Comparision of Machining Parameters for Optimum Surface Roughness of AISI 1045 With TiN and TiAlN Coated Carbide Tools

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Abstract
Hard coatings are well known to improve the performance of machining applications. CNC machine tool is widely used by manufacturing and production area to quickly and effectively set up for new products. The present work carried out the performance of TiN and TiAlN coated carbide tools in machining of medium carbon steel alloy (AISI 1045). The work also analyses the effect of cutting parameters (cutting speed, feed rate, and depth of cut) for surface roughness as a response variable by Taguchi parameter design method. Under the different cutting factors and levels the surface roughness for both TiN and TiAlN coated carbide tool was measured. Experimental runs were conducted for both TiN and TiAlN coated carbide tool using an L'9 orthogonal array, and the ideal combination of controllable factor levels was determined for the surface roughness and signal-to-noise ratio. Confirmation run for both TiN and TiAlN coated carbide insert were used to verify the results. Comparatives study of TiN and TiAlN coated carbide tool showed that the performance of TiAlN coating was much better and economical at these ranges.

Keywords
CNC Lathe, AISI 1045 Alloy Steel, Surface Roughness, Taguchi Method, ANOVA

I. Introduction

The recent developments in science and technology have put tremendous pressure on manufacturing engineering. Maintaining the economic production with optimal use of resources is of prime concern for the engineers. The manufacturing is constantly striving to decrease its cutting costs and increase the quality of the machined parts as the demand for high tolerance manufactured goods is rapidly increasing. In metal cutting process there are various parameter involved that challenges the engineers to find out the optimum figure for the desired product quality and to maximize the performance of manufacturing using the available resources. The need to boost productivity to machine more difficult materials and to improve their quality by the manufacturing industry has been the driving force behind the development of cutting tool materials. Surface roughness is an important parameter to evaluate the productivity of the machine tool as well as machined components. Surface roughness is used as the quality indicator for the machined surface. Extensive effort has been done to study the critical parameters which affect the surface roughness. The aim of this work is to optimize the process parameter for surface roughness using Taguchi method. For attaining superior tribological properties the productivity enhancement of manufacturing processes imposes the acceleration of design and evolution of improved cutting tools. Turning with coated carbide tools has several benefits such as reduction of processing costs, increased productivity and improved mechanical properties. The development of cemented and sintered carbides tools was first occurred in Germany in the 1920s. During World War II it was found that tungsten in carbide cuts metal more efficiently than tungsten in high-speed steel, so to economize on the use of tungsten, carbides were used for metal cutting. After that carbide tools had replaced diamond as material for machining metal. Cemented carbide tools is most suitable for high cutting speed and high temperature due to desire lubricity between cutting tool and chip interface, lower friction coefficient, high hardness and chemically stable . By coating the cutting tools, it will significantly improves the cutting tool life and hence increase the productivity. CNC machine tool is widely used by manufacturing engineers and production personnel to quickly and effectively set up manufacturing processes for new products .This study discusses an investigation into the use of Taguchi Parameter Design methodology for Parametric Study of CNC turning operation for surface roughness as a response variable. The objective of this study is to optimize the surface roughness in turning operation of AISI 1045 steel using coated carbide inserts with the help of Taguchi's L9 orthogonal array, S/N ratios and ANOVA and also to find out optimum levels for each cutting parameters. The results are further confirmed by validation experiment or confirmation run.

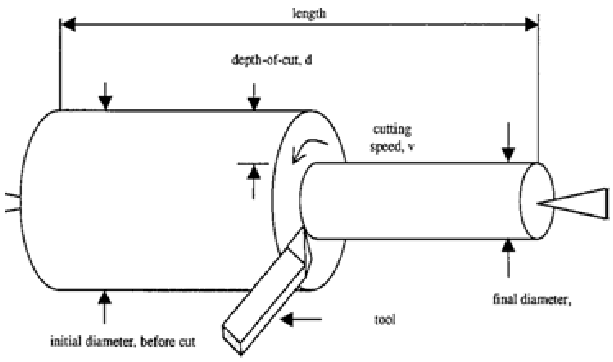

Fig. 1: Turning on CNC Lathe

II Literature Review

P.C Jindal et al. [1] observed that TiAlN coated tools showed the best metal cutting performance, followed by the TiCN and TiN coated tools. The superior performance of the TiAlN was even greater at higher speeds and also provides higher resistance to crater wear and abrasive. According to Maan Aabid Tawqif [2], (TiN,TiC) coated cutting tools gave best results for surface finish as compared to (TiN, TiC, Al2O3), TiN and all uncoated tool, for selected machining conditions. The experimental results also showed that, surface roughness will be decreased when increase cutting speed and decrease feed rate for uncoated tool insert, for single coated layer insert(TiN), for double coated layer insert (TiN/TiC) and for triple coated layer insert ($TiN/Al_2O_3/TiC$).. Zenoraiman Bin Mustapha [3] in his study of surface integrity whilst turning AISI 1045 steel with TiC/WC coated insert showed that the surface roughness value increases with the increasing tool wears. The machining involved turning at high speed on CNC machine without use of cutting fluid. Cutting speed was varied

