EFFECT OF CUTTING PARAMETERS ON OPTIMUM SURFACE ROUGHNESS WHEN TURNING WITH COATED CARBIDE TOOLS

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I. Introduction

The science of metal cutting was pioneered at the turn of the 19th century by F.W. Taylor who performed experiments for 26 years, during which time he performed more than 30,000 carefully recorded experiments and generating about 400 tons of chips. Taylor's goal was to create a simple solution for the intricate problem of setting safe and efficient cutting conditions which could "be solved in less than half a minute by any good mechanic". Conventional machine tools are designed to perform one or several operations on a variety of parts. These tools were developed early in the industrial revolution and are still found in every machine shop, where they are used for general purpose machining of small lots of parts, and for repair work. Their capabilities have been greatly enhanced by the advent of numerical control, which became available on most machine tools during the late 1970s. Production machine tools are used in high-volume manufacturing systems to perform one or a sequence of operations repetitively. They can he adapted for more than one part of the same family but the changes required to switch from one part to another are usually time— consuming and uneconomical. They are composed of a series of simpler machines or mechanisms which resemble conventional machine tools, and which are connected by an automated materials handling system. Because of their lack of flexibility and large capital costs, they are only used when thousands of identical parts are required. CNC machine tools are advanced types of numerically controlled machine tools used to produce a variety of complex parts. They are capable of moving cutting tools along complicated paths, often involving simultaneous motions of multiple axes, according to a stored program. Machining centers are flexible and can produce very complex parts in quantity with

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consistent quality and repeatability. They are generally economical for low or medium manufacturing volume but use in high manufacturing volume if high spindle and feed speeds are available and the part and cutting tools are designed to minimize tool changes. CNC lathes are rapidly replacing the older production lathes due to their ease of setting and operation. They are designed to use modern carbide tooling and fully utilize modern processes. It is still not easy to determine the optimum cutting speeds and feed rates for metal removal processes and surface finish of work piece. The shop floor practice still relies on the "calibrated ear" of the skilled machinist along with lookup tables. For die and mold machining where the geometry of the metal removal process is constantly changing, setting optimum cutting parameters has the potential for great economic benefit, but is also very challenging. Currently, most machining shops employ the traditional method of constant feed rate cutting for sculptured surface parts. This may result in significant tolerance deviations. By varying the feed rate based on the cutter chip load predicted by machining models, a more constant tool deflection can be attained, resulting in much better tolerances in the same machining time or similar tolerances in less time. Proper selection of cutting tools, parameters, and conditions for optimal surface quality (as well as tool life) requires a more methodical approach by using experimental methods and mathematical and statistical models.

II. Literature Review

The implication of fundamental knowledge of the turning process for applying the Taguchi method to this problem warrants a review of past studies involving machining parameters and conditions, and their effect on surface roughness. Feng and Wang [2] found that many published studies include spindle speed and feed rate, and a few included the depth of cut. Decreased feed rate has been found to generally reduce surface roughness; however, the effects of the spindle speed and depth of cut on surface roughness seem to have different interpretations by different authors [1, 4]. Tool nose radius has also been shown to have a direct effect on surface roughness, in that a larger radius can reduce surface roughness [4]. The effect of cutting edge geometry on the surface roughness is remarkably significant. The cutting forces are influenced not only by cutting conditions but also the cutting edge geometry and work piece surface hardness [5]. In the development of a robust process for the optimization of CNC turning tool steel for high dimensional and surface quality, step-like prototype geometry is specifically designed with the aim of ensuring the good range of applications and flexibility of the optimized process [6]. All of these factors, whether controlled or uncontrolled, may be considered when optimizing a turning system for surface roughness. Numerous studies have been conducted on the subject of parameter optimization of turning operations, each focusing on a specific methodology and parameters. There are some excellent examples of published studies available which have been conducted using the Taguchi method for the purpose of optimizing turning parameters as T.R Lin [6] and K.Palanikumar [7]. E. Danial Kirby [3] conducted such a study using an aluminum work piece, with control parameters of spindle speed, depth of cut and feed rate, and the response parameter being the surface roughness. He also conducted a more elaborate study using a controlled factors include feed rate, spindle speed, and depth of cut; and the noise factor is slightly damaged jaws. The noise factor is also included to increase the robustness and applicability of this study. Hari Singh & P. Kumar[8] researched the optimization of parameters for turning EN24 steel bars, using spindle speed, depth of cut, and cutting sequence (first or second cut); and surface roughness as a response parameter. Vernon and Özel presented a Taguchi method analysis of the results of a recent DOE study using a steel work piece; spindle speed, work piece length, and cutting tool material control parameters; and a surface roughness response parameter. Yang and Chen [9] studied a systematic approach for identifying optimum surface performance in milling operation and similar work piece and the same control parameters, but included tool diameter and surface roughness as response parameters. All of these studies successfully produced well-defined and useful correlations between their control and response parameters. The Taguchi method is a technique for optimizing a process or design using multiple input parameters. The complete Taguchi methods are actually comprised of three main phases, which are all intended to be conducted offline. These three phases include system design, parameter. The Taguchi parameter design stage, which is the phase used in this study, is commonly referred to as the Taguchi method, and will be so in this study.

