Analysis and Prediction of Tool Wear, Machined Surface Roughness in Hard Turning

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Abstract—This paper is all about the possible factor that influence in hard turning process. Attempt has to made to show relationship between all input variables like speed, feed, depth of cut, tool materials, workpiece hardness and output variables like surface roughness, tool wear and three force components during hard turning. Various authors have applied statistical analysis and experimentation to validate their work. The contribution of speed, feed and depth of cut is mentioned in this paper based on surface roughness, tool wear and machining force components. Taguchi, ANOVA, response surface method and FE analysis are useful tools to develop relationships between various variables.

Keywords: ANOVA, Hard Turning, CBN tool, Regression analysis

I. Introduction

Hard turning is a cost-effective, highly productive and flexible machining process for ferrous metal work pieces that are often hardened above 45 HRc. Hard machining is performed by using ceramics and polycrystalline cubic boron nitride (PCBN, commonly CBN) cutting tools due to the required tool material hardness. Most hard turning applications involve turning of hardened steels. To implement hard turning successfully, differences between the cutting process physics for machining soft steels (defined as having hardness value below 45 HRc) and hardened steels need to be clarified.

Usually, the cutting parameters are selected based on experience or a handbook by engineer, but it does not yield the accurate results. Therefore, in turning process, it is important task to select cutting parameters for achieving high cutting performance, which greatly influences manufacturing cost. An optimum selection of cutting conditions is extremely important. In order to predict surface quality in advance, it is important to develop theoretical models.

Optimization of turning parameters is usually a difficult work, where the following aspects are required like knowledge of machining, empirical equations relating the tool life, specification of machine tool capabilities, knowledge of mathematical and numerical optimization techniques are also compulsory.

The pioneering work of Taylor (1907) and his famous tool life equation, different analytical and experimental approaches for the optimization of machining parameters have been investigated. Gilbert (1950) studied the optimization of machining parameters in turning with respect to maximum production rate and minimum production cost as criteria. Finding out the optimum parameters levels that are related to certain quality characteristics in order to achieve the objective function such as minimize the unit production cost. These parameters level generally are hard to find.

Conducting an effective Taguchi Parameter Design study requires review of literature regarding turning parameters and similar studies. The most readily controlled factors in turning operation are feed rate, cutting speed and depth of cut each of which may have an effect on surface finish. Several studies exist which explore the effect of feed rate, spindle speed, and depth of cut on surface finish. These studies all supported the idea that feed rate has a strong influence on surface finish. Spindle speed and depth of cut were found to have differing levels of effect in each study, often playing a stronger role as part of an interaction. Some very informative studies were found that were conducted using the Taguchi Parameter Design method for the purpose of optimizing turning parameters.

These studies made use of various workpiece materials and controlled parameters to optimize surface roughness, dimensional accuracy, or tool wear. Each utilized different combinations and levels of cutting speed, feed rate, depth of cut, cutting time, workpiece length, cutting tool material, cutting tool geometry, coolant, and other machining parameters.

II. Liturature Review of Hard Turning

Samir Khamel et. al. [1] had investigated the combined effect of process parameters like cutting speed, feed rate and depth of cut on performance characteristics like tool life, surface roughness and cutting forces using ANOVA. The results delivered from ANOVA analysis and conducting validation experiments have proved that the quadratic models allow predicting response measurements values with a 95% confident interval and high determination coefficient (> 91%) within the limits of the factors studied. Tool life models show that an increase of cutting speed, feed rate and depth of cut by 100%, will lead to reduction of tool life by 59.14%, 16.02% and 2.16%, respectively. When the feed rate is increased, it also increases the surface roughness. Their research seems that hard turning of AISI 52100 bearing steel with CBN tool had achieved simultaneous optimization in the performance characteristics with a cutting speed Vc = 168 m/min, feed rate f = 0.08 mm/rev and depth of cut ap = 0.22 mm.

