Parametric Investigation of Minimum Quantity Lubrication on Surface Roughness and Chip Thickness by Hard Turning of Hardened Alloy Steel AISI-4340 using CBN inserts

Amit Vishwakarma
M.Tech Scholar,
Department of Mechanical Engineering
NRI Institute of Information Science and Technology, Bhopal
Madhya Pradesh, India

Prof. Sachin Jain
Associate Professor
Department of Mechanical Engineering
NRI Institute of Information Science and Technology, Bhopal
Madhya Pradesh, India

Dr. P. K. Sharma
Head of Department
Department of Mechanical Engineering
NRI Institute of Information Science and Technology, Bhopal
Madhya Pradesh, India

***Abstract*—In machining operations the continuous motion of tool and work piece results tool wearing problem and it leads to the failure of tool due to this continuous motion. Various parameters involved in machining operations in which surface finish, cutting temperature, tool life and coolant quality are the important factors in product quality. Coolant generally increases the economy of tools and also maintains work piece surface properties without damages. Conventional cutting fluid application fails to penetrate the chip-tool interface and thus cannot remove heat effectively. To overcome from this problem some alternatives of conventional cutting fluid had been used to minimize damages and also avoid the use large quantity of cutting fluid in machining operations. Dry machining may be used as an alternative but one of the best alternatives is minimum quantity lubrication. In wet machining there is large amount of coolant is used, that is the reason an alternative of minimum quantity lubrication technique has been used. The cutting parameters like feed, speed, depth of cut are changed in three levels in three different environmental conditions; dry, wet and minimum quantity lubrication is planned and after calculating the surface roughness values at different input parameters, the analysis of variance method is used to find the optimal surface roughness value and also compare the minimum quantity lubrication with dry and wet environmental condition. While performing the experiment, analyzing the chip thickness and its behavior at every trial and also investigate the nature of chip at different cutting temperatures.**

Keywords*— *Minimum quantity lubrication, Surface roughness, Analysis of Variance,, Chip thickness, CBN inserts

I. INTRODUCTION

The conventional method of manufacturing a component has some sequences which are machining, heat treatment, fineness grinding and turning fineness grinding as surface finish is one of the important factor in product quality. In order to increase the flexibility and ability to manufacture complex geometry's, hard turning was introduced where the necessity of grinding operation can be eliminated. In the process of hard turning, grinding operation, rough machining can be eliminated and various raw material is supplied in the final heat-treated form. The concept of hard turning may be regarded as an alternative for grinding operations. In hard turning the final finishing process is the fine turning, whereas in normal manufacturing, normally it is grinding. In various cases hard turning leads to substantial cost reduction in manufacturing and therefore hard turning operations are developing wide applications in industry.

Dry machining is now of great interest and actually meet with success in the field of environmentally friendly manufacturing, however, they are sometimes not effective when better surface finish quality and several cutting conditions are required. So for these situations, some less dry operations utilizing very small amounts of cutting lubricants are expected to become powerful tool, in fact, they already play a significant role in a number of practical applications. Minimal quantity fluid application refers to the use of cutting fluids of only a minute amount typically of flow rate of 50 to 500 ml/hour [1]. The concept of minimal fluid application sometimes referred to as near dry lubrication or micro lubrication.

The material used for the present work is hardenable alloy steel AISI 4340 which is hardened to 45 HRC by heat treatment. In the present project work the turning of AISI 4340, 50 mm bar on CNC Lathe is planned .The turning is carried with CBN insert because for hardened steel CBN insert shows the good performance. The cutting parameters which are speed, feed and depth of cut are changed in three levels in three different environmental conditions like dry, wet and MQL is planned. The inserts used are having chamfer and honed tool geometry as the tool geometry is one of the critical process parameter in hard turning.