III. Methodology

In the traditional approach, only one variable at a time is evaluated keeping remaining variables constant during a test run. This type of experimentation reveals the effect of the chosen variable on the response under certain set of conditions. The prima disadvantage of this approach is that it does not show what would happen if the other variables are also changing simultaneously. This method does not allow to study the effect of the interaction between the variables on the response characteristic. On the other hand, full factorial designs require experimental data for all the possible combinations of the factors involved in the study; consequently a very large number of trial need to be performed. Therefore, in the case of experiments involving relatively more number of factors, only a few fraction of combinations of factors are selected that produces most of the information to reduce experimental effort. The Taguchi method provides a solution to this problem.

A. Taguchi's Philosophy

Taguchi's philosophy is founded on the following three very simple and fundamental concepts [Ross (1996), and Roy (1990)]: 1.Quality of product should be designed into the product only and not inspect into it. 2. Quality is the best achieved by minimizing the deviations from the target. The product or process should be so designed that it is immune to uncontrollable environmental variables. 3. The quality costing should be measured as a function of deviation from the standard and the losses should be measured system-wide.

B. Signal-to-Noise Ratios (S/N ratio)

Taguchi transformed the loss function into a concurrent statistic called S/N ratio. The parameters that influence the output can be categorized into two classes, namely controllable (signal) factors and uncontrollable (or noise) factors. S/N ratio is being used to measure the quality characteristic deviating from the desired value. The S/N ratios for surface roughness are calculated as given in equation. S/N ratio for Ra = -10 log10 (LSB)

IV. Experimental Setup

The experiments were conducted on a CNC Lathe machine (HAAS USA TL). The photographic view of CNC Lathe and experimental set-up are shown in fig. 2. Alloy steel AISI 1045 was used as work piece. In this experiment TiN coated carbide insert (VBMT 160408 TN2000) and TiCN coated carbide insert (VBMT 160408 PC9030) were used as cutting tools. Chemical composition of material is given in Table 1.

Table 1: Chemical Composition of AISI 1045 Alloy Steel

Carbon %	Manganese%	Phosphorus%	Sulphur %	Silicon%	Iron%
0.43 to 0.50	0.60 to 0.90	0.04 max.	0.050 max.	0.10 to 0.60	Balance

