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A. Mohd[1*], M. H. L. Adnan[1], N. B. Baba[1], Z. A. Selamat[1], A. N. M. Rose[2], S. B. Mohamed[3]

[1]Faculty of Manufacturing Engineering Technology, University College TATI (UC TATI), Teluk Kalong, 24000 Chukai, Kemaman, Malaysia. Tel +60199142342, Email: aliasmohd@tatiuc.edu.my

[2]Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia. Tel. +0199150707, Email: nasser@ump.edu.my

[3]Faculty of Innovative Design and Technology. Universiti Sultan Zainal Abidin, 21300 Kuala Terengganu, Terengganu, Malaysia. Tel. +0199510808, Email: saiful@unisza.edu.my

Abstract. Numerous type of cutting tools has been developed continuously for use in metal cutting and the coated cemented carbides are the most popular in employing many machining strategies to improve machinability of alloy steel. This paper presents on analyze of surface roughness and tool wear on AISI 4140 alloy steel using CNC lathe machine at various machining parameters such as cutting speed, feed rate and depth of cut. Experiments were conducted using Response Surface Methodology (RSM) and the interactions of machining parameters were analyzed using Analysis of Variance (ANOVA) method. Results showed that the best surface roughness parameter for Ni-YSZ coated tool is at maximum cutting speed, feed rate is minimum and minimum depth of cut which representing 0.28 µm . Whereas, for the tool wear, the best parameter is at minimum cutting speed, minimum feed rate and minimum depth of cut for producing 0.892 µm.

1.0 Introduction

As the demand for high sensitivity of manufactured goods is rapidly increasing, the manufacturing industry is constantly struggle to reduce its cutting costs and increase the quality of components. The need for increased productivity, more difficult materials to be machined and higher volume quality improved by the manufacturing industry was the driving force behind the growth of cutting tool materials [1-3]. Single point cutting tools are used to process ferrous metal pieces that are usually hardened between (45–70 HRC) in hard turning [4]. This has been made possible by recent improvements in the rigidity of machine tools and the availability of modern cutting tool materials such as cubic boron nitride (CBN) and ceramics. The traditional method of treatment of hardened materials was heat treatment for rough turning [5-6].

Research by Mandal *et al.* (2012) investigated the machinability of AISI 4340 hardened Aluminum Zirconia (ZTA) steel inserts. The insert was prepared using the powder metallurgy process and the experiments were conducted using the Response Surface Methodology (RSM). The optimized conditions obtained a cutting speed of 420m/min, a feed rate of 0.12mm/rev and a cutting depth of 0.50mm give 81.83 percent desirability.

During the transition of superduplex stainless steel (SDSS)-Grade UNS S32750, commonly known as SAF 2507 [7], more research was conducted on wear mechanisms and tribological effectiveness of uncoated and coated carbide tools. The results showed that the wear mechanisms for all the tools investigated were adhesion and chipping and that the AlTiN coating device had better performance compared to the CVD TiCN + Al2O3 coated cutting insert and the uncoated carbide insert, with significantly reduced reliability in all respects, in particular the built-up edge shape. Isik, Y., (2010) studied dry cutting compared to liquid floods normally used in the TiC+AI2O3+TiN CVD-coated carbide insert (ISO P25). The material is a CVD coated carbide TiC+AI2O3+TiN cutting tool that is best performed in wet machining compared to a multilayer TiN / TiCN / Al2O3/TiN coated in AISI 4340 hard turning steel [10].

Chinchanikar *et al*. (2013) studied the effect of hardness of the working material and the cutting parameters on hardened steel AISI 4340 at various hardness levels. Multiple linear regression models have established associations between cutting parameters and performance metrics, such as cutting speed, surface roughness and tool life. The use of lower feed rate, lower cutting depth and limiting cutting speeds to 235m/min and 144m/min while turning 35HRC and 45HRC work material has been used to ensure better surface roughness and improved tool life. The comparison between the surface roughness criteria (*Ra*, *Rz* and *Rt*) of the wiper inserts with conventional inserts during hard turning of AISI 4140 hardened steel (60 HRC) were studied by Said Elbah *et, al*. (2013). The design of the experiments was based on the Taguchi orthogonal L27 array. The response surface methodology (RSM) and the variance analysis (ANOVA) were used to check the validity of the quadratic regression model and to evaluate the relevant surface roughness parameter. The results show that the surface quality obtained with the ceramic wiper insert improved significantly compared to conventional ceramics, which is the acceptable level of wear of 0.3 mm and the roughness of Ra did not exceed 0.9 μm. The goal of this research work is therefore to investigate the degree of surface roughness and tool wear and to optimize manufacturing machining parameters using coated and uncoated insert for machining AISI 4140 alloy steel.

