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Experimental Investigation on Influence of Varying Nozzle Stand-Off Distance and Pressure on Surface Roughness and Cutting Temperature in Turning of EN 31 Steel (Hardened) Using Minimum Quantity Lubrication

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***Abstract*— in this era of machining process, to cope with the demands of higher productivity it is required to optimize the cost, quality and continuous improvement in machining technology. Industries are striving to maximize production through elimination of unnecessary practices to adjust gap between present market demands and requirement. For these newer machine set ups and cutting tools have been developed. Such demands call for the use of new technologies such as dry machining and minimum quantity lubrication. Studies show that dry machining also becomes non efficient and uneconomical during cutting of harder materials at higher cutting speed, feed and depth of cut, although it is environmental friendly and economical at particular machining level. So to minimize all these Problems of health hazards, non-economy, intense tool wear in case of flood cooling and dry machining, the minimum quantity lubrication (MQL) has been applied in this present work.**

Hard turning is introduced in this work as an alternative to grinding process. This paper presents a review on influence of varying nozzle stand-off distance and cutting fluid pressure on surface roughness and cutting temperature in turning of EN 31 steel (hardened) using minimum fluid application using regression analysis and mathematical modeling approach. In addition, ANOVA will be performed to find out the significant parameters using statistical design of experiments.

***Index Terms*— Hard turning, Minimum Quantity Lubrication (MQL), EN 31, Coated carbide tool, Regression, ANOVA**

I. INTRODUCTION

The conventional method of manufacturing a component has the following sequences namely soft machining, heat treatment, rough turning and fine grinding. In order to increase the flexibility and ability to manufacture complex geometry, hard turning was introduced where the necessity of grinding operation can be eliminated. In hard turning rough machining, final grinding can be eliminated and raw material is supplied in the final heat treated condition. Hard turning can seriously be regarded as an alternative for grinding Operations under certain circumstances. Generally hard turning requires large quantities of coolants and lubricants. The cost of procurement, storage and disposal of coolants and lubricants increases the total cost of production considerably [2]. Eliminating use of cutting fluids, if possible can be a significant economic incentive. Conventional cutting fluid application fails to penetrate the chip-tool interface and thus cannot remove heat effectively [4]. Also, hard dry turning requires rigid cutting systems and superior cutting tools like CBN or ceramic tools [2].

Considering the high cost associated with the use of cutting fluids and projected costs when the stricter environmental laws are enforced, some alternatives has been sought to minimize or even avoid the use of cutting fluid in machining operations. Some of these alternatives are dry machining and machining with minimal fluid application. Dry machining is now of great interest and actually, they meet with success in the field of environmentally friendly manufacturing. However, they are sometimes less effective when higher machining efficiently, better surface finish quality and serve cutting conditions are required. In these situations, semi 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 fluid application refers to the use of cutting fluids of only a minute amount typically of flow rate of 50 to 500 ml/hour. The concept of minimal fluid application sometimes referred to as near dry lubrication or micro lubrication [4].

According to the regulations of Occupational Safety and Health Administration (OSHA), the permissible exposure level (PEL) for mist within a plant is 5mg/m³ and is likely to be reduced to 0.5 mg/m³.By introducing the cutting fluid precisely at the cutting zone, better cutting performance can be achieved which will result in better surface finish, low cutting force and reduction of tool wear. In minimal fluid application, extremely small quantities of specially prepared cutting fluids are required and it almost resembles dry turning. In the case of minimal application, heat transfer is predominantly in the evaporative mode, which is more efficient than the convective heat transfer prevalent in conventional wet turning [2]. The review of the literature suggests that minimal fluid application provides several benefits in machining. This present paper deals with performance of coated carbide tool in machining hardened steel with minimum fluid application by varying parameters such as nozzle stand-off distance, cutting speed and coolant pressure keeping feed and depth of cut constant. The influence of different cutting and fluid application

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parameters for coated tools on machining performance is analyzed by applying Taguchi's statistical approach.