D.I. Lalwani et. al. [2] had studied the effect of cutting parameters like cutting speed, feed rate and depth of cut on cutting forces feed force, thrust force and cutting force and surface roughness in finish hard turning of MDN250 steel using coated ceramic tool. Their research seems that cutting speed has no significant effect on cutting forces and surface roughness. A linear model best fits the variation of cutting forces with feed rate and depth of cut. Depth of cut is the dominant contributor to the feed force, accounting for 89.05% of the feed force whereas feed rate accounts for 6.61% of the feed force. In the thrust force, feed rate and depth of cut contribute 46.71% and 49.59%, respectively. In the cutting force, feed rate and depth of cut contribute52.60% and 41.63% respectively, plus interaction effect between feed rate and depth of cut provides secondary contribution of 3.85%. A non-linear quadratic model best describes the variation of surface roughness with major contribution of feed rate and secondary contributions of interaction effect between feed rate and depth of cut, second order (quadratic) effect of feed rate and interaction effect between speed and depth of cut.

Gerard Poulachon et. al. [3] had investigated the tool-wear mechanisms of CBN cutting tools in finish turning of the following hardened steels: X155CrMoV12 (AISI D2) cold work steel, X38CrMoV5 (AISI H11) hot work steel, 35NiCrMo16 hot work steel and 100Cr6 bearing steel (AISI 52100), treated at 54 HRC. The major influencing parameter on tool-wear is the presence of carbides in the steel microstructure. There is a large variation in the hardness of the various carbides .For example; MC carbides are four times harder than the martens tic matrix. The four steels studied above contain carbides of various types in their microstructure.

Mehdi Remadna et. al. [4] had investigated the evolution of descriptive parameters during time when machining a hard material (alloyed steel 52 HRC-1900MPa) with a cubic boron nitride (CBN) tool. They had focused on the turning of hard materials with CBN inserts, the correlation between wear evolution and the direction of cutting forces during high-speed machining. An experimental result shows that the geometry of the cut evolves considerably according to the lifetime of a CBN tool. This duration increases while the shaving section decreases, but our observations and measurements show a strong evolution of the cut geometry in all cases in parallel and in correlation, all the components of the cutting force evolve. Essentially, this concerns the repulsion component, while the cutting component evolves very slowly. In other words, the intensity of the force which is generated by the cutting evolves very slowly. However, the orientation changes considerably in the course of the insert lifetime.

Zahia Hessainia et. al. [5] had worked on the elaboration of a surface roughness model in the case of hard turning by exploiting the response surface methodology (RSM). The quadratic model of RSM associated with response optimization technique and composite desirability was used to find optimum values of cutting parameters and tool vibration with respect to announced objectives which are the prediction of surface roughness. Response surface methodology combined with the factorial design of experiment is useful for predicting machined surface roughness. Only a small number of experiments are required to generate helpful information exploited for predicting roughness equations. Analysis of variance (ANOVA) demonstrates that the feed rate and the cutting speed have the highest influence on the evolution of machined surface roughness. For the arithmetic average roughness(Ra) the influences are 67.32%, 22.02% for (f) and(Vc), respectively. For the maximum peak-to-valleyheight (Rt), the feed rate (f) effect is 73.72%. Nevertheless, the depth of cut has no influence on the surface roughness. By referring to the surface roughness model Ra, it can be noted that the feed rate provides the primary contribution regarding the other working parameters and influences the surface roughness evolution, significantly. The interaction between, on the one side cutting speed and feed rate, and on the other side quadratic effect of cutting speed and feed rate provide secondary contribution to the model. Vibrations have no statistically significant effects. The quadratic model of RMS with correlation coefficient of 99.9% and 96.4% for models Ra and Rt respectively, have strong correlation with the predicted variable. The ANOVA results show that both models are valid at a high significance.

Tugrul Ozel [6] had studied the improvement in Productivity and quality in the finish turning of hardened steels by utilizing predicted performance of the cutting tools. They have used predictive machining approach with neural network modeling of tool flank wear in order to estimate performance of chamfered and honed Cubic Boron Nitride (CBN) tools for a variety of cutting conditions. The major advantage of the neural network predictions is that the algorithms can estimate flank wear progress quite accurately once the forces are known. Therefore, obtaining force information without using a force sensor would definitely improve the implementation of proposed approach in shop floor practice. It is needless to say that such tool conditioning systems have great potential to improve precision hard part machining using advanced cutting tools such as CBN.