II. LITERATURE REVIEW

The major objective of the cutting fluid in hard turning is to serve as coolant as well as lubricant due to more heat generation in machining. Generally hard turning requires large quantities of coolants and lubricants. Due to the multiplicity of being negative effects the cutting fluid wastes produce on mankind and our environment. In addition to this effect the cost of procurement, excess storage and disposal of coolants and lubricants increases the total cost of production considerably. It is the fact that a conventional application of flood coolant has limitations and hampers the machining productivity if the input parameters are not properly controlled and monitored. Thus the new technique that reduces the above draw backs are used by few authors. The function of the cutting fluid in the machining process is to provide lubrication and cooling and to minimize the heat produced between the surface of the part and tool. Cooling is required for the economically feasible service life of tools and the required service qualities. It cannot be eliminated completely particularly when tight tolerances are required or when the machining of difficult to cut materials is involved [3]. These approaches are Minimum Quantity Lubrication (MQL), cryogenic lubrication and coolant and water vapor as coolant and lubrication. Jitendra. M. Varma, Chirag. P. Patel (2013) [5], concluded that the application of solid lubricant in dry machining has proved to be a feasible alternative to cutting fluid, if it can be applied properly. There is a considerable improvement in surface roughness and quality of product produced. But this is cost consuming lubricant as compared to MQL. The surface roughness quality is better than solid lubricant. The present investigation is related to explore the possibility of application of minimum cutting fluid in the machining area.

MQL provides better surface finish; various authors proved that minimum quantity lubrication minimize roughness of work piece surface. A. Bhattacharya et al. (2009) [10] investigated the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI 1045 steel using ANOVA and Taguchi design. These results showed a significant effect of cutting speed on surface roughness and power consumption, while the other parameters have not substantially affected the response. The performance and life of the machined/ground component are affected by its surface finish. Dhar at al., (2007) [1] states that MQL gives better surface finish than the dry and flood cutting irrespective of cutting velocity feed rate and length of cut. Lima et al. [7] investigated the machinability of hardened AISI 4340 and D2 grade steels at different levels of hardness by using various cutting tool materials. The experimental data were further analyzed to predict the optimal range of surface roughness (Ra) [4]. The AISI 4340 steels were hardened maximum at range from 42 to 48 HRC and then turned by using coated carbide and CBN inserts.

III. OBJECTIVE OF WORK

The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of dimensional accuracy and surface finishing, high production rate and cost effective, with a reduced environmental impact. These goals are affected by several elements among one of them is the cooling lubricant and its application method. Many authors have been studied the performance in machining of different materials with dry, flood coolant, MQL and cryogenic cooling and it is observed that finished surface, cutting forces and chip formation are all affected with the type of coolant, cutting speed, feed and depth of cut. Very little investigation in MQL for cooling in machining of hardened alloy steel which is difficult to cut has been available in literature. Hence the MQL for cooling in machining of hardened alloy steel AISI 4340 has been selected to study the effect on surface roughness, cutting forces at different cutting temperatures. The various objectives of the present work is:-

1. To modify the existing set up for the experimentation.
2. Design of experiments.
3. Conducting the experiments.
4. Comparison of experimental results of hard turning with minimum quantity cutting fluid (MQL) application with dry and wet turning of AISI 4340 steel by CBN tool.
5. Analysis of experimental results using Taguchi Method.

IV. EXPERIMENTAL WORK

In the present work an attempt has been made to study the effect of minimal quantity lubrication (MQL) turning of hardened alloy steel 4340 by CBN insert on cutting force, cutting temperature and surface finish and its comparison with dry and wet turning.

This chapter presents detailed experimental plan and its implementation carried out for MQL turning and process related parameters during MQL, dry and wet turning of AISI 4340 with CBN insert. The response variables selected to achieve better machining and tool performance are surface roughness and cutting force. The process parameters used in the work are cutting speed, feed rate, depth of cut and tool related parameter as nose radius. The experiments were conducted using standard L_{18} (2^1 x 3^7) Taguchi mixed Orthogonal Array. The following section clears the design of experiment and related parameters.

The effects of varying cutting parameters and different environmental condition on chip reduction coefficient are also observed from results obtained, analysis chips are made.

A. Experimental Details

1) Workpiece Material

The workpiece material used is hardened alloy steel 4340 with diameter 50 mm and 150 mm working length. The chemical composition and mechanical properties are given in Table 1 and Table 2 respectively. The material is hardened up to 45 HRC.

Designation: American- AISI 4340
British - EN 24
Indian - 40 Ni 2 Cr 1 Mo 28

Chemical composition of this material is Carbon 0.35 to 0.45%, Silicon 0.10 to0.35%, Manganese 0.4 to 0.7, Nickel 1.25 to 1.75%, Chromium 0.9 to 1.3%, Molybdenum 0.2 to 0.35.