II. LITERATURE REVIEW

Many researchers have presented reviews on MQL technique in machining processes. The positive effect of the use of fluids in metal cutting was first reported in 1894 by F.Taylor, who noticed that by applying large amounts of water in cutting area, the cutting speed could be increased up to 33 % without reducing tool life. Since then, cutting fluid effect has been studied resulting in an extensive range of products covering most work piece material and operations. However the costs associated mainly with fluid handling, recycling and disposal are leading to alternatives such as new tool material and coating which allows dry machining and application of small quantities of fluid as mist spray.Byrne and Scholta [1] states that the costs related to cutting fluids are frequently higher than those related to cutting tools. Consequently, eliminating use of cutting fluids, if possible, can be a significant economic incentive. B.Ramamoorthy [2] reported the overall performance of the cutting tools during minimal cutting fluid application was found to be superior to that compared to dry turning and conventional wet turning on the basis of parameters such as cutting force, temperature and surface finish. The influence of operating parameters in minimal fluid application was evaluated and it was observed that cutting performance mainly depends on fluid application parameters such as pressure and delivery rate. Chaudhary S. M. A. and others [3] has experimentally investigated the Effect of minimum quantity lubricant on temperature, chip formation and cutting force in turning of medium carbon steel. The MQL has been provided in the form of spray using vegetable oil. The result obtained from this experiment shows 20% reduction in average chip-tool interface temperature and 5% to 20%.reduction in cutting forces. Dhar N.R. and others [4] reported that the cutting performance of AISI 1060 by minimal quantity lubrication machining by vegetable oil is better than that of dry machining because minimal quantity lubrication provides the benefits mainly by reducing the cutting temperature, which improves the chip tool interaction and maintains sharpness of the cutting edges. Dhar and others [5] has experimentally investigated the Effect of Minimum Quantity Lubrication (MQL) on Tool Wear, Surface Roughness and Dimensional Deviation in Turning of AISI-4340 Steel, result obtained from this investigation suggested that MQL machining is better than that of dry and conventional flood cutting because MQL provides the benefits mainly by reducing the cutting temperature, which improves the chip-tool interaction and maintains sharpness of the cutting edges. Gurpreet Singh and others [6] has experimentally investigated machining performance into turning of EN 31 steel with dry and vegetable based oil minimum quantity lubrication. In this study soya bean oil has been used as a cutting fluid. MQL has reduced surface roughness by 20-40% as compared to dry machining during different cutting conditions. Gurpreet Singh, Ajay Kumar [7] has experimentally investigated impact of nozzle stand-off distance on cutting temperature in turning of EN-31 steel with MQL, by vegetable oil based cutting fluid, results obtained from this study shows variation of cutting temperature and surface roughness during variation of stand-off distance and depth of cut. In this study maximum temperature recorded at 55mm distance from cutting zone and least cutting temperature recorded at 30 mm nozzle distance. D.V. Lohar and C.R. Nanavaty [8] have evaluated the performance of MQL system during turning on hardened AISI 4340 material by using Taguchi method. Cutting speed, feed rate, and depth of cut was selected as a process parameter for analysis of cutting forces, surface roughness, cutting temperature. MQL system was found superior to the dry & wet lubrication system in terms of cutting force & temperature and surface finish. Abhang L.B and others [9] has experimentally investigated the performance of MQL machining of alloy steel with 10% boric acid by weight mixed with SAE- 40 base oil during turning of EN-31 steel using tungsten carbide cutting tool. Minimum quantity lubricant has reduced the chip-tool interface temperature by 20 to 30%.From literature survey it is found that minimum quantity lubrication provides several benefits in machining. But less focus has been given on the effect of varying the nozzle distance from the cutting zone and lubricant pressure during turning operation. So there is a need of study which will consider this important parameter for finding the best nozzle distance from cutting zone in terms of cutting temperature, surface roughness and cutting forces in turning operation using minimum quantity lubrication.

Thus, the objective of the present work has been set to have a systematic study to evaluate the Performance of coated carbide tools.