K.S. Neoa et. al. [7] had studied the feasibility of using PCBN tools for direct ultra-precision machining of Stavax, a type of alloy steel from ASSAB. The performance characteristics in terms of surface roughness and tool wear of PCBN (Sumitomo IZ900) and conventional CBN (Sumitomo BN600) under different machining conditions were studied and their results were compared. Their research shown that to achieve good quality surface on Stavax, high rotational cutting speed is required for both the CBN and PCBN tools with the latter being able to achieve a better surface finish. It was found that at the higher cutting speed range, the PCBN tool is able to resist wear much better, suggesting that it has better mechanical and thermal properties. Surface roughness and wear rate increase rapidly with the increase in doc. It was found that the doc should not exceed 7.5 m in order to achieve a surface roughness of 0.05m Ra for both the PCBN and CBN tools. It was found that the PCBN tool is able to resist wear better at various docs. Surface roughness increases rapidly when the federate exceeds 7.5 m/rev for both PCBN and CBN cutting tools. To maintain surface roughness of less than 0.05 m Ra, the feed rate should be kept below 5m/rev, and in this range there is no significant difference between the two cutting tools. In terms of wear, it was found again that the wear rate is higher for the CBN tools.

Gaurav Bartarya et. al. [8] had studied that the type of tool material, cutting edge geometry and cutting parameters affect the process efficiencies in terms of tool forces, surface integrities integrity, and white layer. Radial force seems to be dominant in hard turning which makes it different from the conventional machining but effective investigation about force and friction conditions are still to be taken up. No work related to modeling addressing the dominance of radial force could be found. As in most cases, actual cutting involves a very small amount of multiphase material being removed; hence the force modeling should be performed on microstructure level as the tool would be removing different phases simultaneously. But no literature could be found discussing the modeling of hard turning process at microstructure level as it has being done for micro machining processes. It has been concluded by many researchers that the white layer formation is due to phase transformation to marten site and that the hard turned surfaces have tensile residual stresses, but a very little work has been done in order to reduce these tensile stresses on the machined surface that too without compromise the cutting parameters required for a specified surface finish.

Y. Sahin [9] had compared the tool life between ceramics and cubic boron nitride (CBN) cutting tools when machining hardened bearing steels using the Taguchi method. The L9 (34) orthogonal arrays were adopted to investigate the effects of cutting speed, feed rate and hardness of cutting tools on the tool life. The results showed that the cutting speed exerted the greatest effect on the tool wear, followed by the hardness of cutting tool, lastly the feed rate. The estimated/N ratio using the optimal testing parameter for the tool life was calculated. The regression model was also supported by the exponential model and second order model as well. Furthermore, CBN/TiC cutting tools showed the best performance than those of other tools. The improvements of the S/N ratio from the initial testing parameters to the optimal cutting parameters were ranged from 18% to 51% depending on the ANOVA results or S/N ratios. Moreover, the ANOVA indicated that the cutting speed was high significant but other parameters were significant effects on the tool life at 90% confidence level. The percentage contributions of cutting speed, tool's hardness, and feed rate were about 41.63, 32.68, and25.22 on the tool life, respectively.

Gaurav Bartaryaa et. al. [10] had studied the force prediction model during finish machining of EN31 steel (equivalent to AISI52100 steel) hardened to 60±2 HRC using hone edge uncoated CBN tool and to analyze the combination of the machining parameters for better performance within a selected range of machining parameters. The regression model developed that shows the dependence of the cutting forces i.e. cutting, radial and axial forces and surface roughness on machining parameters are significant, hence they could be used for making predictions for the forces and surface roughness. Depth of cut is the most influential parameter affecting the three cutting forces followed by the feed. Their research seems that cutting speed was least significant in case of axial and radial force models but was not significant forth regression model of cutting force. For the surface roughness predictions, the model developed from the analysis was found insignificant. The response surface analysis showed that forces first decreased and then increased with increase in cutting speed. It showed critical range of cutting speed when thermal softening might have occurred that caused reduction in the forces generated. The most energy efficient cut can be achieved for relatively lower and moderate cutting speeds with moderate depth of cut in the range of parameters selected for nearly all selected feed values.