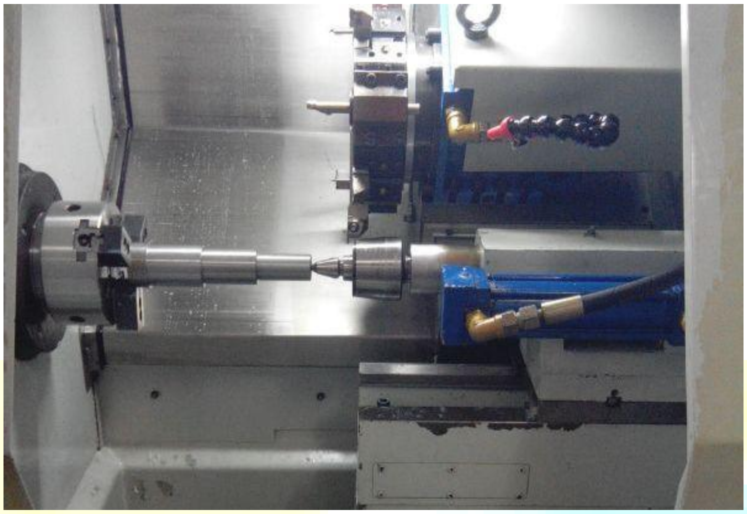

Fig. 1: Experimental Setup on CNC

A. Surface Roughness measurement

The measurement of surface characteristics (surface roughness) of the turned specimen was accomplished under Mitutoyo Surftest SJ-201 P/M. The unit of Ra is in µm. Ra can be directly obtained after machining the work piece. The average value of Ra is recorded for each number of trials in order to obtain the accurate result. The length of measurement for each specimen will be 60mm.

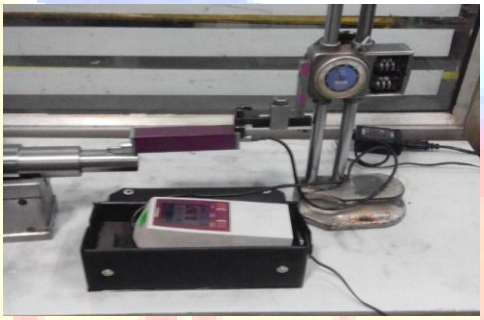

Fig. 2: Surface Roughness Measurement Device-Mitutoyo Surf test SJ-21

B. Selection of Process Parameters

The selection of parameters of interest was based on some experiment preliminary .The following process parameters were thus selected for the present work: 1.Cutting speed – (A), 2.Feed rate – (B), 3.Depth of cut – (C), The feed rate and depth of cut were selected from within the range of parameters for turning. The two coated carbide insert of different coating were chosen one TiN coated carbide insert and other TiCN coated Carbide insert to compare their performance and to find the best optimum speed, feed and depth of cut among the chosen one.

Table 2: Parameters, Codes, and Level Values Used for the Orthogonal Array

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Parameter	**Code**	**Level 1**	**Level 2**	**Level 3**
Control factors				
Cutting speed (m/min)	A	100	150	200
Feed rate (mm/rev)	B	0.1	0.2	0.3
Depth of cut (mm)	C	0.50	1.00	1.50

Each three level parameter has 2 degree of freedom (DOF) (Number of level – 1), the total DOF required for three parameters each at three levels is 6[=3x (3-1)]. As per Taguchi's method the total DOF of the OA must be greater than or equal to the total DOF required for the experimentation. So an L9 OA (a standard 3- level OA) having 6(=9-3) degree of freedom was selected for the present analysis. Minitab 16 software was used for graphical analysis of the obtained data.

Table 3: Results of the L9 (33) Experiment Using TiCN Coated Carbide Insert

S. NO.	**CUTTING SPEED (m/min)**	**FEED RATE (mm/rev)**	**DEPTH OF CUT (mm)**	**Ra1 (µm)**	**Ra2 (µm)**	**Ra3 (µm)**	**MEAN (µm)**	**SN RATIO (db) (SMALLER IS BETTER)**
1	100	0.5	0.1	1.67	1.69	1.77	1.71	-4.6599
2	100	1.0	0.2	2.57	2.54	2.42	2.51	-7.9935
3	100	1.5	0.3	3.08	3.14	3.17	3.13	-9.9109
4	150	0.5	0.2	0.90	0.79	0.83	0.84	1.5144
5	150	1.0	0.3	3.66	3.60	3.72	3.66	-11.2696
6	150	1.5	0.1	1.46	1.39	1.53	1.46	-3.2871
7	200	0.5	0.3	1.93	2.17	2.05	2.05	-6.2351
8	200	1.0	0.1	0..50	0.57	0.43	0.57	4.8825
9	200	1.5	0.2	3.07	3.25	3.16	3.16	-9.9937