2.0 Methodology

2.1 Selection of material, machine and cutting tool

AISI 4140 alloy steel as shown in Figure 1 is chosen as a workpiece material due to its excellent mechanical properties, such as strength, wear resistance and toughness. The surface of an alloy is treated for the improvement of surface properties i.e. fatigue strength. This process including surface coating, coating and heat treatment which used external energy to improves surface properties. The chemical compositions of alloy steel AISI D3 is shown in Table 1.

Figure 1: AISI 4140 Alloy Steel with diameter of 30.5 mm

Table 1: Chemical composition of AISI D3 steel

Std	Grade	C	Mn	P	S	Si	Cr	Mo
ASTM A29	4140	0.38 – 0.43	0.75 – 1.00	0.035	0.040	0.15 – 0.35	0.8 – 1.10	0.15 – 0.25

2.2 Machine and cutting tool selection

The machine used was CNC Lathe Daewoo Puma 230 with FANUC control with a fixed piece length tubeless steering wheel of Ø330x 500 mm and a bar passage of Ø65 mm. The tool used was cemented carbide with hard titanium-based particles as shown in Figure 2. The name cermet is a combination of ceramic and metal words. Originally, TIC and nickel composites are cermets. Whereas typical cermets are built in structure of titanium carbonitride Ti (C, N) core particles which is second phase (Ti, Nb, W) and W-rich cobalt binder and it is free of nickel. Ti (C, N) enhance wear resistance to the group, the second hard phase increases resistance to plastic deformation, and the amount of cobalt affects the strength. Relative to cemented carbide, cermets have improved wear resistance and reduced cracking patterns. It is also has lower compressive strength and thermal shock resistance. In addition, cermets can also be PVD-coated to improve wear resistance. The thickness of coating is 20 µm. The control machining parameters and the levels used in the experimental works are shown in the Table 2.

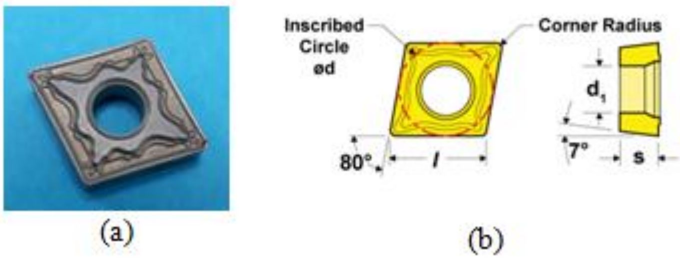


Figure 2: (a) Cermet Insert, (b) Schematic diagram of insert

Table 2**:** Machining parameters and levels

Machining Parameters	**Level**
Cutting speed (v) m/min.	75 – 210
Feed rate (f) mm/rev.	0.08 – 0.20
Depth of cut (d) mm	0.1 – 0.4

2.3 Central composite design (CCD)

A Central Composite Design (CCD) is an experimental design that applied in this research work. It is useful in response surface methodology (RSM) for constructing a second order (quadratic) response variable model without the need for a full three-level factor study. CCDs are very effective, providing a large amount of information on experimental variable effects and overall experimental error in a minimum number of necessary sequences. The CCDs are very versatile. The presence of several types of CCDs enables them to be used in a number of research regions of interest and operability.

3.0 Results and Discussion

According to ANOVA (P-Value), only the feed rate is significant for Ra. Machining parameters, such as cutting speed and feed rate, have a significant impact on tool wear. Tables 3 and 6 display the values of surface roughness and tool wear at different cutting speed, feed rate and cutting depth using coated and uncoated cemented carbide inserts.

3.1 Surface roughness

Figure 4 shows the 3D graph representing the surface roughness quality by the interaction of cutting speed and feed rate. The maximum surface roughness value of the CNC is the uncoated insert which representing 2.02 µm comparing to the coated insert giving 1.78 µm as shown in Table 3. The surface roughness was found to be the highest when the cutting speed and feed rate of the CNC lathes were set at a maximum of 210 m/min and 0.20 mm/rev for coated and uncoated inserts respectively.