2) Cutting Tools and Tool Geometry

Two Cubic Boron Nitride (CBN) cutting tool inserts are used for turning operations. Both are having chamfered and honed tool geometry. One is having tool nose radius 0.4 mm and other having 0.8 mm.

3) Cutting inserts

ISO designation: CNGA 12 04 08 S 0 1025
and CNGA 12 08 08 S 0 1025
Grade : KB 5625
Make : Kennametal
Material: Cubic Boron Nitride (CBN)
The inserts are rigidly attached to a tool holder as shown in fig. 1.

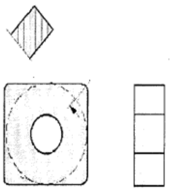

Fig.1

4) Specification of tool holder:

ISO designation: PCLNL 2525 M 12

Make: Kennametal

Tool Geometry (fig.2):

Principal cutting edge angle: 95°

Orthogonal rake angle : -6°

Clearance angle : 0°

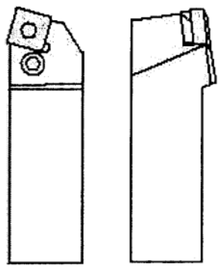

Fig.2

5) Cutting Fluid Application

Since the quantity of cutting fluid used in this method is very low (5ml/min), specially formulated cutting fluid is used. The base oil is commercially obtainable mineral oil. The oil is properly formulated by adding additives such as surfactant, evaporator, emulsifier, stabilizer etc agents. The oil is commercially obtainable in formulated form.

A special fluid supply system is considered to sustain the fluid supply as 5 ml/min. It consists of a lubricator that is used in pneumatic system to regulate the fluid supply. The capacity of lubricator is 0.60 lit. The initial of the lubricator is connected to the compressor which supplies the air with 6 bar pressure. The mist air coming out from the lubricator is used as cutting fluid. The lubricator nob is accustomed such that the oil flow rate is 5 ml/min. The fluid is supplied at the tip of tool.

B. Experimental apparatus

The lathe machine used for experimentation is CNC lathe. The measurement of surface finish is calculated by Surface tester machine. The detailed specifications of the lathe machine and surface tester are as follows:

1) NH22 (HMT) Lathe:

7.5 HP lathe with the maximum spindle speed of 1020 rpm

a) Capacities:

Height of center: 220 mm
Type of bed: Straight
Swing over bed: 500 mm

b) Feed:

Longitudinal feed range: 60 from 0.04-2.24 mm/rev.
Cross feed range: 60 from 0.020-1.120 mm/rev.

c) Carriage:

Cross slide travel: 300 mm.
Top slide travel: 150mm.

d) Power:

Main motor: 11 kW.
Coolant pump motor: 0.1 kW.

2) Surface roughness tester:

The surface roughness of the machined samples was measured by Taylor Hobson Surface roughness tester.

3) Tool Makers Microscope:

a) Specification:

METZ: 1395
Least count: 0.02 mm
Materials: Tip- Diamond
Skid - Sapphire
Measuring range: 10 nm- 600 μm
Spot diameter: 2 μm
Roughness angle: ±13° Pickup size: 0.20 X 97

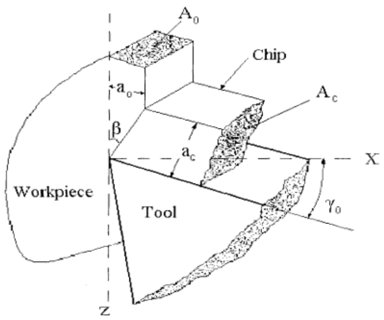

Fig.3. Geometry of Chip formation

C. Experimental Procedure

The cylindrical work piece of alloy steel 4340 having diameter 50 mm and length 150 mm was mounted on rigid CNC lathe machine with tail stock support. A CBN insert of tool specification MT KB 5625 grade clamped on tool holder PCLN L 2525 M12.