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from 300m/min to 600m/min. Shamshul Asri Bin Mohd Yusuf [4] analysis the performance of TiC coated carbide cutting tool in turning AISI 1045 steel. In his study he presented the flank wear characteristics of titanium carbide (TiC) as coated material on cemented carbide tool during machining AISI 1045 steel in dry machining. The rate of the wear growth and wear mechanism at the end of the tool life was investigated in detail using image analyzer from where it was observed that the time taken for the cutting edge of the TiC coated carbide tools to initiate cracking and fracturing is longer when cutting at low speed than at high speed. Leonardo R. Silva et al. [5] In this research work, investigate the effect of cutting speed on cutting forces and surface roughness when dry precision turning AISI 1045 steel using coated and uncoated cemented carbide tools. The results showed, the turning force components tend to decrease or remain practically stable as cutting speed increased. M. Kumara Swamy et al. [6] investigated that simulation can increase the understanding of the cutting process and reduce the number of experiments. In this study the metal cutting process is analyzed with FEM model for 3D simulation of turning of AISI 1045 steel with solid single point cutting tool. Upinder Kumar Yadav et al. [7] analyzed that feed rate is the most significant factor affecting surface roughness followed by depth of cut. Mohd Hilmy Bin Mohd Yusuf [8] defines the effects of turning cutting parameter (cutting time, speed and feed rate) on the surface integrity and results shows that surface roughness and flank wear increased due to increased of the cutting time by fixing the cutting time, the cutting temperature can be controlled as the machining is subjected to the heat generate. G.G. Ye et al. [9] study of cutting AISI 1045 steel at very high speeds the influence of cutting speed and mass transfer on the temperature distribution during high speed machining and analyzed high speed cutting over a wide range of cutting speeds from 30 m/s to 200 m/s. The investigation of chip morphology, micro-structures, micro-hardness and the finished surface integrity were carried out. Domnita Fratila & Cristian Caizar [10] investigated the influence of process parameters on the surface quality of AISI 1045 during turning. Numerical and graphical optimizations shows the minimam level of depth of cut, the maximum cutting speed, and the maximum lubricant flow rate resulted in a better quality of machined surface. M.Y. Noordin et al. [11] studied the application of response surface methodology and investigated that the feed is the most significant factor that influences the surface roughness. Kyung Hee Park et al. [12] analyze the flank wear on the multi-layer ($TiCN/Al_2O_3/TiCN$) coated carbide inserts after turning AISI 1045 steel, results was the hardness of the coating is the most important requirement to resist flank wear. Therefore, the multilayer coating scheme does not provide any significant benefit to resist flank wear.

III. Methodology

A. Taguchi Method

are statistical approach developed by Genichi Taguchi to improve the quality of manufactured products, and more recently also applied to engineering [15],biotechnology [16], marketing [17] and advertising [18]. Professional statisticians have welcomed the improvements brought about by Taguchi methods, especially by Taguchi's development of designs for studying variation. Taguchi's work includes three principle contributions to statistics

1. A specific loss function
2. The philosophy of off-line quality control
3. Innovations in the design of experiments.

The Taguchi-based experimental design used in this study is an L9 orthogonal array.

B. Signal-to-Noise ratios (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 used to measure the quality characteristic deviating from the desired value. The S/N ratios for surface roughness are calculated as given in equation.

$$LSB = [1/n \sum_{i=1}^{n} 1/y_{sr(i)}^2]$$

S/N ratio for Ra = -10 $\log_{10}$ (LSB)

IV. Experimental Setup

The experiments were conducted on a CNC Lathe machine (HAAS USA TL) installed at Central Institute of Plastic Engineering and Technology, Murthal (Sonepat), India. The photographic view of CNC Lathe and experimental set-up are shown in Figure 2 Alloy steel AISI 1045 with a diameter of 50mm and 200mm length was used as work piece. In this experiment VBMT 160408 TN2000 and VBMT 160408 PC9030 coated carbide inserts were used as cutting tools. Chemical composition of material is given in Table1