This result revealed that the depth of the cut did not play a significant role in the effect of surface roughness. The roughness of the surface was significantly affected by the cutting speed and feed rate. For the minimum value for coated and uncoated insert represents 0.4 µm and 0.28 µm respectively.

The surface roughness value is minimal when the cutting speed is maximum (210 m/min) and the feed rate is minimum (0.08 mm/rev). The 3D graph (Figure 4) shows that the cutting speed and feed rate had a higher impact on the surface roughness than on the cutting depth. The cutting speed and feed rate have been found to have a positive effect on the surface roughness. Therefore, the Ni-YSZ coated tool can achieve the best surface finish compared to the uncoated tool.

Table 3: Values of surface roughness of the work pieces machined using carbide inserts

Std. Run Expt.	**Cutting speed, v (m/min)**	**Feed rate, f (mm/rev)**	**Depth of Cut, c (mm)**	**Surface roughness uncoated (µm)**	**Surface roughness coated (µm)**
1	210.00	0.08	0.10	0.40	0.28
2	75.00	0.20	0.40	1.12	0.88
3	210.00	0.08	0.40	0.84	0.62
4	75.00	0.08	0.10	0.86	0.68
5	142.50	0.14	0.25	0.96	0.74
6	210.00	0.20	0.10	1.52	1.34
7	142.50	0.08	0.25	0.85	0.63
8	210.00	0.20	0.40	2.02	1.78
9	142.50	0.20	0.25	1.62	1.40
10	142.50	0.14	0.40	1.10	0.82
11	75.00	0.14	0.25	0.94	0.76
12	142.50	0.14	0.25	0.83	0.65
13	142.50	0.14	0.25	0.96	0.76
14	75.00	0.08	0.40	0.48	0.40
15	142.50	0.14	0.25	0.97	0.75
16	75.00	0.20	0.10	1.62	1.54
17	142.50	0.14	0.10	0.92	0.86
18	142.50	0.14	0.25	0.86	0.62
19	210.00	0.14	0.25	0.85	0.66
20	142.50	0.14	0.25	0.84	0.64

Table 4 revealed the ANOVA analysis of the uncoated surface roughness insert. The model p-value of less than 0.0500 shows that the chosen model was significant. Meanwhile, for the quadratic model F-value of 48.71 shows that the experiment was significant. The p-value for the terms B, AB, AC and B^2 was < 0.0001, 0.0009, < 0.0001 and < 0.0001. The lack of fit F-value of 2.61 is not significantly related to the pure error. The term C (cutting depth) has no significant effect, but there has been a significant interaction between A (cutting speed) and B (feed rate) as shown in Table 4. Equation (1) shows quadratic models of uncoated surface roughness, given the coded factors below.

Table 4: ANOVA Analysis of Uncoated for Surface Roughness

Response 1 **SURFACE ROUGHNESS UNCOATED**
ANOVA for Response Surface Reduced Quadratic Model
Analysis of variance table (Partial sum of squares – Type III)

Source		Sum of squares	DF	Mean Square	F Value	Prob > F	Remarks
Model		2.57	6	0.43	48.71	< 0.0001	Significant
CUTTING SPEED	A	0.014	1	0.014	1.55	0.2345	
FEED RATE	B	1.79	1	1.79	203.15	<0.0001	
DEPTH OF CUT	C	0.023	1	0.023	2.62	0.1298	
	AB	0.16	1	0.16	18.44	0.0009	
	AC	0.31	1	0.31	35.43	<0.0001	
	B^2	0.27	1	0.27	31.08	<0.0001	
Residual		0.11	13	8.808E-003			
Lack of fit		0.092	8	0.012	2.61	0.1529	Not significant
Pure error		0.022	5	4.427E-003			
Cor Total		2.69	19				

Uncoated surface roughness = +0.92 + 0.037*A +0.42*B+ 0.048*C + 0.14*A*B + 0.20*A*C + 0.23* B2 (1)