1. Assess performance of PVD coated carbide cutting tools in hard turning of EN31 steel (45-50HRC) under varying process parameters such as cutting speed, nozzle tip distance and coolant pressure with respect to surface roughness and cutting temperature using Taguchi L9 orthogonal array design.
2. Perform tests with minimal fluid application using servo cut oil at flow rate of 50-100 ml/hr commercially used at IGTR Aurangabad.
3. Develop the mathematical model for responses using regression analysis and validate for its accuracy.
4. Perform analysis of variance (ANOVA) to find significant parameters which affect responses to large extent.

III. EXPERIMENTAL DETAILS

A. Work Piece: the work piece material is hardened alloy steel EN 31 with diameter 40mm and length 100mm.The size is selected from the review of other similar work and machine specifications available for experimental work. The heat treated samples were cleaned by removing the hardened outer skin by machining to get the required diameter. The end faces were turned.

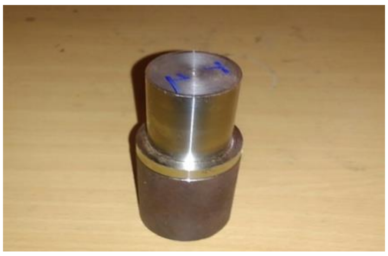

Figure1: EN 31 Work piece Material

B. Cutting Tool: carbide inserts CNMG 120408 of nose radius 0.8mm of sandwik coromant is selected for experimentation.

Figure 2: Cutting Tool

C. Machine: A high speed CNC Lathe (HASS controller) having 7.5 HP electric motor and 3500 rpm is used for experimental work. Experimental setup is prepared on CNC lathe at IGTR Aurangabad.

Figure 3: CNC Lathe

D. Cutting Fluid Application: The quantity of cutting fluid used in this method is very low (50 to 100ml/hr), the cutting oil is available commercially is servo cut oil. The lubricator used in pneumatic system is adjusted to supply a jet of cutting fluid at a rate of 1 droplet per two seconds at varying pressure. The supply is directed at tool-work piece contact zone. FRL unit used for experimentation as shown in fig.4 into which air and oil with fixed quantity is mixed at varying air pressure from 2 to 6 bars.

Figure 4: FRL unit

E. Process Parameters and their Levels: Based on the literature review the process parameters were chosen which are listed in following table. The parameters which directly affecting the hard turning process are cutting speed, feed, depth of cut and cutting fluid application. These parameters are selected from OVAT analysis.

Sr. no.	Parameters	Level 1	Level 2	Level 3
1	Nozzle distance(mm)	20	25	30
2	Cutting speed(Rpm)	2400	2550	2700
3	Coolant pressure (bar)	3.5	4	4.5

Table 1: Parameters with Levels

F. Response Variables: It is seen from the published literature that the machinability of hard turning process is evaluated in terms of cutting forces, surface roughness, cutting temperature, tool wear and tool life. Considering the practical constrains surface roughness and cutting temperature were selected as a response variables to assess the machining performance in hard turning of alloy steel EN 31.The performance can be evaluated and compared by measurement of surface finish using Mitutoyo surface tester, cutting temperature by non contact type temperature indicator.

G. Design of Experiment: During the experimentation, a large number of experiments have to carry out as the number of machining parameters increases. Taguchi's design of experiment involves proper selection of an orthogonal array to accommodate variables (input factors) and their interactions. The experiments were conducted using standard L9 (3x3) Taguchi orthogonal array. According to the array nine experiments were conducted as per selected orthogonal array.

Run no.	Nozzle stand-off distance (mm)	Cutting speed (Rpm)	Lubricant pressure (bar)	Surface roughness Ra (µm)	Cutting temperature (^{o}c)
1	20	2400	3.5	0.467	38
2	20	2550	4.0	0.534	40
3	20	2700	4.5	0.500	36
4	25	2400	4.0	0.512	35
5	25	2550	4.5	0.585	34
6	25	2700	3.5	0.611	33
7	30	2400	4.5	0.688	36
8	30	2550	3.5	0.750	35
9	30	2700	4.0	0.828	34

