 1	SR 2	SR 3	MEAN SR	
600	0.1	0.2	1.90	1.89	1.89	1.90	-5.5751
600	0.2	0.4	1.80	1.82	1.80	1.81	-5.1536
600	0.3	0.6	1.69	1.70	1.71	1.70	-4.6090
800	0.1	0.4	1.37	1.30	1.44	1.37	-2.7344
800	0.2	0.6	1.30	1.31	1.31	1.31	-2.3454
800	0.3	0.2	1.20	1.15	1.25	1.20	-1.5836
1000	0.1	0.6	1.12	1.10	1.10	1.10	-0.8279
1000	0.2	0.2	1.00	0.99	1.00	1.00	0.0000
1000	0.3	0.4	0.51	0.51	0.51	0.51	5.8486

Table 4.1.2: Evaluated signal to noise ratios and orthogonal array setting for evaluation of mean surface roughness responses of 817M40T steel under MQL.

Number of experiment	**Speed (A)**	**Feed Rate (B)**	**Depth of Cut (C)**	**MEAN Surface Response (µm)**	**S/N Ratio**
1	1	1	1	1.90	-5.5751
2	1	2	2	1.81	-5.1536
3	1	3	3	1.70	-4.6090

4	2	1	2	1.37	-2.7344
5	2	2	3	1.31	-2.3454
6	2	3	1	1.20	-1.5836
7	3	1	3	1.10	-0.8279
8	3	2	1	1.00	-0.0000
9	3	3	2	0.51	5.8486

Table 4.1.3: Response Table for Signal-to-Noise Ratio of 817M40T Alloy Steel based on smaller is better quality characteristics under MQL

Level	**A: Spindle Speed (rpm)**	**B: Feed Rate (mm/rev.)**	**C: Depth of Cut (mm)**
1	-5.1125	-3.0458	-2.3862
2	-2.2212	-2.4997	-0.6798
3	-1.6736	-0.1147	-2.5941
Delta	6.7861	2.9311	1.9143
Rank	1	2	3

Table 4.1.4: Response Table for Mean Surface Roughness of 817M40T Alloy Steel based on smaller is better quality characteristics under MQL.

Level	**A: Spindle Speed (rpm)**	**B: Feed Rate (mm/rev.)**	**C: Depth of Cut (mm)**
1	1.8033	1.4567	1.3667
2	1.2933	1.3733	1.2300
3	0.8700	1.137	1.3700
Delta	0.9333	0.3200	0.1400
Rank	1	2	3

Table 4.2.1: Effect of Process Parameter on the Mean Surface Roughness under Dry Condition

No of Exp.	**Speed (rpm)**	**Feed rate (mm/rev)**	**Depth of cut (mm)**	**Surface roughness (µm)**				**S/N Ratio**
				SR 1	SR 2	SR 3	MEAN SR	
1	600	0.1	0.2	2.69	2.70	2.71	2.70	-8.6273
2	600	0.2	0.4	2.51	2.50	2.49	2.50	-7.9588
3	600	0.3	0.6	2.25	2.249	2.25	2.25	-7.0437
4	800	0.1	0.4	1.98	1.98	1.98	1.98	-5.9333
5	800	0.2	0.6	1.80	1.79	1.81	1.80	-5.1055
6	800	0.3	0.2	1.70	1.70	1.70	1.70	-4.6090
7	1000	0.1	0.6	1.65	1.649	1.65	1.65	-4.3497
8	1000	0.2	0.2	1.50	1.50	1.50	1.50	-3.5218
9	1000	0.3	0.4	1.25	1.30	1.20	1.25	-1.9382

Table 4.2.2: Evaluated signal to noise ratios and orthogonal array setting for evaluation of mean surface roughness responses of 817M40T Steel under dry

Number of experiment	Speed (A)	Feed Rate (B)	Depth of Cut (C)	MEAN Surface Roughness Response (µm)	S/N Ratio
1	1	1	1	2.70	-8.6273
2	1	2	2	2.50	-7.9588
3	1	3	3	2.25	-7.0437
4	2	1	2	1.98	-5.9333
5	2	2	3	1.80	-5.1055
6	2	3	1	1.70	-4.6090
7	3	1	3	1.65	-4.3497
8	3	2	1	1.50	-3.5218
9	3	3	2	1.25	-1.9382

Table 4.2.3: Response Table for Signal-to-Noise Ratio of 817M40T Alloy Steel based on Smaller is better quality characteristics under dry.