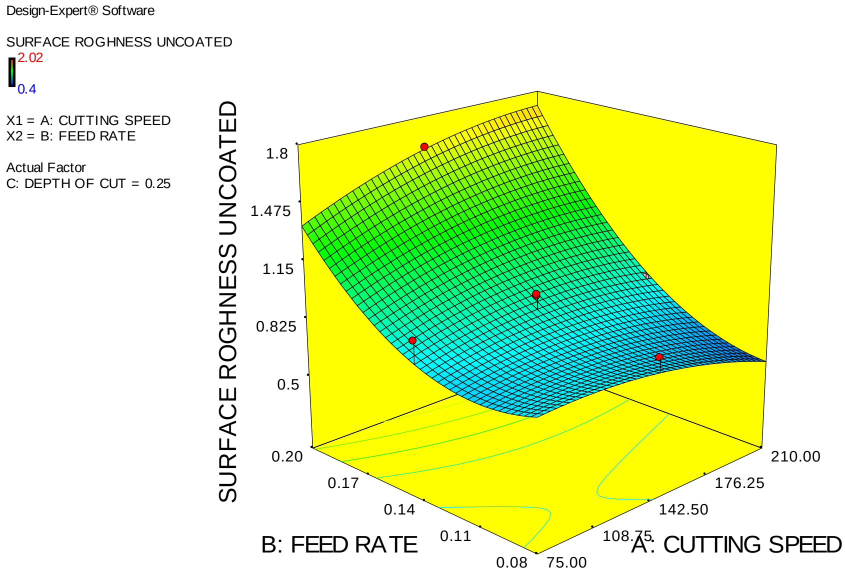
Table 5 shows the ANOVA result of the surface roughness coated insert. The model p-value of less than 0.0500 indicates that the selected models are significant. The quadratic model F-value of 35.73 shows that the experiment was significant. The p-value for the terms B, AB, AC and B^2 was < 0.0001, 0.0046, 0.0002 and 0.0002 respectively. The lack of an acceptable F-value of 4.10 is not significantly related to a pure mistake. The term C (cutting depth) has no significant effect, but there has been a significant interaction between A (cutting speed) and B (feed rate) as shown in Table 5. Equation (2) shows the quadratic models of the coated surface roughness in terms of the coded factors shown below.

Table 5: ANOVA Analysis of Coated for Surface Roughness

Response 2 **SURFACE ROUGHNESS UNCOATED**
ANOVA for Response Surface Reduced Quadratic Model
Analysis of variance table (Partial sum of squares – Type III)

Source		Sum of squares	DF	Mean Square	F Value	p-value Prob > F	Remarks
Model		2.49	6	0.41	35.73	< 0.0001	Significant
CUTTING SPEED	A	6.760E-003	1	6.760E- 003	0.58	0.4587	
FEED RATE	B	1.74	1	1.74	149.98	<0.0001	
DEPTH OF CUT	C	1.600E-004	1	6.760E-004	0.014	0.9083	
	AB	0.14	1	0.14	11.66	0.0046	
	AC	0.30	1	0.30	26.24	0.0002	
	B^2	0.30	1	0.30	25.89	0.0002	
Residual		0.15	13	0.012			
Lack of fit		0.13	8	0.016	4.10	0.0684	Not significant
Pure error		0.020	5	3.987E-003			
Cor Total		2.64	19				

Coated surface roughness = +0.73 + 0.026*A + 0.42*B-4.000E-003*C + 0.13*A*B + 0.20*A*C + 0.25*B2 (2)