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. 2: CNC Lathe Used for Experimentation

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. 3: Ra Measurement Device- Mitutoyo Surftest SJ-201 P/M

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 TiAlN 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: Selection of Process Parameters With Codes, Units and Levels

Parameter (Control factors)	Code	Level 1	Level 2	Level 3
Cutting speed (m/min)	A	150	200	250
Feed rate (mm/rev)	B	0.1	0.2	0.3
Depth of cut (mm)	C	0.75	1.50	2.25

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 L_9 OA (a standard 3- level OA) having 6(=9-3) degree of freedom was selected for the present analysis. Minitab 15 software was used for graphical analysis of the obtained data.

Table 3: Result of the L9OA Experiment Using TiAIN Coated Carbide Insert

Sr. No.	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth Of Cut (mm)	Ra 1 (µm)	Ra2 (µm)	Ra3 (µm)	Mean (µm)	S/N RATIO (db)
1	150	0.1	0.75	1.69	1.60	1.78	1.69	-4.5577
2	150	0.2	1.50	2.66	2.74	2.82	2.74	-8.7550
3	150	0.3	2.25	4.70	4.82	4.76	4.76	-13.5521
4	200	0.1	1.50	2.27	2.43	2.35	2.35	-7.4214
5	200	0.2	2.25	2.87	2.80	2.94	2.87	-9.1576
6	200	0.3	0.75	2.55	2.65	2.75	2.65	-8.4649
7	250	0.1	2.25	2.70	2.84	2.77	2.77	-8.8496
8	250	0.2	0.75	2.38	2.44	2.5	2.44	-7.7478
9	250	0.3	1.50	3.90	4.0	3.95	3.95	-11.9319

Table 4: Result of the L9 OA Experiment Using TiN Coated Carbide Insert

Sr. No.	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth Of Cut (mm)	Ra 1 (µm)	Ra2 (µm)	Ra3 (µm)	Mean (µm)	S/N RATIO (db)
1	150	0.1	0.75	2.35	2.43	2.51	2.43	-7.7121
2	150	0.2	1.50	3.96	3.89	4.03	3.96	-11.9539
3	150	0.3	2.25	5.82	5.64	5.73	5.73	-15.1631
4	200	0.1	1.50	3.20	3.25	3.15	3.20	-10.1030
5	200	0.2	2.25	3.88	4.02	3.95	3.95	-11.9319
6	200	0.3	0.75	3.67	3.60	3.75	3.67	-11.2933
7	250	0.1	2.25	2.32	2.38	2.35	2.38	-7.5315
8	250	0.2	0.75	2.40	2.33	2.47	2.40	-7.6042
9	250	0.3	1.50	3.90	4.06	3.98	3.98	-11.9977

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 and Table 6 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 TiAlN coated carbide inserts. The influence of feed is the most significant as according literature review. And the influence of depth of cut 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: ANOVA for TiN Coated Carbide Insert, Using Adjusted SS for Tests

Source	DF	SS	MS	F-Ratio	F-Ratio table	P
Cutting speed	2	1.9137	0.9568	6.14	3.49	0.140
Feed rate	2	4.8391	2.4195	15.52	3.49	0.061
Depth of cut	2	2.2766	1.1383	7.30	3.49	0.120
Error	2	0.3118	0.1559			
Total	8	9.3412				

S=0.394814 R-Square=96.66% R-Square (Adj)=86.65%

Table 6: ANOVA for TiAIN Coated Carbide Insert, Using Adjusted SS For Tests

Source	DF	SS	MS	F-Ratio	F-Ratio table	P
Cutting speed	2	0.3786	0.1893	1.09	3.49	0.479
Feed rate	2	3.6885	1.8442	10.58	3.49	0.086
Depth of cut	2	2.2291	1.1145	6.40	3.49	0.135
Error	2	0.3485	0.1742			
Total	8	6.6446				

S=0.417413 R-Square=94.76% R-Square (Adj)=79.02%

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 7 and table 8 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 8 and Table 9 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 7: Response Table for Means using TiN coated carbide insert

Level	Cutting Speed	Feed rate	Depth of cut
1	4.040	2.670	2.833
2	3.607	3.437	3.713
3	2.920	4.460	4.020
Delta	1.120	1.790	1.187
Rank	3	1	2