Level	A: Spindle Speed (rpm)	B: Feed Rate (mm/rev.)	C: Depth of Cut (mm)
1	-7.877	-6.303	-5.586
2	-5.216	-5.529	-5.277
3	-3.270	-4.530	-5.500
Delta	4.607	1.773	0.309
Rank	1	2	3

Table 4.2.4: Response Table for Mean Surface Roughness of 817M40T Alloy Steel based on Smaller is better quality characteristics

Level	A: Spindle Speed (rpm)	B: Feed Rate (mm/rev.)	C: Depth of Cut (mm)
1	2.483	2.110	1.967
2	1.827	1.933	1.910
3	1.467	1.733	1.900
Delta	1.017	0.377	0.309
Rank	1	2	3

For the current research, the desired characteristic for surface roughness is “the smaller the roughness value, the better. Computation of signal-to-noise ratio is required for this investigative study. A basic explanation of the signal-to-noise ratio is: a ratio of the change in output due to the changing variable vs. changes in things we cannot control. The equation to find the S/N ratio for this characteristic (surface roughness) is given below:

$$S/N = -10\log_{10} [\text{Mean of sum of squares of measured data}]$$

$$= -10\log_{10} [(\Sigma y^2)/n]$$

Where n is the number of measurements in a trial and y is the measured value in a trial. The S/N ratio obtained for the turning test is shown in the table 4.1.1 and table 4.2.1 for MQL and dry conditions respectively.

4. EFFECTS OF PROCESS PARAMETERS ON SURFACE ROUGHNESS DURING THE MACHINING OF 817M40T ALLOY STEEL TURNING OPERATION

The main effect plot of the three most influential cutting parameters: cutting speed (A), feed rate (B), and depth of cut (C) on surface roughness for the turning experiments are shown below in Figures 2a and 2b. and also for fig.3a and 3b for dry condition. Figures 2(a) (b)and 3(a)(b): Effect Plot for Surface Roughness vs. Cutting Speed (A), Feed Rate (B) and Depth of Cut(C) .It shows the plots for the process parameters which are the cutting speed , feed rate and depth of cut respectively. The main effects plot shows graphically, the influence of each control factor on surface roughness. These plots reveals that surface roughness is enhanced, as cutting speed increases.

While surface finish is enhanced with decrease in feed rate as well as depth of cut.

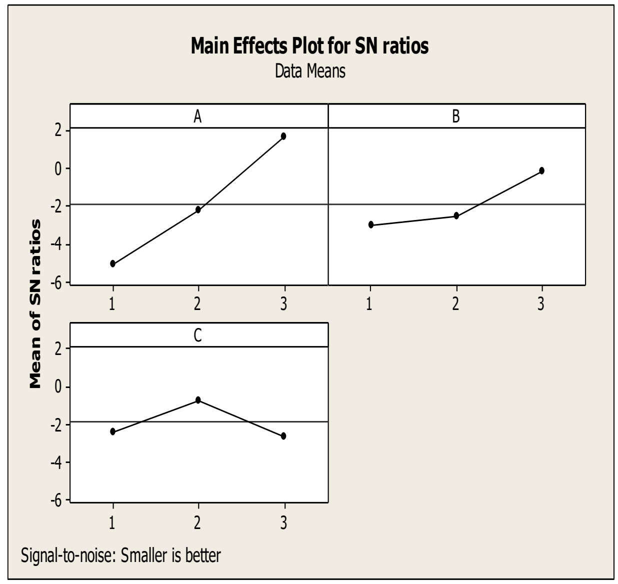
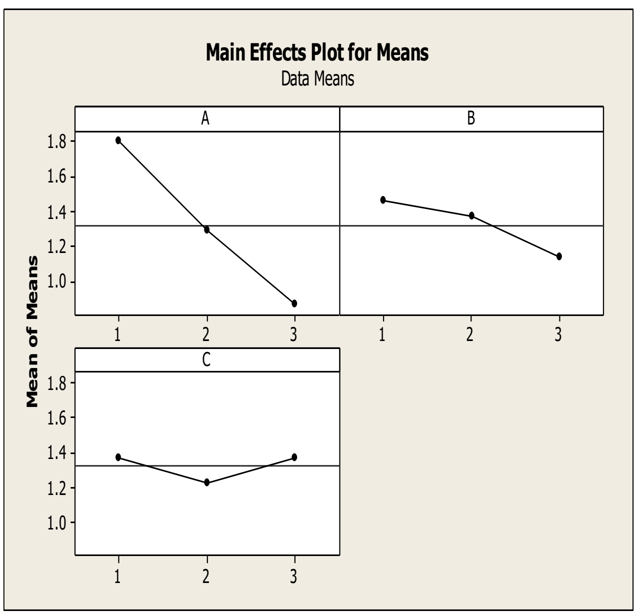


