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Experimental Investigation of the Effect of Feed Rate and Negative Tool Rake Angle in High Speed Hard Turning

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ABSTRACT

The aim of this paper is to study experimentally the influence of feed rate and negative tool rake angle on surface roughness and flank wear length during high speed hard turning. AISI 4340 was used as work piece material. This steel is hardened to 60 HRC, machined by a mixed ceramic tool (Al_2O_3-TiC). The experiment was obtained with constant cutting depth (0.15 mm), constant cutting speed (325 m/min), four different feed rates (0.075 – 0.15 mm/rev) and three different tool rake angles (0^o, -6, -12^o). The experimental results showed that roughness has an increasing trend with the increasing of the feed rate. In contrast, the roughness has a decreasing trend as the rake angle increases in the negative direction from (0^o) to (-12^o). The flanks wear length also affected by the feed rate increasing. Finally in order to identify statistically significant trends in the measured parameters and cutting parameters data i.e. feed rate and rake angle, an analysis of variance (ANOVA) was conducted. By using DOE an optimization solution was obtained.

Keywords: **high speed hard turning, feed rate, negative rake angle.**

1. Introduction

Hardened steels are machined by grinding process in general, but grinding operations are time consuming and are limited to the range of geometries to be produced (Sahin, 2009). The developments of new cutting tools such as ceramics and CBN have led to the use of higher cutting speeds compare with conventional machining. High speed cutting reduces machining costs by increasing production rate. Furthermore, the possibility to turn hardened steels without the use of cutting fluids is considered to be of significant importance (Benga and Abrao 2003). However, high speed cutting leads to the rapid wear of cutting tools, which is caused by the high temperatures generated at the cutting zone and as a result tool life decreases (Diniz and Oliveria, 2008). The effect of increased feed is more complicated. In terms of increasing the volume of material removed with a tool life (or cutting length), but increasing the feed had a detrimental effect on tool life and increase the flank wear rate.

Flank wear has been commonly used to study the effect of tool wear on surface roughness of workpiece because it develops in all machining operations (Manna and Bhattacharayya, 2005). Wear occurs mostly on the flank face, thus flank wear was chosen to define the tool life. The wear development during machining can reach unacceptable levels very fast resulting in a poor surface finish (Ozel and Nadgir, 2002). Flank wear is the main tool life criteria defined in the ISO 3685 standard (ISO 3685, 1993). According to the standard, a tool is considered to have reached its life if the maximum width of flank wear land (VB max) is 0.6 mm when the flank wear is not regularly worn. If the flank wear land is regularly worn, the criterion for tool life is the average width of flank wear (VBB) equal to 0.3 mm. The failure of the cutting tool happens due to different wear mechanisms. Davim (2008) concluded the general mechanisms that cause tool wear are: abrasion, adhesion, diffusion, fatigue and oxidation. Among the different types of wear, abrasive wear, adhesive wear and diffusive wear are very important.

In this research the influence of increasing the feed rate with negative rake angle on the flank wear and roughness, in turning hard materials in high cutting speed was studied experimentally. The results have been analyzed statistically by using the DOE software 8.0.0.6. New models have been developed for predicting the flank wear length and the surface roughness. An optimization by using the desirability function method has been conducted. Figure 1 shows the research methodology in details.