The experiments were performed randomly as per the L_{18} orthogonal array. Before starting the experiment the work piece was prepared for experiment and the turning length was selected as 35 mm. Then the machining parameters were selected according to the first experiment data on CNC lathe machine. The temperature of cutting tool was measured by infrared non-contact type thermometer (CEM make). At the time of experimentation the chips were collected. For every new experiment, the next 35 mm of the work piece was used. Thus on a work piece of 150 mm three experiments were conducted .After each set of three experiments a new work piece of same dimensions was used. According to cutting speed and diameter of work piece the rpm of spindle was adjusted. In this manner total 18 experiments were performed one by one in random order. For eighteen experiments two inserts (4 cutting points) were used and chips were collected. While performing experiment the roughness value were measured by Taylor

Hobson surface Tester and chip cross section and thickness was measured by Nikon measuring microscope.

D. Input or Controllable Factors:

In this experiment study, five parameters as cutting speed, rate of feed, depth of cut, tool nose radius and supply of coolant were selected for the present work

1) Cutting Speed (V):

It is known that the cutting speed has greater effect on cutting force and surface finish than depth of cut. However, there is certain combination of speed, depth of cut and feed which affect the surface finish.

2) Feed Rate (f):

A variation in the feed has greater influence on surface finish than depth of cut. It is possible to obtain better finish surface by increasing the feed rate and cutting speed.

3) Depth of Cut:

It has great influence on cutting force than feed rate .As depth of cut increase the cutting force also increases.

4) Tool Nose Radius:

The tool nose radius is one of the important factors in turning of hardened steel. Hence tool nose radius is taken as one of the input factor.

5) Supply of coolant:

In turning of hardened steel supply of coolant plays important role. Depending on coolant supply method, quantity and quality performance of tool varies. If coolant supply is effective then we can get better surface finish with minimum cutting force.

E. Input factors and their levels

1) Variable factors:-

Tool Nose Radius (mm) : 0.4, 0.8
Cutting Speed, V (m/min) : 100, 120, 140
Feed Rate, f (mm/rev) : 0.08, 0.09, 0.10
Depth of Cut, d (mm) : 0.25, 0.35, 0.50
Environmental condition : Wet, Dry, MQL

The input factors are given in table 1 according to the different levels as given below:-

TABLE 1: INPUT FACTORS WITH LEVELS

Factors	Unit	Levels		
		1	*2*	*3*
Depth of Cut (D)	mm	0.25	0.35	0.5
Feed (F)	mm/rev	0.08	0.09	0.1
Cutting speed(V)	m/min	100	120	140
Environmental condition		WET DRY MQL		

2) Fixed factors:-

Tool geometry (clearance angle = 0°, -80° rhombus shape, nose radius = 0.80 mm, back rake angle = -6°, approach angle = 95°, side cutting edge = 5°)
Tool material (CBN inserts)

From the above factors, L_{18} orthogonal array of Taguchi method has been selected for the experiments in MINITAB 17 software. These experiments were carried out under three different environmental condition wet, dry minimum quantity lubrication. From these above different factors and three different environmental conditions, different values of surface roughness and cutting force have been obtained. The surface roughness values for different environment conditions and at different level are obtained by surface roughness tester (see fig.7) as given below:-

TABLE 2: SURFACE ROUGHNESS VALUES AT VARIOUS ENVIRONMENTAL CONDITION

Exp No.	**Actual values of Control Factor Levels allotted to columns**			**Ra (µm)**
	Depth of Cut (D)	***Feed (F)***	***Cutting speed(V)***	
DRY				
1	0.25	0.08	100	3.067
2	0.35	0.09	120	2.436
3	0.50	0.1	140	1.605
4	0.25	0.08	100	2.152
5	0.35	0.09	120	1.735
6	0.50	0.1	140	1.036
WET				
7	0.25	0.08	100	2.984
8	0.35	0.09	120	2.368
9	0.50	0.1	140	1.291
10	0.25	0.08	100	1.672
11	0.35	0.09	120	1.014
12	0.50	0.1	140	0.973
MQL				
13	0.25	0.08	100	2.691
14	0.35	0.09	120	1.385
15	0.50	0.1	140	0.882
16	0.25	0.08	100	2.021
17	0.35	0.09	120	1.378
18	0.50	0.1	140	0.803

Fig.4. CNC Lathe Machine

Fig.5. MQL Machining

Fig.6. Workpiece After MQL Machining

Fig.7. Taylor Hobson Surface roughness tester operation on workpiece (set up)

V. METHODOLOGY

A. Data Analysis and Results:-

After calculating the surface roughness Ra value at different environmental condition and various cutting parameters, the above results are analyzed with analysis of variance and regression analysis in Minitab 17.