Tugrul O¨ zel et. al. [11] had studied the high speed machining of hardened steels for manufacturing dies and molds offers various advantages, but the productivity often limited by mainly tool life. Their research seems the influence of edge preparation in cubic boron nitrite (CBN) cutting tools on process parameters and tool performance by utilizing practical finite element (FE) simulations and high speed orthogonal cutting tests. An effective rake angle forms in accordance with the trapped work piece material under the chamfer geometry and highly affects predicted cutting forces. Honed CBN tools resulted in lower cutting forces, but higher rake face temperatures. Overall, chamfered CBN tools resulted in lower temperatures on the rake face. Highest temperatures are at the CTI in about 0.10–0.15 mm distant from the cutting edge. The highest stresses in cutting direction were found at the WTI of the chamfered CBN tools. The highest stresses in thrust direction were identified at the CTI of the chamfered CBN tools.

V. Bushlya [12] had studied the super alloy machine ability study with uncoated and coated PCBN tools aiming on increased speed and efficiency. Aspects of tool life, tool wear and surface integrity were studied. It was found that protective function of the coating, increasing tool life up to 20%, is limited to low cutting speed range. Appearance of intensive rake catering and grooving on the tool clearance is normally attributed to chemical wear when machining super alloys. It can be seen that grooving has varying intensity along the edge line. Closer to minor cutting edge grooving ceases and flank wear becomes uniform. Such behavior closely follows temperature field found in hard machining with PCBN round tools and tools with large nose radius. Increase in the cutting speed and application of coating leads to extension of grooving to the minor cutting edge and increase in its depth.

S. Ramesh et. al. [13] had the effect of cutting parameters on the surface roughness in turning of titanium alloy. They have developed equation using response surface methodology which is used for predicting the surface roughness in machining of titanium alloy. They have performed experiment and analysis using RCMT 10T300 – MTTT3500 round insert tool. Taguchi ANOVA analysis shows that the most influencing parameter is feed. The order of importance was feed, followed by depth of cut and cutting speed. 3-D response surface plots are plotted for cutting speed, feed, and depth of cut on surface roughness which display that feed has a great influence on surface roughness.

C. Phaneendra Kiran et. al. [14] had studied the surface quality evaluation of turbine blade steels (ST 174PH, ST 12TE and ST T1/13W) for different combination of cutting parameters viz. speed, feed and depth of cut in a CNC turning process. They have used response surface method to perform experiments. They have analyzed experimental results using ANOVA and different graphical methods like contour plot and 3D surface graphs. The experimental results showed that material ST 17-4PH had the highest surface roughness (4.9 lm) and ST12TE had the lowest surface roughness (0.85 lm) for the same combination of parameters. The surface graphs and contour plots revealed that for the materials ST 17-4PH and ST17/

13W, feed rate and speed had significant effect on the surface roughness and depth of cut was insignificant.

Yong Huang et. al. [15] had focused to model the CBN tool crater wear depth (*K*T) to guide the design of CBN tool geometry and to optimize cutting parameters in finish hard turning. The main wear mechanism in hard turning is abrasion, adhesion, and diffusion. Based on process information, such as cutting geometry, chip velocity, average temperature, average normal stress, the wear volume losses due to the wear mechanism are formulated to model the crater wear depth rate, respectively. Their proposed model requires information about tool geometry, cutting conditions, and tool/work piece material properties to predict the progression of tool crater wear depth. The comparison between predictions and experimental data shows that the proposed model predicts the crater wear depth with satisfactory accuracy under most practical cutting conditions; however, the model needs to be improved for aggressive cutting conditions by including the effect of micro chipping.

S.K. Choudhury et. al. [16] had developed a reliable method to predict flank wear during the turning process. They have introduced the mathematical model which is correlating the ratio of feed force, *F*f, to cutting force, *F*c, and the flank wear height. Their model is recommended to be used for predicting flank wear. Experimental results show that Flank wear increased almost linearly with the feed rate, depth of cut and diameter. The force ratio (*F*f/*F*c) seems to monitor the flank wear reliably.