Table 4: Result of the L9 (33) Experiment Using TiN Coated Carbide Insert

S. NO.	CUTTING SPEED (m/min)	FEED RATE (mm/rev)	DEPTH OF CUT (mm)	Ra1 (µm)	Ra2 (µm)	Ra3 (µm)	MEAN (µm)	SN RATIO (db) (SMALLER IS BETTER)
1	100	0.5	0.1	3.87	3.80	3.94	3.87	-11.7497
2	100	1.0	0.2	7.71	7.47	7.59	7.59	-17.6067
3	100	1.5	0.3	7.66	7.80	7.94	7.80	-17.8449
4	150	0.5	0.2	3.06	2.96	3.16	3.06	-9.7116
5	150	1.0	0.3	6.18	6.50	6.34	6.34	-16.0473
6	150	1.5	0.1	4.0	3.88	3.76	3.88	-11.7811
7	200	0.5	0.3	5.02	4.80	4.91	4.91	-13.8258
8	200	1.0	0.1	0.80	0.59	1.01	0.80	1.9672
9	200	1.5	0.2	5.17	5.01	4.85	5.01	-14.0037

V. Analysis and Discussion of Results

A. Analysis of Raw Data and S/N Ratios

The analysis of variance was carried out for a 95% confidence level. The ANOVA Tables 5 shows that, the F value corresponding to all parameters are greater than the tabulate value of F0.05. The main purpose of the analysis of variance is to investigate the influence of design parameters on optimal surface finish by indicating the parameters that significantly affect the quality characteristics of the machined surfaces. This analysis provides the relative contribution of machining parameters in controlling the response of machining performance criteria i.e. surface roughness height Ra during AISI 1045 alloy steel turning. Table 5, 6, 7 and 8 shows that the cutting speed, feed, and depth of cut are responsible and have influence on surface roughness height Ra while turning with TiN and TiCN coated carbide inserts. The influence of depth of cut is the most significant as according literature review. And the influence of feedrate is significant and cutting speed is less influencing factor as compare to other on the surface roughness height Ra during turning of AISI 1045 steel.

Table 5: Analysis of Variance for SN Ratios For TiCN Insert

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F-value**	**P**
Cutting speed	2	24.38	24.38	12.19	0.29	0.778
Feed rate	2	32.60	32.60	16.30	0.38	0.724
Depth of cut	2	99.17	99.17	49.58	1.16	0.463
Error	2	85.43	85.43	42.72		
Total	8	241.58				

Table 6: Analysis of Variance for Means for TiCN Insert

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F-value**	**P**
Cutting speed	2	0.4922	0.4922	0.2461	0.18	0.846
Feed rate	2	1.7247	1.7247	0.8623	0.64	0.611
Depth of cut	2	4.3458	4.3458	2.1729	1.60	0.384
Error	2	2.7123	2.7123	1.3561		
Total	8	9.2749				

Table 7: Analysis of Variance for SN Ratios For TiCN Insert

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P
Cutting speed	2	76.12	76.12	38.06	1.19	0.457
Feed rate	2	25.02	25.02	12.52	0.39	0.719
Depth of cut	2	123.93	123.93	61.96	1.94	0.340
Error	2	63.94	63.94	31.97		
Total	8	289.00				

Table 8: Analysis of Variance for Means for TiN Insert

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P
Cutting speed	2	12.800	12.800	6.400	3.16	0.240
Feed rate	2	3.983	3.983	1.992	0.98	0.504
Depth of cut	2	19.186	19.186	9.593	4.74	0.174
Error	2	4.046	4.046	2.023		
Total	8	40.015				

Where, DF - degrees of freedom, SS - sum of squares, MS - mean squares (Variance), F-ratio of variance of a source to variance of error, Probability < 0.05 - determines significance of a factor at 95% confidence level. The Ra (mean response variable) effect table under the array in Table 10 and 12 indicates the mean of the response variable means for each level of each control factor. This specifies the mean surface roughness value that each level of each control factor produced during this experiment. The S/N effect table under the array in Table 9 and Table 11 indicate the mean of the S/N values for each level of each control factor. Table 8.2 and Table 8.3 shows average effect response for the raw data and effect response table for S/N ratio.