Figure 2 (a): Response graph of S/N ratio of 817M40T alloy steel under MQL condition



sFigure 2.b: Response graph of Mean of 817M40T alloy steel

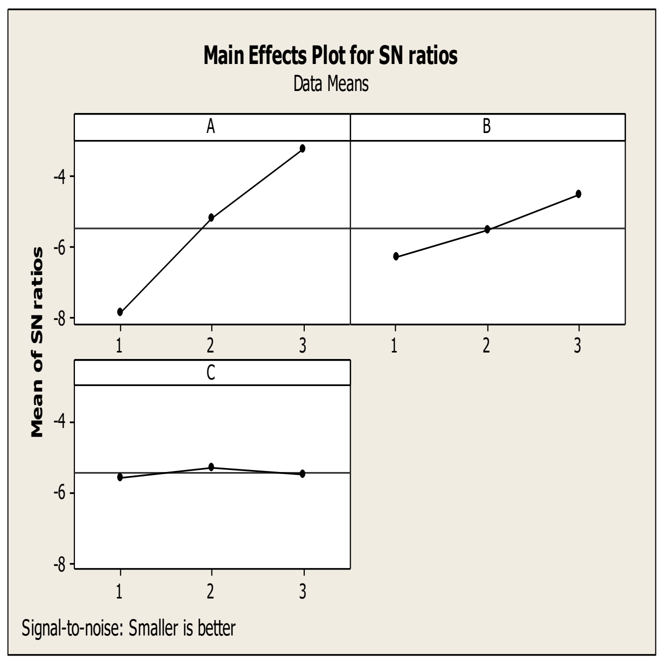


Figure 3.a: Response graph of S/N ratio for Dry of 817M40T alloy steel.

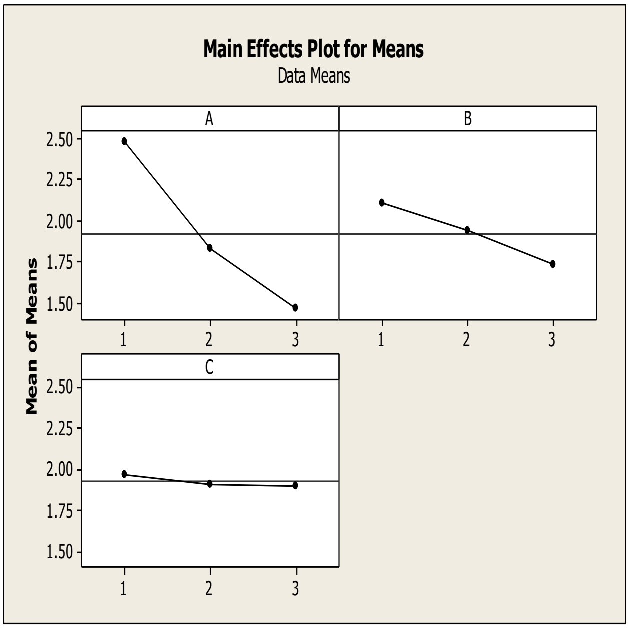


Figure3.b: Response graph of Means for surface roughness of 817M40T alloy steel under Dry condition.

Table 5: Summary of Analysis of Variance on S/N ratio for 817M40T for MQL

Source	**Degree Of freed**	**Seq SS**	**Adj SS**	**Adj MS**	**F-Ratio**	**% Contribution**
Source	Degree Of freedom	Seq SS	Adj SS	Adj MS	F-Ratio	% Contribution
Spindle Speed (A)	2	32.0875	32.0875	16.0438	119.61	55.78
Feed Rate (B)	2	0.4741	0.4741	2.3705	17.67	35.70
Depth of Cut (C)	2	0.0552	6.620	0.0764	0.57	5.52
Residual Error	2	0.0368	6.446	0.1341		3.00
Total	8	95.24				100

om						
Spindle Speed (A)	2	69.581	69.581	34.790	10.79	71.50
Feed Rate (B)	2	14.581	14.581	7.289	2.26	14.10
Depth of Cut (C)	2	6.620	6.620	3.310	1.03	7.80
Residual Error	2	6.446	6.446	3.223		6.60
Total	8	97.224				100

The summary of ANOVA result of 817M40T steel is presented in Table 5. The spindle speed has more contribution (71.50%) on the maximizing the surface roughness followed by feed rate (14.10%) and depth of cut has least effect (7.80%) in maximizing surface roughness of 817M40T steel material.

