The Effect of Machining Factors on Surface Roughness and Flank Wear While Turning Steel Alloy AISI 3415 using Tialn Coated Carbide Insert

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Abstract: This research work is carried out to reveal the effect of turning factors such as cutting velocity, depth of cut and feed rate on the mean surface roughness and flank wear on turning cylindrical AISI 3415 steel alloy components. The experiments are designed based on (3^3) full factorial design and conducted on a turning centre (All Geared Lathe) with Titanium Aluminium Nitride (TiAlN) layered carbide tool of 0.8mm nose radius. The surface roughness of the turned steel alloy parts is deliberated by means of a precise surface roughness apparatus and the assessment of tool flank wear is measured by a toolmaker's microscope with 30x intensification and 1µm resolution. A prediction model is created for mean surface roughness and flank wear by nonlinear regression examination with the aid of MINITAB numerical software.

Index Terms: AISI 3415; Lathe; Surface roughness; TiAlN; Flank wear; Regression analysis.

I. INTRODUCTION

Globalization of the market makes a difficult condition in products promoting [1 – 2]. The high challenge forces the manufacturing sectors to make better quality products within a short time span as well as minimal cost [3 – 4]. Precision items could be produced with the machines at optimal working conditions [5 – 6]. Ideal machining factors are of exceptional worry in assembling conditions, where financial system of machining activity has an impact in aggressiveness [7 - 9]. A typical turning activity produces parts which have essential highlights requiring a specific surface finish. Thus accomplishing a high degree of finish products is most vital for the manufacturers [10 – 11]. Currently, nickel-based steels are broadly utilized for different functions in automotive enterprises [12 – 13]. In the meantime, optimum machining of these alloy steels are difficult, which is being repeatedly detailed by many researchers and practitioners. Also, titanium based cutting tool inserts are most commonly used for turning medium carbon steel alloys due to its ability to cut at higher cutting velocities and improved wear resistance [14 – 17].

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Many researchers and practitioners adapted Design of Experiment (DoE) technique for planning the experiments in the turning of medium carbon steel alloy, few were discussed in the below section;

Yang et al, [18] investigated the processing factors in turning and created a predictor for surface roughness using DoE. Their experimentation reveals, feed was the most prominent factor on roughness, trail by cutting speed. The same result was validated through experimentation by, Zerti et al, [19]. Xiao et al, [20] analyzed the consequence of speed, depth of cut and feed towards surface finish by ANOVA and regression model. It is suggested that feed has the utmost influence on the surface finish compared to depth of cut and speed. Mia and Dhar [21] analyzed the surface finish in turning of steel and found that the material hardness was a most affecting factor on surface finish and interface temperature and increasing cutting speed leads to achieve a good surface finish with high-pressure coolant condition. From the reporting stated above, it turns out to be certain that machining studies have been completed by different scientists. In any case, there stays some trouble in the machining of metal which uncovers that additional investigation must be completed to locate a sensible solution. In this manner, examination on machining is done by making utilization of the demonstrated test structure strategy.

II. EXPERIMENT DETAILS

The experiment details of this research work are given in Table 1.

Table 1: Experiment details

Selection of workpiece	AISI 3415 (ϕ80mm x 150mm)
Cutting tool used	TiAlN coated carbide insert
Machine tool	Turning centre
Cutting fluid	Mineral based (Servocut 'S') emulsion
Coolant application technique	Flooded (wet)
Planning of experiment	Full factorial design (3^3 = 27 experiments).
Repeatability of experiments	3 times
Output response	Surface roughness, Flank wear

A. Work Piece

Round workpiece prepared of AISI3415 steel with a size of (ϕ80mm x 150mm) was preferred for this research. AISI3415 is a nickel-chromium steel alloy and is used for the manufacture of main axis, gear shaft, valve rods, mechanical gears, connecting rods, multidiameter shafts, nuts, and bolts. The chemical composition of AISI3415 steel is given in Table 2.

Table 2: Chemical composition

Element	% Composition	
	Standard	Tested
C	0.1-0.2	0.170
Ni	2.75-3.25	3.120
Cr	0.6-0.95	0.870
Mn	0.3-0.5	0.410
P	0.04max.	0.030
Si	0.15-0.3	0.270
S	0.05max.	0.041
Fe	Rest	95.090

B. Cutting Tool

A universal CNMG diamond finishing TiAlN layered carbide insert of 0.8mm nose radius and PCLNR tool holder was utilized to do the turning operation on AISI3415 steel components.

C. Cutting Fluid

Mineral oil blended with a stream of water was utilized as cutting fluid for this investigation. The properties of the base oil are specified in Table 3.