Table 9: Response Table for S/N Ratios for TiCN Insert Smaller is Better

Level	**Cutting speed**	**Feed rate**	**Depth of cut**
1	-7.521	-3.127	-1.021
2	-4.347	-4.794	-5.491
3	-3.782	-7.731	-9.139
Delta	3.739	4.604	8.117
Rank	**3**	**2**	**1**

Table 10: Responce Table for Means for TiCN Insert

Level	**Cutting speed**	**Feed rate**	**Depth of cut**
1	2.450	1.533	1.247
2	1.987	2.247	2.170
3	1.927	2.583	2.947
Delta	0.523	1.050	1.700
Rank	**3**	**2**	**1**

Table 11: Response Table for S/N Ratios for TiN Insert Smaller is Better

Level	**Cutting Speed**	**Feed rate**	**Depth Of Cut**
1	-15.734	-11.762	-7.188
2	-12.513	-10.562	-13.774
3	-8.621	-14.543	-15.906
Delta	7.113	3.981	8.718
Rank	**2**	**3**	**1**

Table 12: Response Table for Means for TiN Insert

Level	**Cutting Speed**	**Feed rate**	**Depth of cut**
1	6.421	3.946	2.849
2	4.428	4.911	5.222

3	3.575	5.566	6.353
Delta	2.846	1.620	3.504