Jenn-Tsong Horng et. al. [17] had investigated the machinability evaluation of Hadfield steel in the hard turning. The application of RSM on the hard turning of Hadfield steel with Al2O3/TiC mixed ceramic tool had carried out the mathematical models of the flank wear (VBmax) and the surface roughness (*R*a) so as to investigate the influences of machining parameters. They have performed the experiments that proved the mathematical models of the flank wear and surface roughness (*R*a) fit and predict values of the flank wear and surface roughness which is close to those readings recorded experimentally with a 95% confident interval. The flank wear is influenced principally by the cutting speed factor and the interaction effect of feed rate with corner radius of tool with contribution of 43.08% and12.84%, respectively. The cutting speed and tool corner radius with the contribution of 29.67% and 43.18% have statistic significance on the surface roughness.

III. DESIGN OF EXPERIMENT

DOE is a technique of defining and investigating all possible combinations in an experiment involving multiple factors and to identify the best combination. In this, different factors and their levels are identified. Design of experiments is also useful to combine the factors at appropriate levels each within the respective acceptable range, to produce the best results and yet exhibit minimum variation around the optimum results. The design of experiment is used to develop a layout of the different conditions to be studied. And experiment design must satisfy two objectives: first, the number of trials musty be determined; second, the conditions for each trial must be specified.

Before designing an experiment, the knowledge of the product /process under investigation is of prime importance for identifying the factors likely to influence the outcome.

The design of experiments is a method to identify the important factors in process, identify and fix the problem in a process, and also identify the possibility of estimating interactions.

Design of experiments is a key tool. DOE helps to improve processes in a quantum fashion, and is an approach for effectively and efficiently exploring the cause and effect relationship between numerous process variables and the output or process performance variable.

Factors	Level 1	Level 2	Level 3
Speed (m/min)	31	43	63
Feed (mm/rev)	0.06	0.06	0.06
Depth of cut (mm)	0.5	0.4	0.3

Table. 1: Factors and their levels

IV. EXPERIMENTAL SETUP

Based on the literature review and an examination of prior experimental studies, a methodology is developed to study the progression of flank wear of the cutting tools and the change in the surface roughness of the machined part in turning. Since the present trend in the manufacturing industry is high speed dry machining, it is suggested to apply dry machining and high turning speed to simulate the machining conditions that are observed in typical manufacturing industries.

This chapter describes the steps which are taken to achieve the objectives of this study. Commercially available cutting tools that are used by numerous manufacturing industries are ordered from cutting tools distributors, and the appropriate machining parameters are Each work piece was first center-drilled on one side. This was necessary in order to support the work piece from both sides while turning on the lathe, and in turn, reducing the vibration of the work piece material and minimizing any impact forces on the cutting tool. The work piece is supported by dead center shown in figure.

Fig. 1: The work piece setup

The work piece was then set up on the lathe machine as shown in. The work-piece was attached to the lathe by the chuck, which is attached to the spindle. A tailstock assembly was used to support the work piece center drilled end. The cutting tool was allowed to slightly touch the right side of the work piece material shown in Figure and the coordinates of the start of the work piece were set on the lathe. The cutting tool was then allowed to slightly touch the surface of the work piece material, and the diameter of the work piece was set in the lathe. The work piece length to be machined was of 300 mm length; 240mm was used for turning and remaining 30 for fixing the round bar in chuck and 30 mm to keep the clearance between the end of the machined surface and the chuck to avoid any interference with the chip flow.

A pre cut with a 0.1 mm depth of cut was performed on each work piece prior to the actual turning tests using a different cutting tool insert. This was done in order to remove the rust layer from the outside surface and to minimize any effect of in homogeneity on the experimental results.

The cutting performance tests involved turning operation on cutting speed of 31 m/min, 43m/min and 63 m/min, feed rates used were 0.06 mm/rev, and depth of cuts used were 0.5 mm, 0.4 mm and 0.3 mm to analyze their effect on surface roughness by using CBN applied cutting tool insert getting optimum cutting parameters.