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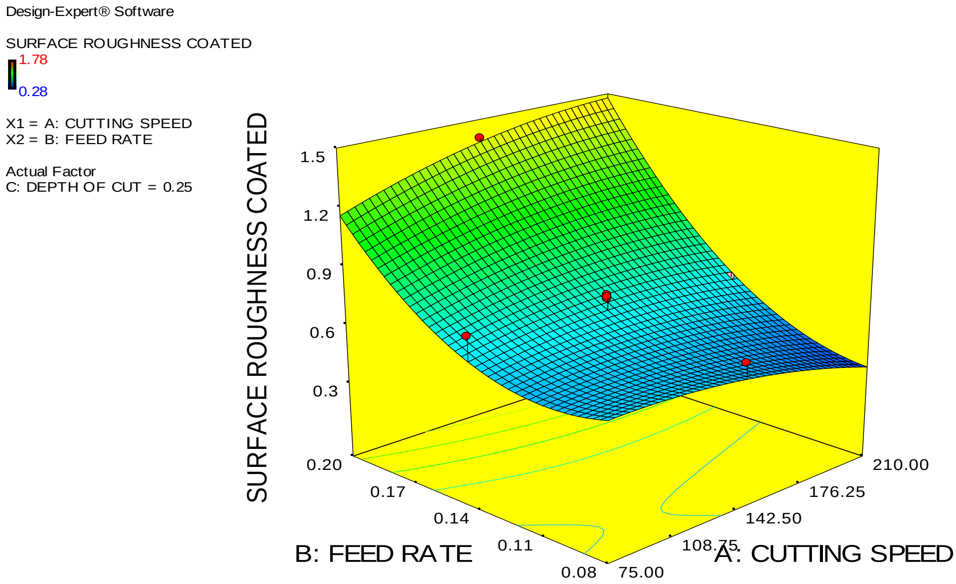


(b)

Figure 4: 3D Plot Effect Surface Roughness of Interaction between cutting speed and feed rate for (a) Uncoated insert and (b) coated insert.

3.2 Tool wear

Figure 5 shows the wear of cemented carbide inserts during the AISI 4140 tool steel turning process with changes in cutting speed, feed rate and cutting depth. Figure 6 displays the 3D graph showing the impact tool wear relationship between cutting rate and feed rate. Maximum value of the CNC machining parameters for uncoated insert is 1.287 mm and for coated insert is 1.194 mm as shown in Table 6.

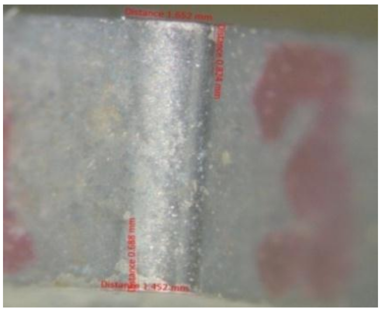


Figure 5: Tool wear measurement

The tool wear was found to be maximum for both inserts when the maximum cutting speed value (210 m/min) and the maximum feed rate value (0.20 mm/rev) of the CNC machining parameters are used. Change in cutting depth does not have a significant role to play in changing tool wear, but with a change in cutting speed and feed rate there is a significant change in tool wear. For the minimum value, coated tool is 0.984 mm and uncoated is 0.892 mm. Tool wear is minimum when cutting speed is minimum (75 m/min) and feed rate is minimum (0.08 mm/rev).

Table 6: Values of tool wear of the work pieces machined using carbide inserts

Std. Run Expt.	**Cutting speed, v (m/min)**	**Feed rate, f (mm/rev)**	**Depth of Cut, c (mm)**	**Tool wear uncoated (µm)**	**Tool wear coated (µm)**
1	210.00	0.08	0.10	1.202	1.104
2	75.00	0.20	0.40	1.032	0.932
3	210.00	0.08	0.40	1.213	1.119
4	75.00	0.08	0.10	0.984	0.892
5	142.50	0.14	0.25	1.146	1.061
6	210.00	0.20	0.10	1.252	1.134
7	142.50	0.08	0.25	1.126	1.048
8	210.00	0.20	0.40	1.287	1.194
9	142.50	0.20	0.25	1.167	1.098
10	142.50	0.14	0.40	1.159	1.088
11	75.00	0.14	0.25	1.042	0.945
12	142.50	0.14	0.25	1.179	1.096
13	142.50	0.14	0.25	1.166	1.082
14	75.00	0.08	0.40	1.025	0.926
15	142.50	0.14	0.25	1.169	1.086
16	75.00	0.20	0.10	1.054	0.958
17	142.50	0.14	0.10	1.132	1.044
18	142.50	0.14	0.25	1.154	1.075
19	210.00	0.14	0.25	1.248	1.128
20	142.50	0.14	0.25	1.171	1.092

When dry cutting process, easy-to-wear inserts do not induce a coolant to minimize friction and temperature and therefore reduce tool wear. Due to the high friction force between the insert and the material during the machining process, the high cutting speed and the high feed rate can easily affect the wear of the flank. The effect of poor surface finish and reduced accuracy of the finished part occurred when the insert worn out. The 3D graph (Figure 6) shows that the cutting speed and feed rate had a greater effect on tool wear than the cutting depth. It is observed that the cutting speed and feed rate had a positive effect on tool wear. The graph shows that the Ni-YSZ coated tool is good for minimizing tool wear compared to the uncoated tool.