Table 3: Properties of Oils

Property	Value
Flash Point(^{0}C)	150
Kinematic Viscosity at 40^{0}C(cSt	20
Specific gravity(No Unit)	0.877

D. Experimental Conditions

The most influencing turning factors such as feed rate, cutting velocity and depth of cut considered for the experimentation and their levels are indicated in Table 4. The trials were arranged in view of (3^3) full factorial design in a turning centre (All Geared Lathe), appeared in Figure 1. The turning action is made on AISI3415 cylindrical components of 80 mm diameter by utilizing TiAlN coated carbide insert in traditionally flooded machining condition. The photograph of measuring arrangement and surface roughness apparatus is shown in Figure 2(a) and Figure 2(b) correspondingly.

Table 4: Control factors and Levels

Notation	Control factors	Unit	Levels		
			1	2	3
v	Cutting velocity	m/min	225	275	325
f	Feed rate	mm/rev	0.1	0.15	0.2
d	Depth of Cut	mm	0.2	0.4	0.6

Figure 1: Experimental setup

(a) **(b)**

Figure 2: Photograph of measuring arrangement (a) and Surface roughness tester (b)

III. RESULTS AND DISCUSSION

A. Experimental plan and results

The experimental plan and the outcome are given in Table 5, where, 'Ra' is the average surface roughness value of the trials Ra_1, Ra_2, Ra_3, Ra_4 of a single machined component and 'VBc' is the flank wear, and the assessment of tool flank wear is measured by a toolmaker's microscope with 30x intensification and 1μm resolution after each trial.

B. Analysis of Variance

The noteworthy factor on the output response (mean surface roughness and flank wear) was analyzed through ANOVA and F-test with a chance of probability (p=0.05), which was shown in Table 6 and Table 7.

The estimation of "Prob.>F" in Table 6 and Table 7 for the model is under 0.05, which demonstrates that the representation is important, which is pleasing as it shows that the terms in the representation significantly affect the yield responses (mean surface roughness and flank wear). From ANOVA results, it is clear that the feed impacts more on the mean surface roughness trail by depth of cut and cutting velocity. In case of flank wear depth of cut influences more trail by feed rate and cutting velocity. This is harmonizing with the current hypotheses of machining.

Table 5: Experimental plan and results

Sl. No.	Control factors			Surface Roughness(µm)					Flank Wear (mm)
	v	f	d	Ra1	Ra2	Ra3	Ra4	Average, Ra	VBc
1	225	0.1	0.2	0.59031	0.59867	0.59255	0.59897	0.5951	0.048
2	225	0.1	0.4	0.66439	0.67275	0.66534	0.67976	0.6706	0.075
3	225	0.1	0.6	0.73847	0.74683	0.71534	0.76976	0.7426	0.099
4	225	0.15	0.2	1.23371	1.24207	1.26955	1.28597	1.2578	0.051
5	225	0.15	0.4	1.40292	1.41128	1.20535	1.22177	1.3103	0.093
6	225	0.15	0.6	1.57213	1.58049	1.14115	1.15757	1.3628	0.135
7	225	0.2	0.2	1.87711	1.88547	1.94655	1.97297	1.9205	0.056
8	225	0.2	0.4	2.14145	2.14981	1.88235	1.90877	2.0206	0.114
9	225	0.2	0.6	2.40579	2.41415	1.81815	1.84457	2.1207	0.171
10	275	0.1	0.2	0.59533	0.61099	0.68496	0.69138	0.6457	0.048
11	275	0.1	0.4	0.71256	0.72822	0.62076	0.62718	0.6722	0.086
12	275	0.1	0.6	0.82979	0.84545	0.81434	0.82976	0.8298	0.125
13	275	0.15	0.2	1.1179	1.13356	1.12544	1.16296	1.1350	0.052
14	275	0.15	0.4	1.33026	1.34592	1.29776	1.31418	1.3220	0.106
15	275	0.15	0.6	1.54262	1.55828	1.31574	1.24998	1.4167	0.160
16	275	0.2	0.2	1.64047	1.65613	1.70354	1.61076	1.6527	0.055
17	275	0.2	0.4	1.94796	1.96362	1.97476	2.00118	1.9719	0.128
18	275	0.2	0.6	2.25545	2.27111	1.91056	2.11196	2.1373	0.197
19	325	0.1	0.2	0.51646	0.50862	0.49934	0.53676	0.5153	0.046
20	325	0.1	0.4	0.76073	0.78369	0.71317	0.71959	0.7443	0.098
21	325	0.1	0.6	0.92111	0.94407	0.96334	0.91076	0.9348	0.151
22	325	0.15	0.2	1.00209	1.02505	1.00454	1.01076	1.0106	0.050
23	325	0.15	0.4	1.2576	1.28056	1.39017	1.30006	1.3071	0.119
24	325	0.15	0.6	1.51311	1.53607	1.48314	1.50216	1.5086	0.187
25	325	0.2	0.2	1.40383	1.42679	1.39314	1.46416	1.4220	0.055
26	325	0.2	0.4	1.75447	1.77743	1.76024	1.69996	1.7480	0.141
27	325	0.2	0.6	2.10511	2.12807	2.00297	2.02939	2.0664	0.224