1) Analysis Of Variance (ANOVA)

Analysis of variance (ANOVA) method is used to examine various experimental results which are obtained after machining at different cutting parameters [10] [6]. The Analysis of variance investigation results with surface roughness values and different cutting parameters can be calculated using Minitab 17 software. This analysis was carried out for a confidence level of 95%. The analysis of variance tabulation for above mentioned environmental conditions is exposed in table 3, 4 and 5 respectively.

TABLE 3: ANOVA FOR DRY MACHINING

Source	DF	Adj SS	Adj Ms	F	P
CS (V)	2	0.42176	0.42176	26.54	0.981
DOC (D)	2	4.32169	2.25867	43.68	0.682
FR (F)	2	2.32065	0.84271	12.74	0.028
F × D	4	0.31564	0.15732	32.14	0.872
V × F	4	0.63879	0.24714	8.92	1.184
D × V	4	0.15783	0.04863	2.64	1.002
Error	8	0.48691	0.01524		
Total	26	8.66527			
S = 0.497177 R-Sq = 59.01% R-Sq(adj) = 53.54%					

TABLE 4: ANOVA FOR WET MACHINING

Source	DF	Adj SS	Adj Ms	F	P
CS (V)	2	0.76832	0.02122	33.12	0.001
DOC (D)	2	2.41564	0.98313	58.75	0.041
FR (F)	2	1.67529	0.76358	16.68	0.000
F × D	4	0.68923	0.22367	4.78	1.612
V × F	4	0.09648	0.01267	2.82	4.368
D × V	4	0.13835	0.03598	1.32	1.836
Error	8	0.02543	0.01984		
Total	26	5.80874			
S = 0.275436 R-Sq = 91.18% R-Sq(adj) = 81.31%					

TABLE 5: ANOVA FOR MQL MACHINING

Source	DF	Adj SS	Adj Ms	F	P
CS (V)	2	0.04243	0.64981	24.67	0.019
DOC (D)	2	2.35039	1.1769	54.64	0.026
FR (F)	2	5.33486	2.6677	11.42	0.002
F × D	4	1.00624	0.2472	2.35	0.080
V × F	4	0.89357	0.41673	1.79	5.618
D × V	4	0.10244	0.01155	1.02	2.162
Error	8	0.2276	0.07587		
Total	26	9.95753			
S = 0.123469 R-Sq = 98.78% R-Sq (adj) = 96.96%					

2) Optimal Values of Surface Roughness:-

Best possible Values of Surface Roughness for particular Environment conditions at different levels

TABLE 6: OPTIMAL SURFACE ROUGHNESS VALUE (MQL)

Level	Surface Roughness Value (Ra)		
	CS (V)	*DOC (D)*	*FR (F)*
1	1.698	1.326	1.716
2	1.162	0.982	1.082
3	0.948	1.078	0.836
Delta	0.788	0.466	0.894
Rank	2	3	1

In table 6 optimal values at different cutting parameters have obtained. But some best possible results obtained at significant inputs which fit best at particular level. In above table two underlined Ra values gives better significant results at two different levels and the cutting parameters are categorized by factor ranking.

The obtained results validated by using regression equation, which was obtained by using MINITAB 17 software and also compare with recent work.

a) Regression equation

The second order multiple regression equation has implemented to obtain the results between the machining parameters and the measured surface roughness. The R^2 value gives the estimation of correctness of the above mentioned results. The equation obtained from MINITAB software was as follows:

$$Ra = -1.09763 - 2.7463\times D + 24.6591\times F + 0.0619\times V + 5.5049\times D^2 - 31.8217\times F^2 - 0.0000\times V^2 - 0.2904\times V\times F - 0.0027\times D\times V - 0.7639\times D\times F \quad (R^2 = 96.96\%) \quad (1)$$

With the help of above regression equation Ra values at different cutting parameters can be calculated and surface roughness plots with individual cutting parameters are obtained which are shown in plot 8 and plot 9 respectively.