Table 8: Response Table for Means for TiAlN coated carbide insert

Level	Cutting speed	Feed rate	Depth of cut
1	3.063	2.270	2.260
2	2.623	2.683	3.013
3	3.053	3.787	3.467
Delta	0.440	1.517	1.207
Rank	3	1	2

Table 9: Response Table for S/N Ratios for TiN coated carbide insert

Level	Cutting speed	Feed rate	Depth of cut
1	-11.610	-8.449	-8.870
2	-11.109	-10.497	-11.352
3	-9.044	-12.818	-11.542
Delta	2.565	4.369	2.672
Rank	3	1	2

Table 10: Response Table for S/N Ratios for TiAlN coated carbide insert

Level	Cutting speed	Feed rate	Depth of cut
1	-8.955	-6.943	-6.923
2	-8.348	-8.553	-9.369
3	-9.510	-11.316	-10.520
Delta	1.162	4.373	3.596
Rank	3	1	2

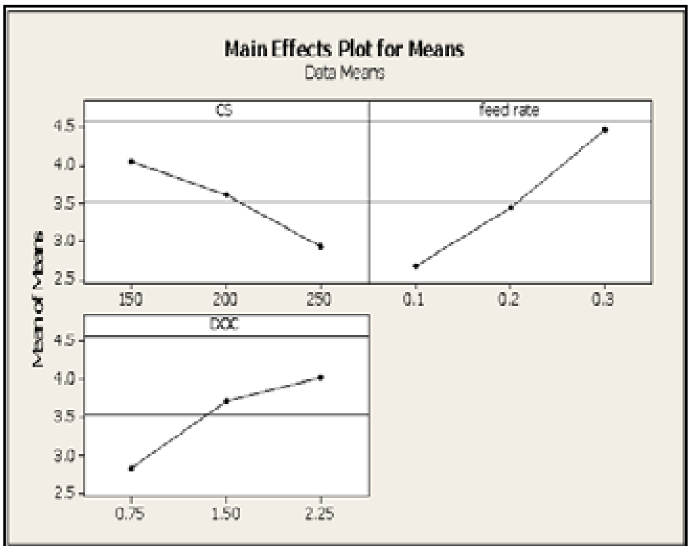

Figure 4: Main effect plot for means using TiN coated carbide insert

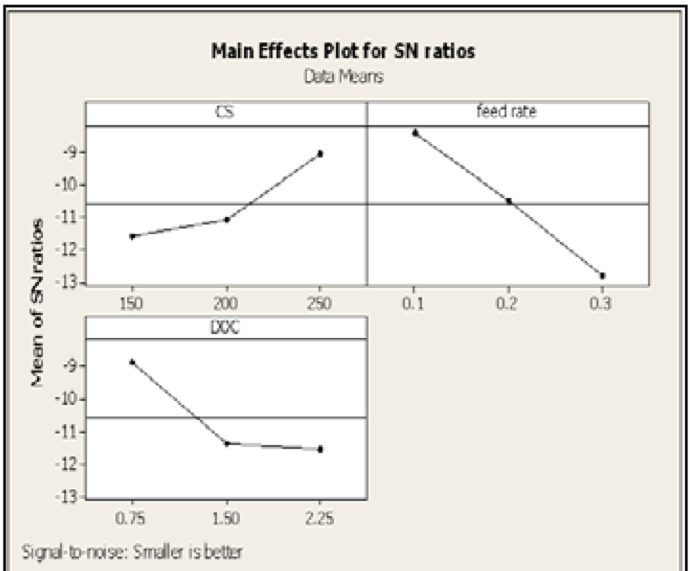

Figure 6: Main effect plot for SN ratios using TiN coated carbide insert

Predicted values for TiN coated carbide
Mean
1.37889
Factor levels for predictions

CS	FR	DOC
250	0.1	0.75

Predicted values for TiAlN coated carbide
Mean
1.32667
Factor levels for predictions