V. RESULTS AND ANALYSIS

This chapter presents the results for the machining performance of the CBN cutting tools and the uncoated cutting tool in turning of D-2steel round bar. There are two parts; in first part, the optimum cutting parameters based on surface roughness are found by using CBN insert and in the second part, the results and analysis for the flank wear of CBN tool and the surface roughness of the machined D-2 STEEL work-piece are presented. These two results are compared to those which are obtained using the CBN TOOLS in order to obtain the effectiveness of the different coatings on the flank wear and the surface roughness.

Sr.No.	**Depth of cut (mm)**	**Feed rate (mm/rev)**	**Cutting speed(m/min)**	**Surface roughness (µm)**
1	0.5	0.06	31	1.912
2	0.5	0.06	31	1.910
3	0.5	0.06	31	0.794
4	0.4	0.06	43	0.823
5	0.4	0.06	43	1.292
6	0.4	0.06	43	0.378
7	0.3	0.06	63	2.890
8	0.3	0.06	63	0.721
9	0.3	0.06	63	1.711

Table. 2: Experimental Data

A. *Signal to Noise ratio:*

Analysis of the influence of each control factor (S, F and D) on the surface roughness has been performed with a so-called signal to noise ratio response table. Response table of S/N ratio for surface roughness are shown in table. It shows the S/N ratio at each level of control factor and how it is changed when settings of each control factor are changed from one level to other.

We are using the S/N ratio as smaller to better because of minimize the response and data is non negative.

CUTTING SPEED (m/min)	Feed (mm/rev)	Doc (mm)	SR(µm)	SNR	MEAN
31	0.06	0.5	1.912	-5.62976	1.912
43	0.06	0.5	1.910	-5.62067	1.91
63	0.06	0.5	0.794	2.00359	0.794
31	0.06	0.4	0.823	1.692003	0.823
43	0.06	0.4	1.292	-2.22525	1.292
63	**0.06**	**0.4**	**0.378**	**8.450164**	**0.378**
31	0.06	0.3	2.891	-9.21796	2.89
43	0.06	0.3	0.721	2.841295	0.721
63	0.06	0.3	1.711	-4.665	1.711

Table. 3: SNR results

Level	D	F	S
1	-3.681	-1.375	-4.385
2	2.639	-1.375	-1.668
3	-3.082	-1.375	1.930
Delta	6.320	0.000	6.315
Rank	3	1	2

Table. 4: Levels of SNR

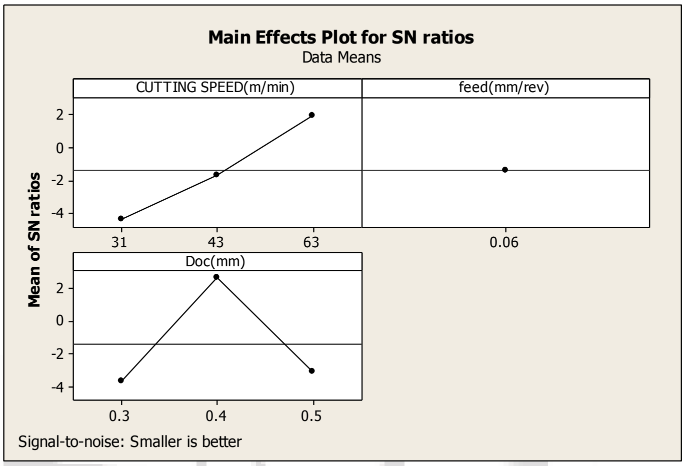

Fig. 2: SNR for Test

B. *Flank wear:*

Flank wear of uncoated carbide tool was measured at every 3 cut (at every 750 mm cutting length) by using tool maker's microscope and readings are mention in table 5.

Sr. No.	**Cutting Length(mm)**	**Flank wear(mm)**
1	90	0.12
2	180	0.25
3	270	0.29
4	360	0.34
5	450	0.37
6	540	0.39
7	630	0.43
8	720	0.50
9	810	0.57