Table 2: Experimental Results

IV. EXPERIMENTAL RESULTS

Hard turning operation involves various input variables that include cutting speed, feed rate, and depth of cut, nose radius, nozzle distance and coolant pressure. These variables have direct as well as indirect effect on the performance of hard turning process. The effect of nozzle distance and coolant pressure can be expressed in terms of the performance variables such as surface finish and cutting temperature is observed and analyzed. Based on the experimental work, the results are analyzed and it consists of the assessment of cutting temperature and surface roughness components during hard turning of alloy steel EN 31. The regression analysis is performed in order to determine the effect of nozzle distance and coolant pressure on the cutting temperature and surface roughness component and Statistical analysis is performed using MINITAB software. The analyzed results are presented using ANOVA analysis and mean effects plots.

Analysis of Surface Finish

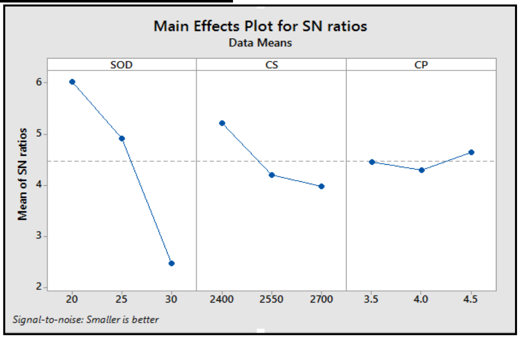

Figure 5: Main effect plots for surface finish

Fig.5 shows almost all machining parameters show linear dependence on the variation in surface roughness produced during hard turning. During MQL condition, fluid is correctly placed at the contact of the tool and the work piece. Hence the chips are easily removed and give better surface finish. It is observed from main effect plot generated using MINITAB that nozzle distance ($P<0.05$) has higher contribution to the variability of surface roughness over the other experimental factors.

The main effect plot shows the range of surface roughness varies from 0.5 µm to 0.75 µm for MQL environment. The next significant parameter is cutting speed. Minimum surface roughness is observed at 20 mm nozzle distance, 2400 rpm and 4.5 bar pressure. Hence, optimum parameters are SOD1 CS1 and CP3 respectively.

Regression Analysis: SR versus SOD, CS, CP

Source	DF	Adj. SS	Adj. MS	F value	P value
Stand-off distance	2	0.104382	0.052191	44.37	0.022
Cutting Speed	2	0.013299	0.006649	5.65	0.150
Pressure	2	0.001705	0.000852	0.72	0.580
Error	2	0.002353	0.001176		
Total	8	0.121738			

Table 3: ANOVA Analysis of surface finish

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0342977	98.07%	92.27%	60.87%

Regression Equation

Surface Roughness = -0.726 + 0.02550 (Stand-off distance) + 0.000302 (Cutting Speed) - 0.0183 (Pressure)

Analysis of Variance (ANOVA) is carried out using MINITAB software to investigate difference in average performance of factors under test. ANOVA breaks total variation in to accountable sources and helps to determine the most significant factors in the experiments [8]. A mathematical model is also developed to show the relationship between other factors. The obtained R square value is 98.07 %.

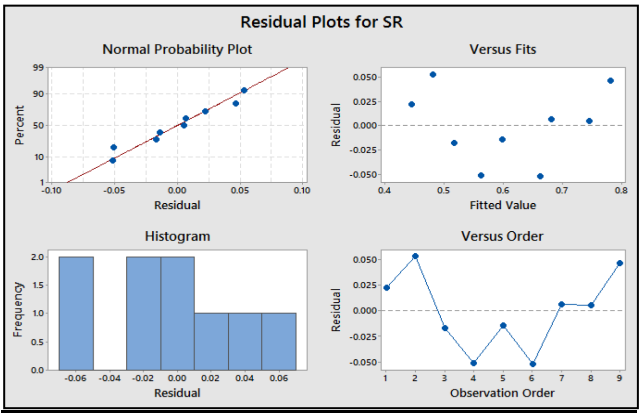

Figure 6: Residual plots for surface roughness

Analysis of Cutting Temperature

The cutting temperature is one of the most important factor which affects tool life and tool performance, quality of work surface. From graph it is observed that, Optimum parameters are 25 SOD, 2700 rpm CS and 3.5 bar coolant pressure. Also, there is a sudden variation in observations in all three graphs can be seen.