Table 6: ANOVA for mean surface roughness

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
v	1	0.03075	0.43%	0.00460	0.00460	3.05	0.0960
f	1	6.37206	89.28%	0.61646	0.61646	408.91	0.0001
d	1	0.48839	6.84%	0.01879	0.01879	12.46	0.0020
vf	1	0.08526	1.19%	0.08526	0.08526	56.56	0.0001
vd	1	0.10255	1.44%	0.10255	0.10255	68.02	0.0001
fd	1	0.02783	0.39%	0.02783	0.02783	18.46	0.0001
Error	20	0.03015	0.42%	0.03015	0.00151		
Total	26	7.13700	100.00%				
R^2 – 0.99				**R^2 (Adj) – 0.99**			

Table 7: ANOVA for flank wear

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
v	1	0.002917	4.16%	0.000317	0.000317	517.35	0.0001
f	1	0.007439	10.62%	0.000222	0.000222	363.49	0.0001
d	1	0.054408	77.68%	0.000022	0.000022	36.33	0.0001
vf	1	0.000003	0.00%	0.000003	0.000003	4.29	0.0520
vd	1	0.002174	3.10%	0.002174	0.002174	3551.22	0.0001
fd	1	0.003085	4.41%	0.003085	0.003085	5041.09	0.0001
Error	20	0.000012	0.02%	0.000012	0.000001		
Total	26	0.070037	100.00%				
R^2 – 0.99				**R^2 (Adj) – 0.99**			

C.

Mathematical model

By means of regression examination with the aid of MINITAB17 numerical software, the outcome of control factors on average surface roughness(Ra) and Flank wear(VB) was modeled as follows.

Ra = 0.0863-0.0576 v+0.6672 f -0.1165 d-0.0843vf +0.0924vd +0.0482fd (1)

VBc=0.05001-0.015122v-0.012676f-0.004008d+0.000468vf+0.013458vd+0.016035fd (2)

For equation (1), it was found that R^2 = 0.99 and for equation (2) also, R^2=0.99. Where 'R' is the correlation coefficient and the value of 'R^2' indicates the nearness of the mathematical model in lieu of the yield response. The models obtained for surface roughness and flank wear was verified with the actual values and an average variation of 2.6% was observed in case of surface roughness and a minimal variation of 0.7% was observed in case of flank wear. The comparison plot of actual and predicted values for the surface roughness is shown in Figure 3 and for flank wear in Figure 4.

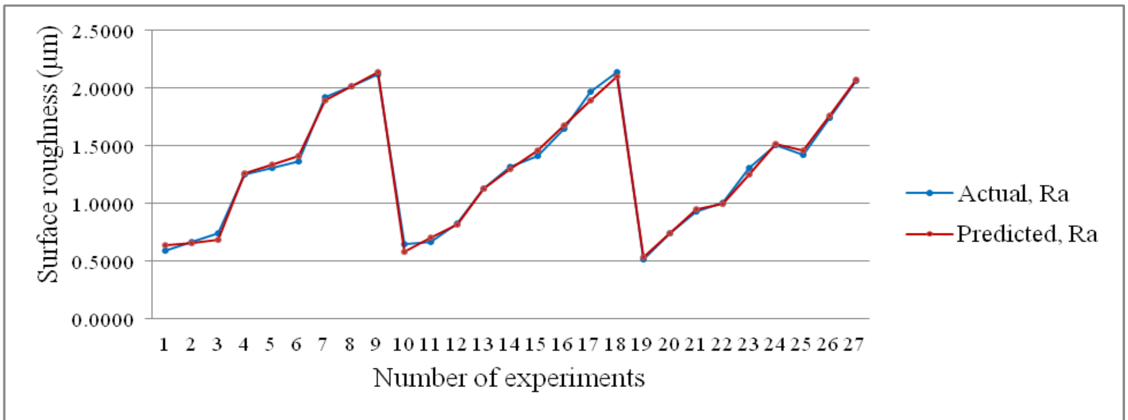

Figure 3: Comparison plot for surface roughness

Figure 4: Comparison plot for flank wear

Effect of machining factors

The effect of machining factors on the mean surface roughness and the flank wear was studied and presented in the below section.