Table. 5 : Tool flank wear of CBN cutting tool insert

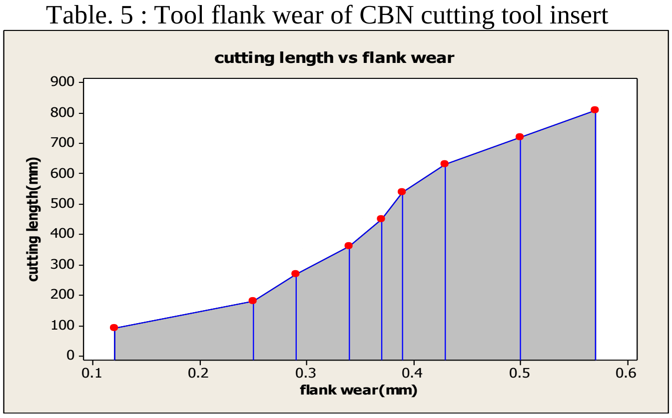

Fig. 3: Graph of Cutting length Vs Flank Wear

Weighted analysis using weights in Flank wear in mm

The regression equation is

Flank wear in mm = 0.122222 + 0.000533333 Cutting length

Coefficients

Term	Coef	SE Coef	T	P
Constant	0.122222	0.0218214	5.6010	0.001
Cutting length	0.000533	0.0000431	12.3783	0.000

Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	1	0.138240	0.138240	0.138240	153.222	0.0000052
Cutting length	1	0.138240	0.138240	0.138240	153.222	0.0000052
Error	7	0.006316	0.006316	0.000902		
Total	8	0.14455				

Summary of Model

S = 0.0300370 R-Sq = 95.63% R-Sq(adj) = 95.01%

PRESS = 0.0125803 R-Sq(pred) = 91.30%

The P-value for the cutting length was calculated using regression analysis using the Minitab 16 software for the flank wear v/s cutting length for the uncoated tool. To reject the null hypothesis, the P-value must be less than the value of α. In this study, a 95 percent confidence is used, and so the value of α is equal to 0.05. This means only 0.05 (five percent) of all values will exceed this interval. The P value for this regression is 0.000. Since it is less than 0.05, the null hypothesis is rejected. And so it can be concluded that the cutting length has a significant effect on wear.

C. Surface Roughness:

Experimental readings of surface roughness of turned round bar are shown in table at every three cut or a every 90 mm cutting length by using surface roughness tester SJ-201

Sr.No	Cutting length (mm)	Surface roughness (μm)
1	90	0.585
2	180	0.590
3	270	0.602
4	360	0.610
5	450	0.615
6	540	0.618
7	630	0.625
8	720	0.653
9	810	0.655

Table. 6: Surface roughness of CBN cutting tool insert

Now plot the graph of above readings of surface roughness by using origin 6.1 software. Figure 5.3 shows that the surface roughness increased steadily until around cutting length 630 mm. After that the surface roughness oscillated while increasing at a lower rate.

Table shows the output for the regression of surface roughness on the cutting length using Minitab 16 software. A null hypothesis (Ho) that the cutting length has no effect on the surface roughness and an alternative hypothesis (Ha) that the cutting length has an effect on surface roughness were used. Again using α-value of 0.05, the null hypothesis is rejected in favor of the alternative hypothesis since the P value for this regression is 0.000. And so it can be concluded that the cutting length has a significant effect on surface roughness.

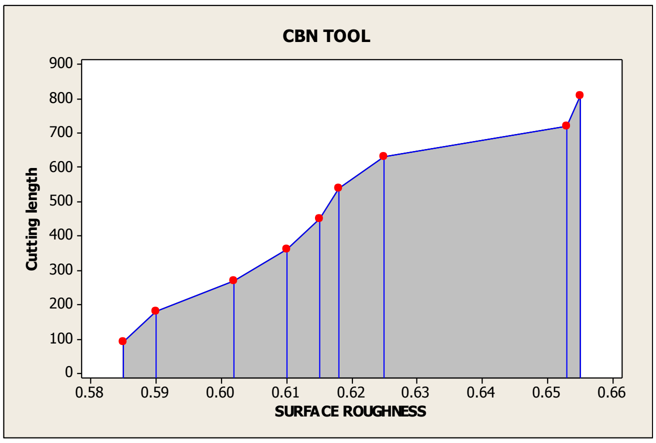

Fig. 4: Graph of Cutting length Vs Surface roughness **of** CBN cutting tool insert