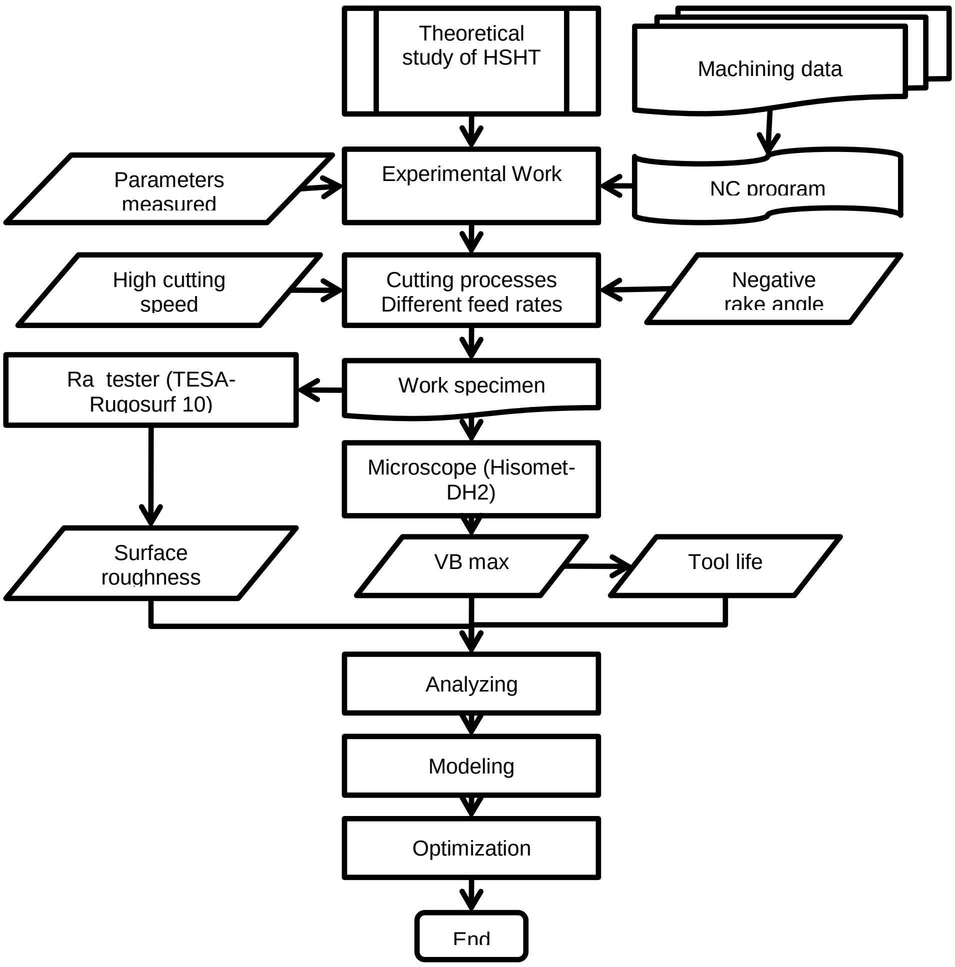


Figure 1 research methodology

2. Experiment work

AISI 4340 (hardened to 60 HRC) was used as work piece material. This steel is machined by a mixed ceramic tool of chemical composition 70%Al_2O_3+30%TiC. Totally 120 experiments were performed in order to measure the flank wear length, and roughness. The experiments were obtained with dry cutting, constant cutting depth (0.15 mm), constant cutting speed (325 m/min) four levels of feed rate (0.075-0.15mm), and three different tool rake angles (0^o ,-6 and -12^0).

1. Measured parameters: Roughness and Flank wear
2. Instruments: the instruments that are used in the experiment were as the following; CNC turning machine (Romi- Bridgeport 2), Microscope picture (Motic digital microscope), Microscope wear rate (Hisomet-DH2) and Roughness tester (TESA-Rugosurf 10).
3. Experiment design: The experiment was obtained with constant cutting depth (0.15 mm), constant cutting speed (325 m/min), four different feed rates (0.075 – 0.15 mm/rev) and three different tool rake angles(0^o ,-6 -12^0).

2.1 Roughness measurement

The roughness was measured by using the Roughness tester (TESA-Rugosurf 10). The value of the roughness was measured in each cutting for five different positions. An average surface roughness (Ra) on the machined surface was measured perpendicular to the feed marks after every cut. The instrument was calibrated for each set of experimental results for consistency and accuracy. Fig.1 (a, b, c and d) show the effect of different feeding rate and rake angle to the roughness.

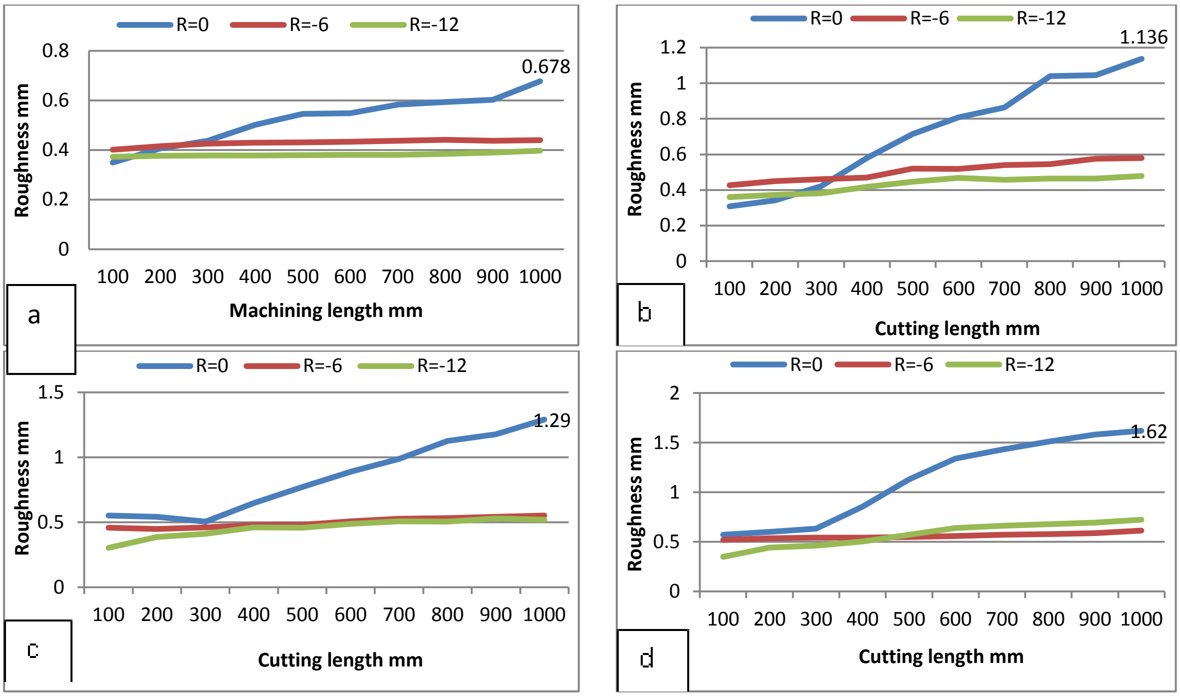


Fig.1: roughness with different rake angle: (a) feed rate =0.075 mm/rev (b) feed rate=0.1 mm/rev, feed rate=0.125 mm/rev, (d) feed rate =0.15 mm/rev