The analysis of variance (ANOVA) of uncoated tool inserts for tool wear is shown in Table 7. Statistically, the quadratic model F-value of 47.28 suggests that the model was significant. The p-value is less than 0.0500, implying that the model is relevant. It can be seen that the term A and the term B of the model was significant. The p-value for the terms A and B was a significant factor of < 0.0001 and 0.0026. There was no significant factor for words C, AB, AC, and BC. The lack of fit F-value of 4.13 shows that the lack of fit is that it is not substantially compared to the pure error. The quadratic model of uncoated tool wear in terms of coded factors is given below from Equation (3).

Based on Table 8 for the coated tool wear insert, the F-value of the model was 117.12, which indicates that the model is significant. There is only a 0.17 % chance that such a large "Model F-Value" will occur due to noise. Values of Prob > F less than 0.0500 suggest that model terms are relevant. In this case, only the term A is a relevant model term. Values less than 0.1000 indicate that the model terms are not relevant. The p-value of the term A is a significant factor of 0.0002. The lack of fit F-value of 0.1.93 shows that the lack of fit is not significant in comparison to the pure error. Equation (4), the quadratic model of the coated tool wear is given below in terms of the coded factors.

Table 7: ANOVA Analysis of Uncoated for Tool Wear

Response 1 **TOOL WEAR UNCOATED**

ANOVA for Response Surface 2FI Model

Analysis of variance table (Partial sum of squares – Type III)

Source		Sum of squares	DF	Mean Square	F Value	Prob > F	Remarks
Model		0.12	6	0.020	47.28	< 0.0001	Significant
CUTTING SPEED	A	0.11	1	0.11	266.63	<0.0001	
FEED RATE	B	5.856E-003	1	5.856E-003	13.77	0.0026	
DEPTH OF CUT	C	8.464E-004	1	8.464E-004	1.99	0.1819	
	AB	2.761E-004	1	2.761E-004	0.65	0.4349	
	AC	9.113E-005	1	9.113E-005	0.21	0.6511	
	BC	1.901E-004	1	1.901E-004	0.45	0.5155	
Residual		5.530E-003	13	4.254E-004			
Lack of fit		4.803E-003	8	6.004E-004	4.13	0.0675	Not significant
Pure error		7.268E-004	5	1.454E-004			
Cor Total		0.13	19				

Tool wear uncoated=+1.16+0.11*A + 0.024*B + 9.200E-003*C + 5.875E-003*A*B + 3.375E-003*A*C - 4.875E - 003*B*C - 0.015*A^2 - 0.013*B^2 (3)

Table 8: ANOVA Analysis of Coated for Tool Wear

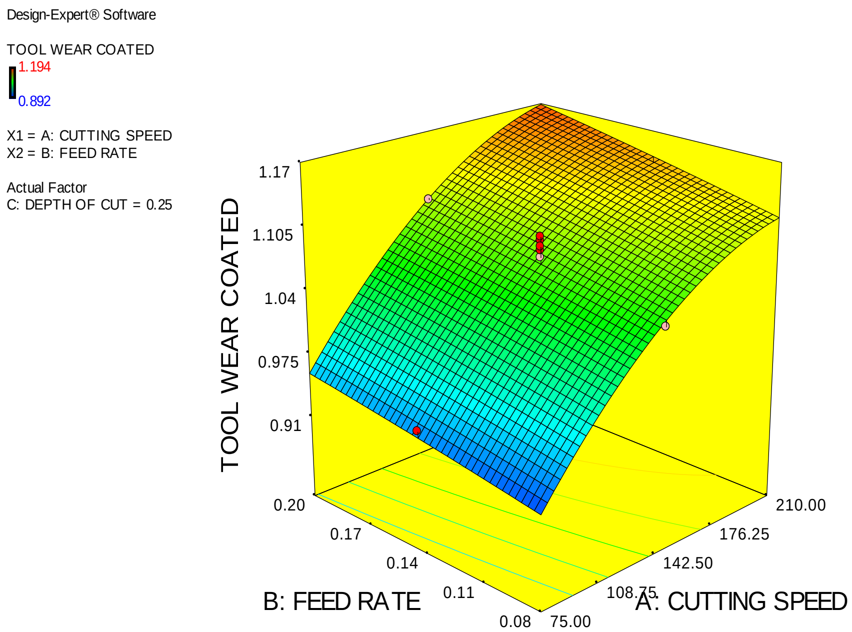
Response 2 **TOOL WEAR COATED**

ANOVA for Response Surface Reduced Quadratic Model

Analysis of variance table (Partial sum of squares – Type III)