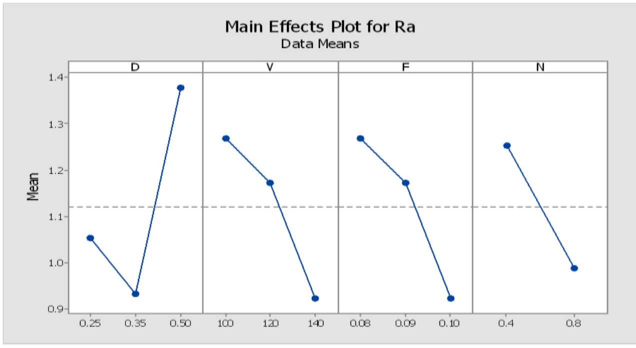

Fig.8. Main effects plot for Surface Roughness

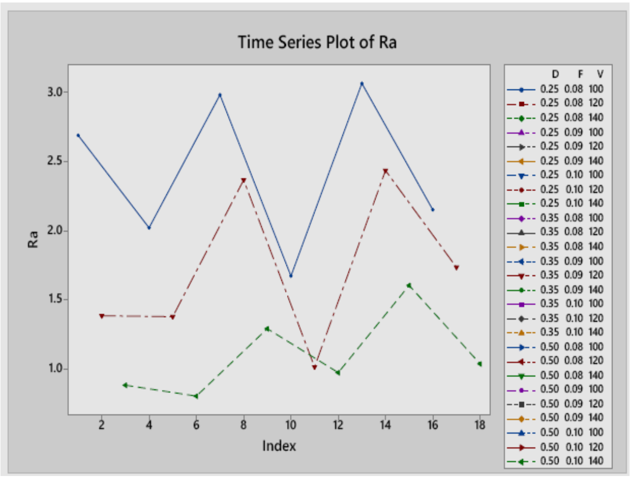

Fig.9. Time Series plot of Surface Roughness

3) Analysis of Chip Formation

The form of the chip produced is one of the major parameter influencing productivity in metal cutting trade. According to research work by Kaladhar et.al [9] there are two toys of chip forms one is acceptable chips and other unacceptable chips, based on the convenience of behavior. Acceptable chips do not interface with work or tool and do not cause tribulations of disposal. Unacceptable chips break off regular manufacturing operation, as they tend to snarl around the tool and workpiece and pose safety problems to operators. These chips can lead to unexpected surface finish and tool wear.

It is observed that tightly coiled chips are formed during wet turning and during MQL that could hardened easily and long snared chips are prevalent during dry turning. The chips created during MQL were similar to that when wet turning in spite of fluid application rate which only 0.05 % of that in wet turning. It is clear that MQL promotes acceptable chips that can handle easily.

Chip formation mechanism in machining of Inconel is influenced by the machining process and tool related variables. The main factors which largely govern the chip formation are the temperature condition in the shear region. Chip changes its appearance from continuous to saw tooth type when the cutting speed crosses the threshold value and enters in the high-speed machining range. The deformation is non-homogeneous and twin deformation regions are formed, one is with pure deformation and other is no deformation at all, therefore pure narrow, concentrated shear band formation results and chips are saw tooth type. When the machining was done at temperature of 25 °C, the chips were continuous long and curly chips with silvery glazy type. But when machining at 400 °C, the workpiece becomes more ductile, hence chips becomes longer and continuous but curled as well as conical helical in nature. These chips are yellowish brown. Again, at higher temperature (600 °C), the chips were too long and snarled ribbon type. These chips appear blue radish brown in colour and burnt type due to very high temperature. These chips do not break easily because of its ductility at high temperature. Hence these chips wound the workpiece and ruin the machined surface.

Fig.10. Chip formation at feed rate 0.1mm, 0.2mm and 0.4mm

TABLE 7: CHIP THICKNESS RATIO

Exp. No.	Chip thickness t_c (mm)	Feed rate/ (mm/rev)	Chip thickness ratios *(K)*
1	0.1679	0.08	2.098
2	0.1387	0.09	1.5411
3	0.1062	0.1	1.062
4	0.4751	0.08	5.9387
5	0.2328	0.09	2.586
6	0.2057	0.1	2.057
7	0.0853	0.08	1.0662
8	0.1335	0.09	1.4833
9	0.3253	0.1	3.253
10	0.1586	0.08	1.9825
11	0.1682	0.09	1.8688
12	0.1243	0.1	1.243
13	0.3843	0.08	4.8037
14	0.4250	0.09	4.7222
15	0.2030	0.1	2.030
16	0.4863	0.08	6.0787
17	0.3320	0.09	3.6888
18	0.1493	0.1	1.4930

Sometimes the chips clogs between the cutting edge and the machined surface which reduces cutting action, increases friction and results increase in higher forces and breaks the cutting tool by catastrophic failure. Therefore, while machining at high temperature a very effective chip breakers are necessary.