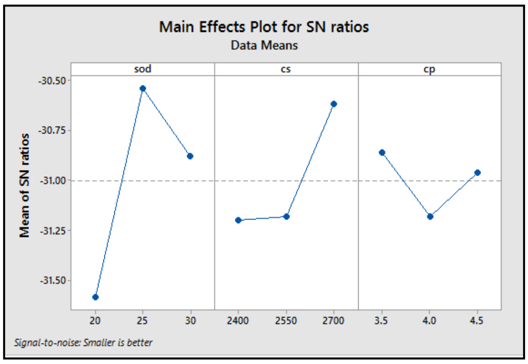

Figure 7: Main effect plots for cutting temperature

Regression Analysis: TEMP versus SOD, CS, CP

Source	DF	Adj. SS	Adj. MS	F value	P value
Stand-off distance	2	29.5556	14.7778	33.25	0.029
Cutting Speed	2	10.8889	5.4444	12.25	0.075
Pressure	2	2.8889	1.4444	3.25	0.235
Error	2	0.8889	0.4444		
Total	8	44.2222			

Table 4: ANOVA Analysis of cutting temperature

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.666667	97.99%	91.96%	59.30%

Regression Equation

Cutting Temperature = 61.6 - 0.300 (Stand-off distance) - 0.00778 (Cutting Speed) + 0.33 (Pressure)

From ANOVA table, F value for SOD is 33.52 hence; distance is a most significant parameter. Next significant parameter is cutting speed and coolant pressure. In MQL the cutting fluid particles can reach up to tool chip interface in the form of small drops. During wet turning, the heat is extracted only by convective heat transfer, but MQL facilitates both convective and evaporative heat transfer leads to lowering of cutting temperature [8].

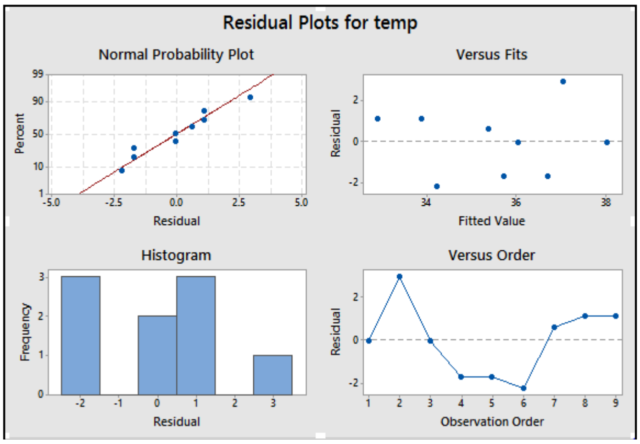

Figure 8: Residual plots for cutting temperature

V. CONFIRMATION EXPERIMENT

In order to validate the result, confirmation experiment has been conducted at the optimal settings of the process parameters determined from the analysis.

Parameter	Model value	Experimented value	Error %
Surface roughness	0.426	0.412	3.29
Cutting temperature	35	34	2.86

Table 5: Confirmation Experiment

VI. CONCLUSION

From the experimental investigations in hard turning of alloy steel EN31 based on Taguchi's method and the analysis of response variables, the following conclusions are drawn:

1. MQL provided better performance in turning hardened EN 31 steel at different nozzle distances, cutting speed and coolant pressure for responses like surface roughness and cutting temperature.
2. It is observed that nozzle stand-off distance is found to be a most significant parameter. Of two, the cutting speed was found next significant parameter compared to coolant pressure.
3. It is observed that minimum surface finish obtained in hard turning of hardened EN31 is 0.467 µm. optimum parameters for surface roughness are 20 mm nozzle distance, 2400 rpm and 4.5 bar pressure.
4. It is observed that the minimum cutting temperature in hard turning of hardened EN31 is 33^{o}c.optimum parameters for cutting temperatures are 25 mm SOD, 2700 rpm CS and 3.5 bar pressure.

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