Source		**Sum of squares**	**DF**	**Mean Square**	**F Value**	**p-value Prob > F**	**Remarks**
Model		0.12	4	0.030	117.12	< 0.0001	Significant
CUTTING SPEED	A	0.11	1	0.11	405.48	<0.0001	
FEED RATE	B	5.153E-003	1	5.153E-003	19.85	0.0005	
DEPTH OF CUT	C	1.613E-003	1	1.613 -003	6.21	0.0249	
	A^2	9.592E-003	1	9.592E-003	36.95	<0.0001	
Residual		3.894E-003	15	2.596E-004			
Lack of fit		3.092E-003	10	3.092E-004	1.93	0.2428	Not significant
Pure error		8.020E-004	5	1.604E-004			
Cor Total		0.13	19				

Tool wear coated = +1.08+0.10*A + 0.023*B+0.013*C +4.125E-003*A*B + 8.375E-003*A*C - 1.875E-003 *B*C - 0.038*A^2 - 1.409E-003*B^2 - 8.409E-003*C^2 (4)



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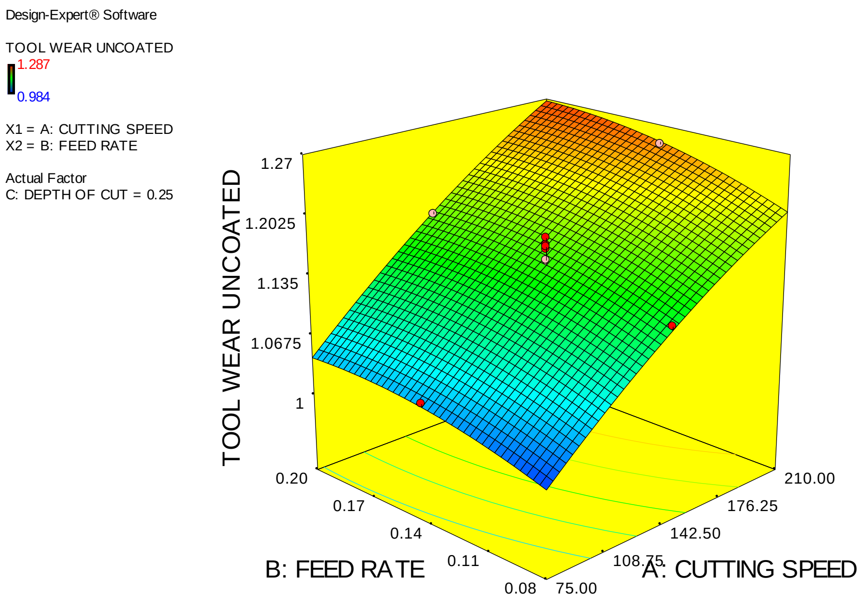

(b)

Figure 6: 3 D Plot Effect Tool Wear of Interaction between cutting speed and feed rate for (a) uncoated insert and (b) coated insert.

4. Conclusion

In this study, the effects of the coated cemented tool with Ni-YSZ coated and uncoated machining tool AISI 4140 Alloy Steel was investigated using selected machining parameters, namely cutting speed, feed rate and cutting depth. The following conclusions are drawn on the basis of the experimental work:

i. The best surface roughness parameter for Ni-YSZ coated tool is the maximum cutting speed (210 m/min), the feed rate is the minimum (0.08 mm/rev) and the minimum cutting depth (0.10 mm) producing the surface roughness value of 0.28 µm.
ii. For tool wear, it is recommended that the machining parameters be carried out at a minimum cutting speed (75 m/min), a minimum feed rate (0.08 mm/rev) and a minimum cutting depth (0.10mm) in order to produce a total tool wear of 0.892 mm.

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