CS	FR	DOC
200	0.1	0.75

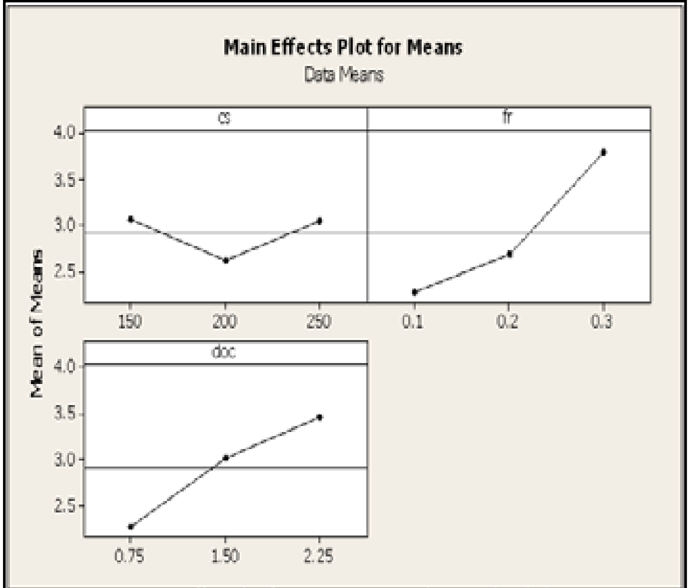

Figure 5: Main effect plot for means using TiAlN coated carbide insert

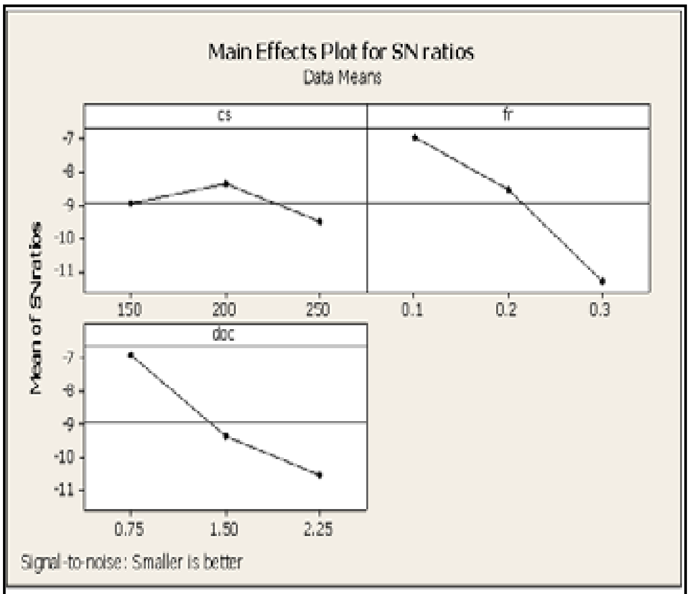

Figure 7: Main effect plot for SN ratios using TiAlN coated carbide insert

VI. Confirmation Experiments

No. of Run	Ra (µm) (TiN coated carbide insert)	Ra (µm) (TiAlN coated carbide insert)
1	1.456	1.408
2	1.460	1.400
3	1.479	1.418
4	1.454	1.428
5	1.461	1.411
Mean Ra(µm)	1.462	1.413

Table 11: Results of the confirmation run

A. Comparison Between TiN and TiAlN Coated Carbide Insert Performance

Fig. 8 showed that TiAlN coated carbide insert is a better option for the selected range of the control factors. TiAlN 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. Beside that when cutting with TiAlN coated insert, a dense and highly adhesive protective layer Al_2O_3 surface film is formed and prevent diffusion of oxygen into the tool.

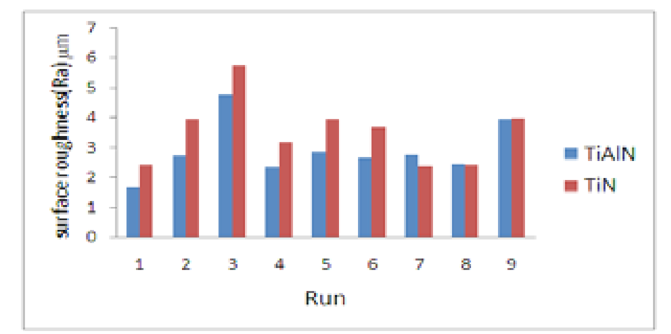

Figure 8: Comparison between TiN and TiAlN coated carbide insert performance

VII. Conclusion

The present research can be concluded in the following steps:

1. Taguchi design of experiment technique can be very efficiently 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 feed rate having the highest effects for both TiN and TiAlN coated carbide insert.
3. Optimum parameter setting for surface roughness for TiN is obtained at a cutting speed of 250m/min, feed rate 0.1mm/rev. and depth of cut 0.75mm and for TiAlN obtained at a cutting speed of 200m/min, feed rate 0.1mm/rev. and depth of cut 0.75mm.
4. The measurement of the work pieces in this confirmation run 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 TiAlN coated carbide tool it was found that TiAlN is a better option for these ranges.
6. The predictive value for TiN coated carbide tool is 1.37889µm

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and for TiAlN is 1.32667μm.

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