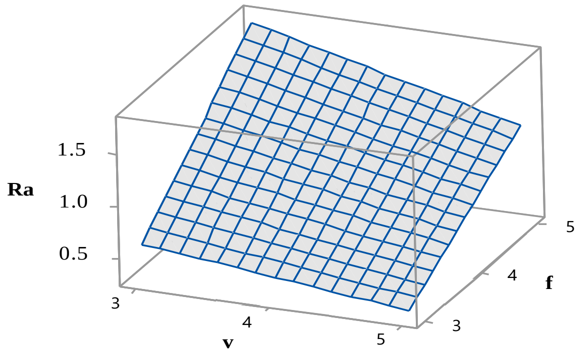

Figure 5: Plot of mean surface roughness versus cutting velocity and feed rate

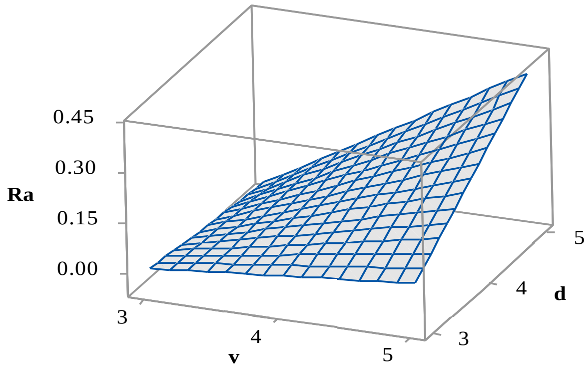

Figure 6: Plot of mean surface roughness versus cutting velocity and depth of cut