Weighted analysis using weights in Surface roughness in μm

The regression equation is

SURFACE ROUGHNESS^L-1)/(L*g^(L-1)) = -0.131169 + 9.58316e-005 Cutting length

(L = Lambda = -7, g = 0.616569 is the geometric mean of SURFACE ROUGHNESS)

Coefficients

Term	Coef	SE Coef	T	P
Constant	-0.131169	0.0033767	-38.8451	0.000
Cutting length	0.000096	0.0000067	14.3734	0.000

Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	1	0.0044633	0.0044633	0.0044633	206.594	0.0000019
Cutting length	1	0.0044633	0.0044633	0.0044633	206.594	0.0000019
Error	7	0.0001512	0.0001512	0.0000216		
Total	8	0.0046145				

Summary of Model

S = 0.00464802 R-Sq = 96.72% R-Sq(adj) = 96.25%

Table. 7: Regression of surface roughness on the cutting length for CBN tool.

D. Validification of Regression model

In table we seen that wear value obtained by experimentation and values predicted by regression models. It is obvious that the predicted values are very close to the experimental readings. It is seen that there is a strong relationship between the predictor variables and response variables, which is confirmed by the results of Table 6.6

The regression equation is

Flank wear in mm = 0.122222 + 0.000533333 Cutting length

Predicated value using regression equation :
1) Cutting length = 150 mm
Flank wear in mm = 0.122222 + 0.000533333 *150

= 0.20222 mm
2) Cutting length=400 mm
Flank wear in mm = 0.122222 + 0.000533333 *400
= 0.3355 mm

Sr no	Cutting length	Predicted value using regression equation in mm	Practical value
1	150	0.20222	0.21
2	400	0.3355	0.35

Table. 8: comparison of predicated and actual practical value

VI. CONCLUDING REMARKS

the present study, an attempt has been made to investigate the effect of process parameters (cutting speed, feed rate and depth of cut) on the performance characteristics (tool life(wear), surface roughness) in finish hard turning of D2 steel hardened at 55 TO 57 HRC with CBN tool. The parameter are optimize by taguchi L9 Orthogonal array through S/N Ratio. The combined effects of the process parameters on performance characteristics are investigated while employing the analysis of variance (ANOVA). The relationship between process parameters and performance characteristics through the Regression model .

From the results found in this study, the following conclusions were drawn:

1) The results delivered from ANOVA analysis and conducting validation experiments have proved that the quadratic models allow predicting response measurements values with a 95% confident interval and high determination coefficient (> 91%) within the limits of the factors studied.
2) From the tool life models, it is found that an increase of cutting speed, feed rate and depth of cut by 100%, will lead to reduction of tool life by 59.14%, 16.02% and 2.16%, respectively.
3) The surface roughness is highly affected by feed rate, which explains until 65% of the total variation, SO in our study we take minimum available constant value where increasing feed rate will increase the surface roughness values. The cutting speed has effect (25%), whereas the effect of depth of cut is negligible (1.35%).
4) Simultaneous optimization of the performance characteristics (tool life, surface roughness) when hard turning D2 steel with CBN tool was achieved with a cutting speed Vc = 63 m/min, feed rate f = 0.06 mm/rev and depth of cut = 0.4 mm. BY S/N RATIO .
5) The proposed experimental and statistical approaches bring a reliable methodology to optimize and to improve the hard turning process. Also, they can be extended efficiently to study other machining processes.

VII. FUTURE SCOPE

In Recent years, hard turning of steel parts that are often hardened above 46 HRC became very popular technique in manufacturing of gears, shafts, bearings, cams, forgings, dies and molds. In order to withstand the very high mechanical and thermal loads of the work piece and cutting materials with improved performances, such as ultrafine grain cemented carbides, cermets, ceramics, cubic boron nitrides (CBN), polycrystalline cubic boron nitride (PCBN) and polycrystalline diamonds, have been developed and applied . Hard turning is a developing technology that offers many potential benefits compared to grinding using CBN TOOL, which remains the standard finishing process for critical hardened steel surfaces . Some decisive factors leading to this manufacturing trend are: substantial reduction of manufacturing costs, decrease of production time, achievement of comparable surface finish. A good correlation between flank wear aspect and machined surface was observed during studied which is very helpful to industries.

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