Rank	**2**	**3**	**1**

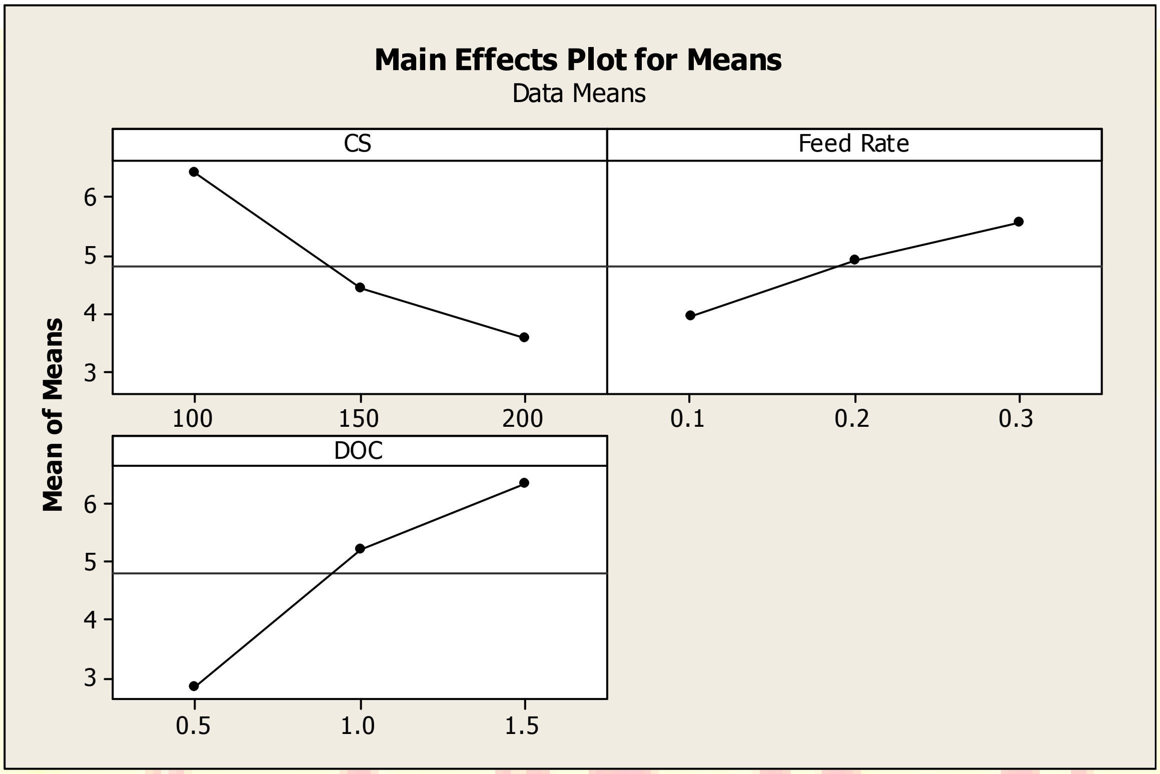


Fig. 3: Main Effect Plot for Means Using TiN Coated Carbide Insert

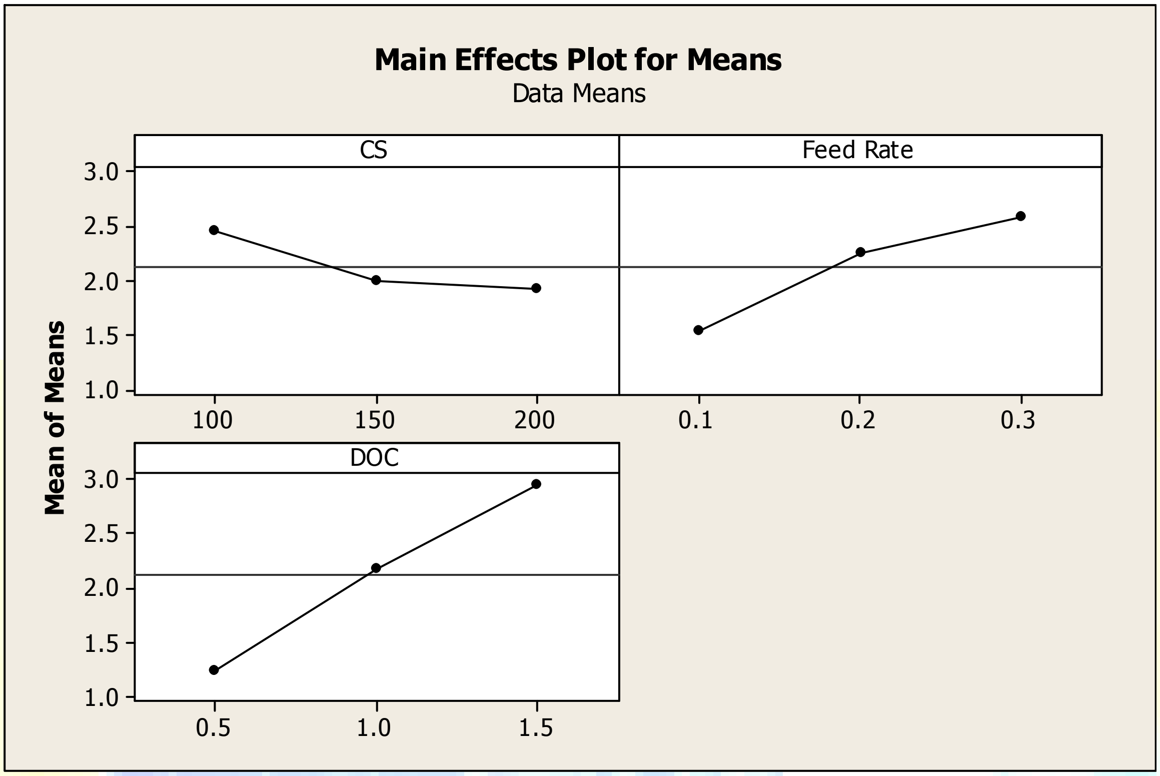


Fig 4: Main Effect Plot for Means Using TiCN Coated Carbide Insert

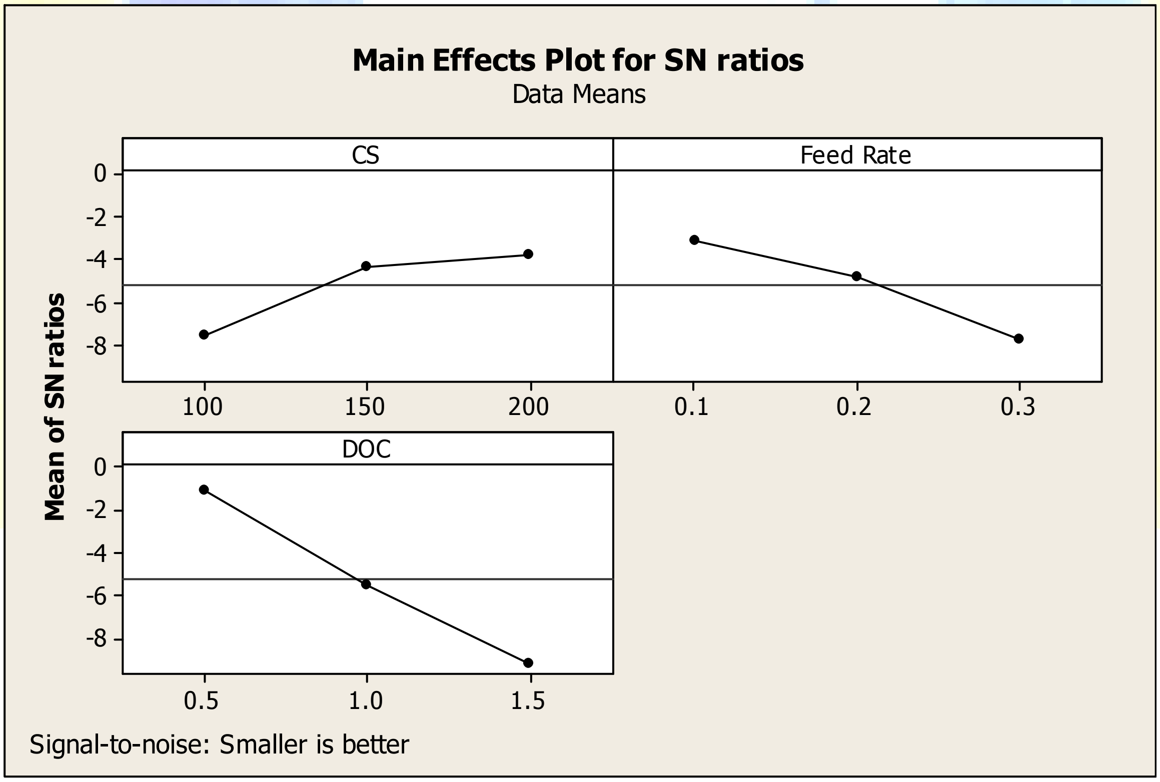


Fig. 5: Main Effect Plot for SN Ratios Using TiN Coated Carbide Insert

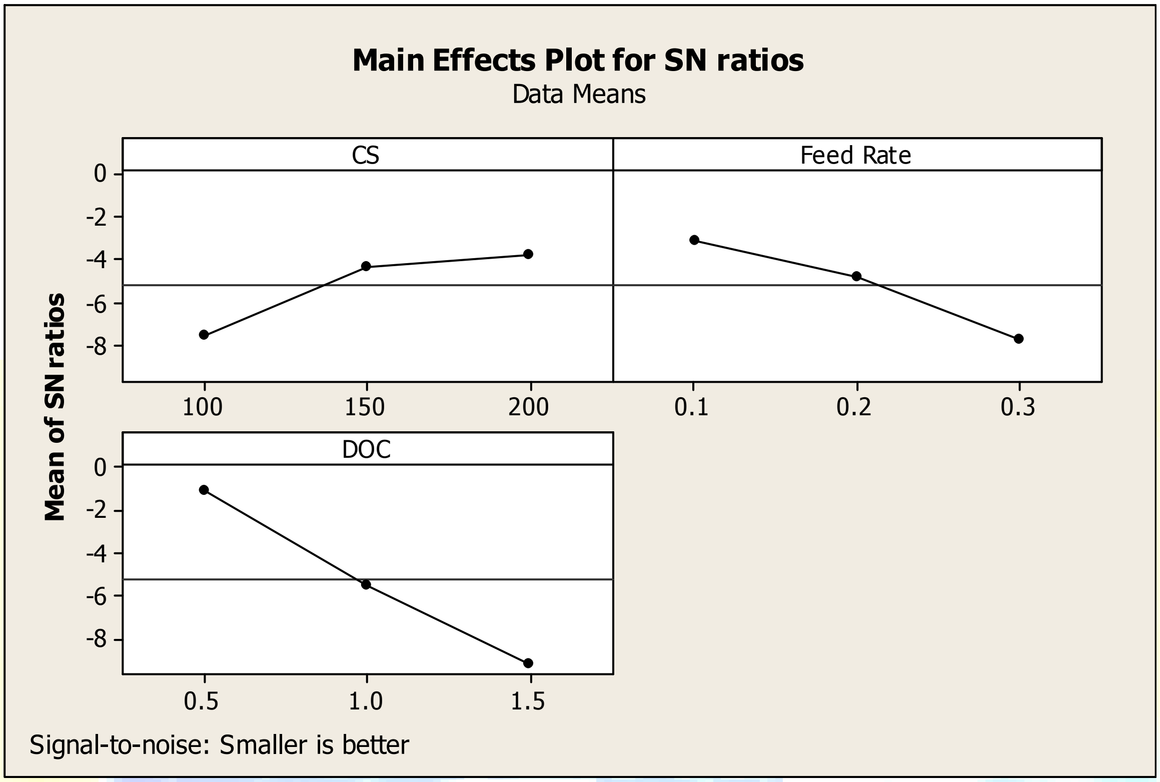


Fig. 6: Main Effect Plot for SN Ratios Using TiCN Coated Carbide Insert

Predicted values for TiN coated carbide Mean

0.754333

Factor levels for predictions

CS	FR	DOC
200	0.1	0.5

Predicted values for TiCN coated carbide Mean

0.464444

Factor levels for predictions

CS	FR	DOC
200	0.1	0.5

VI. Confirmation Experiments

Table 13: Results for the Confirmation Run

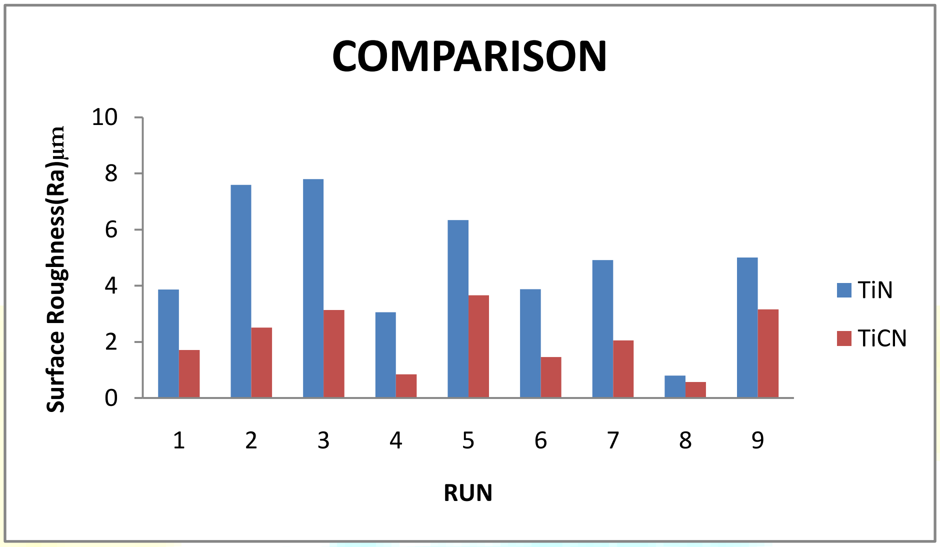
Sample #	**Ra (µm)**
1	0.7884
2	0.7332
3	0.7433
4	0.7189
5	0.7298
Mean Ra(µm)	**0.7427**