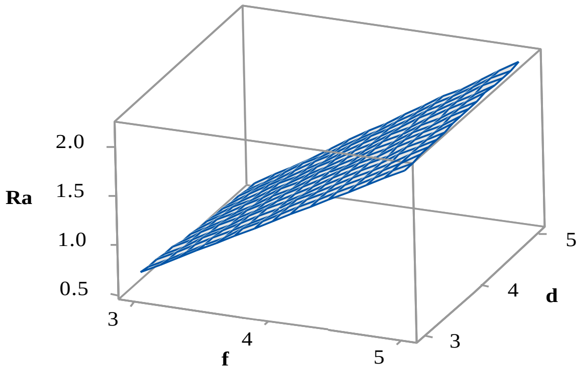

Figure 7: Plot of mean surface roughness versus feed rate and depth of cut

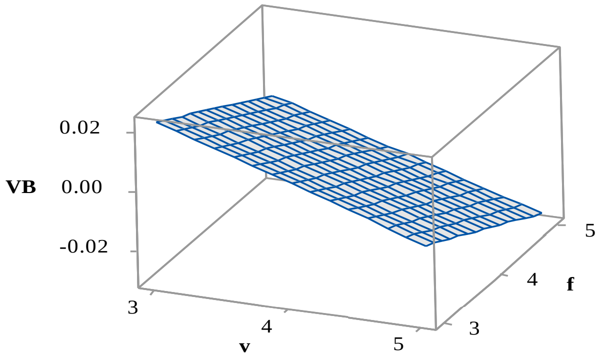

Figure 8: Plot of flank wear versus cutting velocity and feed rate

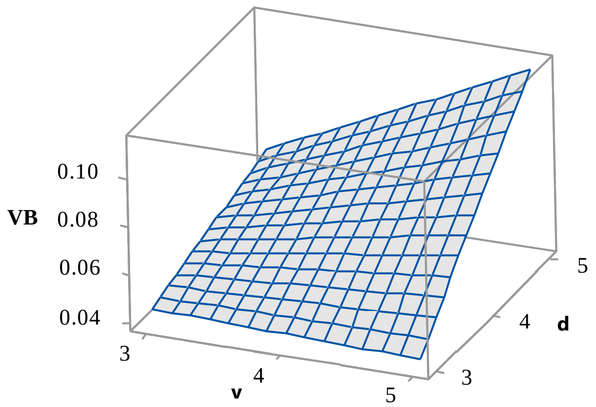

Figure 9: Plot of flank wear versus cutting velocity and depth of cut

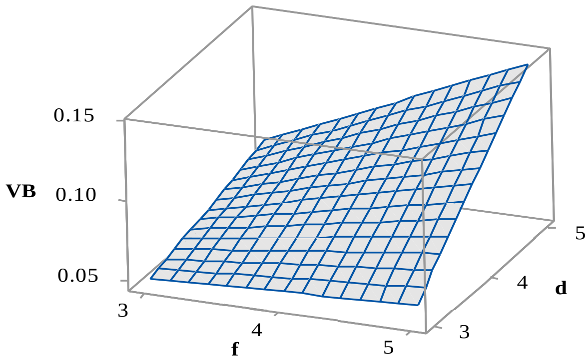

Figure 10: Plot of flank wear versus feed rate and depth of cut

D.

Figure 5 depicts the outcome of cutting velocity and feed rate on the mean surface roughness, where the depth of cut is kept constant. From Figure 5 it is so evident that feed rate has the most influence on surface roughness than cutting velocity and the interaction between the feed rate and cutting velocity has also a noteworthy influence on surface roughness, at maximum cutting velocity and minimum feed rate minimum surface roughness was observed. Similarly, Figure 6 depicts the outcome of cutting velocity and depth of cut on the mean surface roughness, where feed rate is kept constant. From Figure 6 it is evident that the depth of cut influences less on surface roughness than the cutting velocity, at a maximum depth of cut poor surface quality products, were obtained and Figure 7 depicts the outcome of feed rate and depth of cut on the mean surface roughness, where cutting velocity is kept constant. From Figure 7 it is evident that feed rate has the most influence on surface roughness and the depth of cut has the least influence on surface roughness.

Figure 8 depicts the outcome of cutting velocity and feed rate on flank wear, where the depth of cut is kept constant. From Figure 8 it is so evident that feed rate influence more on flank wear than cutting velocity; at maximum feed rate minimum flank wear was observed. Similarly, Figure 9 depicts the outcome of cutting velocity and depth of cut on the flank wear, where feed rate is kept constant. From Figure 9 it is obvious that the depth of cut more influence on flank wear and the cutting velocity has the least influence on flank wear, at maximum depth of cut the flank wear was also maximum and Figure 10 depicts the outcome of feed rate and depth of cut on flank wear, where cutting velocity is kept constant. From Figure 10 it is evident that the depth of cut has the most influence on flank wear and the interaction between the depth of cut and the feed rate has also a significant influence on flank wear.

IV. CONCLUSION

In this background, the study reported in this paper was surface roughness and flank wear test conducted during turning operation of AISI 3415 steel with TiAlN coated cutting tool insert in flooded coolant condition. The following conclusions were drawn out from the present examination;

i. The ANOVA and F-test of the experimented results exposed that the feed rate has a superior control on the mean surface roughness, subsequently by the cutting velocity and the feed rate and in the case of flank wear; it is the depth of cut has the most influence trail by feed rate and cutting velocity.

ii. Generalized mathematical models were developed through regression analysis using Minitab statistical software for the mean surface roughness and flank wear. From those equations, the mean surface roughness and flank wear values could be calculated if the factors namely feed rate, cutting velocity and depth of cut are known.

iii. The mathematical models obtained for surface roughness and flank wear was verified with the actual values and an average variation of 2.6% was observed in case of surface roughness and a minimal variation of 0.7% was observed in case of flank wear.

iv. From the experimentation it is clear that, at maximum cutting velocity of 325m/min, minimum feed rate of 0.1mm/rev and minimum depth of cut of 0.2mm, minimum surface roughness of 0.5153µm was achieved, minimum surface roughness is the sign of better quality machined components.

v. From the experimentation it is clear that, at maximum cutting velocity of 325m/min, maximum feed rate of 0.2mm/rev and maximum depth of cut of 0.6mm, maximum flank wear of 0.224mm was observed, increase in flank wear reduces the tool life, which reflects poorly in the production economy.

vi. The optimum turning conditions found in this research work can be used when AISI 3415 steel alloy are turned for the typical applications like mechanical gears, gear shaft, main axis, valve rods, connecting rods etc.

Nomenclature

v	Cutting velocity in m/min
f	Feed rate in mm/rev
d	Depth of cut in mm
TiAlN	Titanium Aluminium Nitride
R	Correlation coefficient
Mn	Manganese
C	Carbon
S	Sulphur
P	Phosphorus
Si	Silicon
Fe	Iron
^{0}C	Degree Celsius
cSt	Centistokes
PCLNR	ISO designation for tool holder
AISI	American Iron and Steel Institute
CNMG	ISO designation for tool

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