Table 6: Summary of Analysis of Variance on S/N ratio for 817M40T under Dry condition.

The comparative magnitude among the process parameters were investigated through the ANOVA. The summary of ANOVA result for Dry condition of 817M40T steel is presented in Table.6. The spindle speed has more contribution (55.78%) on the maximizing the surface roughness followed by feed rate (35.70%) and depth of cut has least effect (5.52%) in maximizing surface roughness of 817M40T steel material.

Estimation of expected responses based on optimum settings

The expected response is estimated using the optimum process factor setting from the main effects plots, by employing the response table for signal to noise ratio and the responsible table for mean [2];[14], the expected response model is below:

$$ER = AVR + (A_{opt} - AVR) + (B_{opt} - AVR) + (C_{opt} - AVR) + \text{-----} (n^{th}_{opt} - AVR) \quad (1)$$

Where ER = expected response, AVR = average response, A_{opt} = mean value of response at optimum setting of factor A, B_{opt} = mean value of response at optimum setting of factor B, and C_{opt} = mean value of response at optimum setting of factor C.

ER(MQL) = 1.3222 + (1.803 – 1.3222) + (1.4567 – 1.3222) + (1.3700 – 1.3222)

= 1.3222 + 0.4808 + 0.1345 + 0.0478

= 1.9853 µm

Table 7: Optimum setting of control factors and expected optimum surface roughness of steel at MQL

Condition	**Control factors**	**Optimum level**	**Optimum setting**	**Optimum value**
Specimen	A	3	1000	1.9853 µm
	B	1	0.1	
	C	2	0.4	

ER $_{(DRY)}$ = 1.9257 + (2.484 – 1.9254) + (2.110 – 1.9257) + (1.967 – 1.9257)

= 1.9257 + 0.5583 + 0.1843 + 0.0413

= 2.7096 µm

Table 8: Optimum setting of control factors and expected optimum surface roughness of steel under dry condition.

Condition	**Control factors**	**Optimum level**	**Optimum setting**	**Optimum value**
Dry condition	A	1	600	2.7096 µm
	B	1	0.1	
	C	1	0.2	

5. CONCLUSIONS

This work has contributed to existing knowledge by providing study of turning 817M40T steel through a well-designed three-factor three -level experiment, using L9 Orthogonal Array of Taguchi Robust Design. Hence, using turning of 817M40T steel to achieve analysis of mean (ANOM) and analysis of variance (ANOVA) MQL condition.

In this study, the effects and optimization of process parameters on surface roughness during turning operation of 817M40T Alloy Steel were established. By constructing the response table for signal-to-noise (S/N) ratio, the characteristics of the main effects were seen and optimal cutting condition obtained. The use of Minitab 16 Software package facilitated handling of the experimental data, development of the ANOVA table and formulation of high performance surface response prediction for the 817M40T Alloy Steel material. The significant conclusions drawn from the present research are summarized as follows:

. From the experimental results, in MQL condition, the optimal machining performance for the machine surface roughness optimization is obtained at a cutting speed of 1000rpm, feed rate of 0.1mm/rev and depth of cut of 0.4mm. The value of the optimized surface finish is 1.9853 µm. while in dry condition, the optimal machining performance for the surface roughness optimization is obtained at a cutting speed of 600rpm, feed rate of 0.1mm/rev. and depth of cut 0.2. the optimized surface value is 2.7096µm.

• In the order of influence to surface roughness, in MQL condition, cutting speed was found to be most influencing factor contributing 71.5% to surface roughness, feed rate 14.1% and depth of cut 7.80% respectively for the test material used. The effect of each factor was found to be mainly linear, and there exists no cross product effects (interactions) among the individual factors.
Also, for dry condition, spindle speed of 55.78 % contribution, followed by feed rate 35.7% and depth of cut has least effect of 5.52%.

This research is limited to evaluation of cutting (process) parameters in determining surface roughness response, therefore, power consumption rate and time can be considered in subsequent research.

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