Table 14 Results of the confirmation run for TiCN coated carbide insert

Sample #	**Ra (µm)**
1	0.4933
2	0.4462
3	0.4666
4	0.4873
5	0.4798
Mean Ra(µm)	**0.4746**

A. Comparison Between TiN and TiCN Coated Carbide Insert Performance Fig. 7 showed that TiCN coated carbide insert is a better option for the selected range of the control factors. TiCN is better coated carbide insert due to its high hardness, better wear resistance, and good chemical and thermal stability as compare to TiN coated carbide insert. Adding carbon to a TiN film increases the hardness nearly 80 percent, resulting in additional tool life. Beside that Titanium

Carbo Nitride (TiCN) has a thin film coating that was developed from Titanium Nitride



VII. Conclusion

The present research can be concluded in the following steps: Taguchi design of experiment technique can be very efficiently 1. used in the optimization of machining parameters in metal cutting processes. 2.This research found that the control factors had varying effects on the response variable, with depth of cut having the highest effects for both TiN and TiCN coated carbide insert. 3.Optimum parameter setting for surface roughness for both carbide insert is obtained at a cutting speed of 200m/min, feed rate 0.1mm/rev. and depth of cut 0.5mm. The measurement of the work pieces in this confirmation run 4. led to the conclusion that the selected parameter values from this process produced a surface roughness that was much lower than the other combinations tested in this study. 5.Comparing the performance of both TiN and TiCN coated carbide tool it was found that TiCN is a better option for these ranges. 6.The predictive value for TiN coated carbide tool is 0.754333µm and for TiCN is 0.464444µm.

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