A prominent observation found from the experiments that at higher cutting speed the chips becomes more ductile and continuous in nature because of increased temperature of the shear region.

VI. CONCLUSIONS AND DISCUSSIONS

The experiments and analysis were carried out to express the effect of coolant quantity on the cutting force; cutting temperature and surface roughness in hard turning of hardened alloy steel AISI 4340. From the experimental investigations based on Taguchi's method and the analysis considering the limits of the variables employed, the following conclusions are drawn:-

a) It is observed that the surface finish in hard turning of hardened AISI 4340 is better as compared to dry and wet turning.

b) It is observed that the chip thickness in hard turning of hardened AISI 4340 is minimum followed by wet and dry turning. Hence MQL turning gives the higher cutting ratio than other two which is helpful for reduction in friction at the tool- chip interface and formation chips of thinner sections.

c) ANOVA for feed force shows that, the depth of cut and feed rate has less statistical significance at 92% and 91% CI respectively. It is found from the main effects plots that as the cutting speed increases the magnitude of feed force decreased. Initially as the feed rate increases, the forces increased rapidly and shows declining trend of the machining continues.

d) From the analysis of variance, it shows that all input process parameters have linear variation with the radial force while turning of Inconel 718. The cutting speed has lesser effect on the radial forces where as feed rate has more significant effect above 95% confidence interval.

e) As the Inconel 718 possess very low thermal conductivity, heat accumulation in the machining region causes the increase in rake face temperature up to 1200 °C when the cutting speed increased to 100 m/min [2]. Since, the work material has high chemical affinity for tool material, it leads to diffusion wear or stresses on the cutting edge goes high producing catastrophic failure of cutting tool.

f) The regression model of the response variables formulated shows well correlation within the experimental values ± 10% error.

g) It is observed from the Taguchi regression analysis that the most influential factor affecting the entire response variable is feed rate. The order of importance of the input factors to the multi-performance characteristics is feed rate, cutting speed, depth of cut and workpiece temperature. The optimum parameters found are: cutting speed - 60 m/min, feed rate - 0.1 mm/rev, depth of cut - 0.75 mm and workpiece temperature - 400 °C.

h) The chips during machining were observed and found that at higher cutting speed, the chips becomes more ductile and continuous in nature because of increased temperature of the shear zone. However, as the depth of cut increases, the chip becomes more and more segmented or discontinuous in nature. However, while machining of this alloy in the presence of external heating, a very efficient chip breaker is required.

VII. FUTURE SCOPE

For future experimental work Inconel 718 Nickel-base super alloy frequently used for components subjected to high dynamic stresses at working high temperatures up to 1273K. They are used mainly to make blades, disks and housing components for the hot sections of stationary gas turbines and jet engines, in the manufacture of tools and dies for the hot working of metals, and in the nuclear, chemical and petrochemical industries. It is very important to manufacture parts at a high level of productivity and quality. To achieve this, any potential improvement of cutting materials, cutting tools, conventional and non-conventional machining processes must be considered and evaluated. There is also challenge for scientists to increase tool life while machining with proper selection of machining parameters. In view of the above, the following issues related to research on this material can be continued in the future.

- Hot machining of Inconel 718 with using different heating sources like plasma arc, electric heating (resistance, induction .AC, DC heating), LPG heating, and radiation heating etc. to observe its effect on the process.
- Machining of Inconel with different tool materials, tool coatings and different tool geometry.
- Machining with different coolants or steam coolant and with dry condition.
- Experimentation by varying all input process parameters at different levels, the experimentation can be done to achieve better machining performance for MQL.
- There is scope for investigation with different response variables such as surface Integrity, surface damage and dimensional variations while machining at minimum quantity lubrication.

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