There are slightly different in the roughness in the range of 0-300 mm of machining, however after 300 mm, the roughness increase rapidly in zero rake angle, in contrast the roughness on -6 and -12 is smooth and stable.

2.2 Flank wear measurements

Flank wear length of the tool wear was measured using Hisomet II tool maker microscope of model DH II 3178 during the tool life experiment. This microscope is non contact measuring microscope. The flank wear was measured after each passes (100mm) so the total was ten values during each rake angle. Fig (2) shows the flank wear length for the cutting tool in three different rake angles in four different feeding rates.

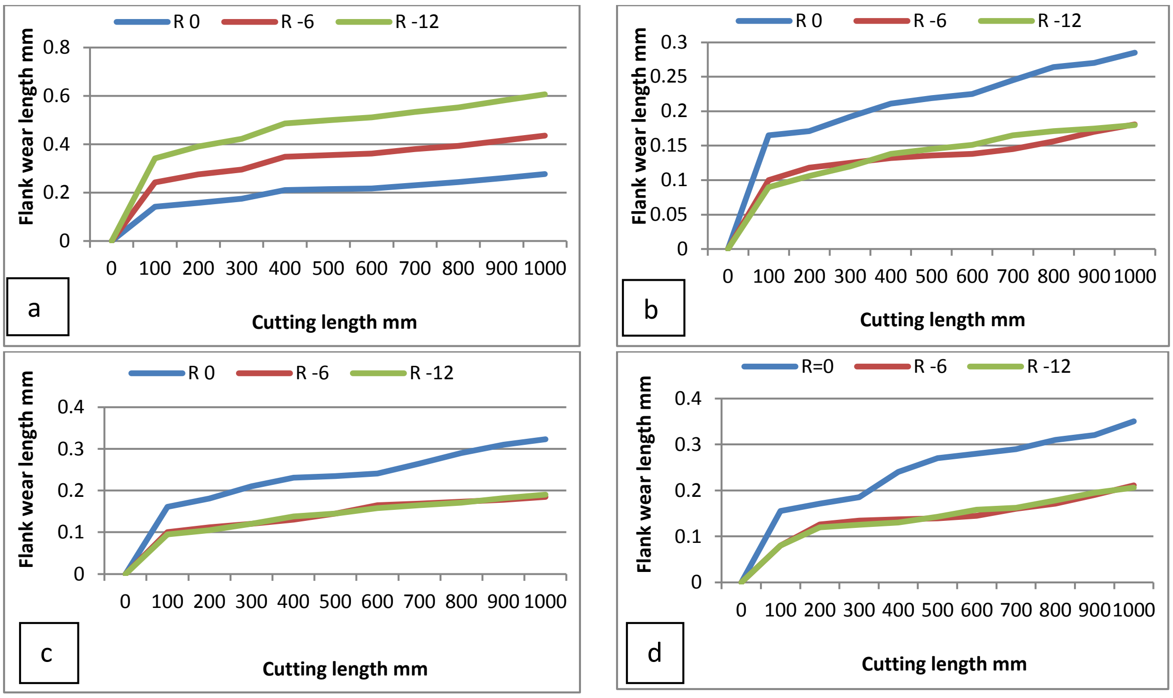
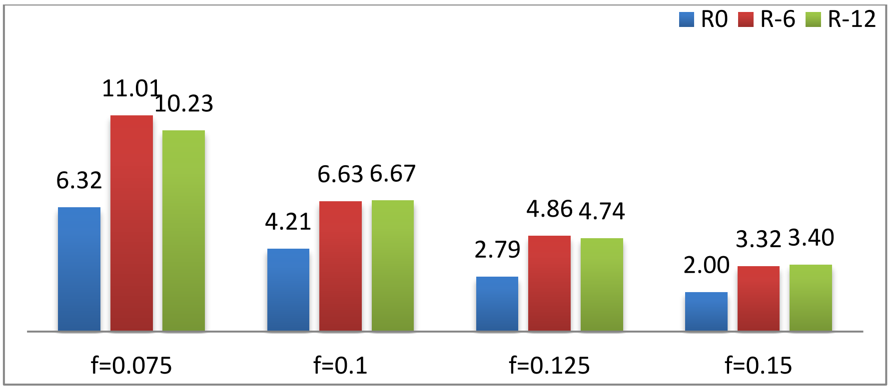


Fig 2 Flank wears length (a) feed rate =0.075 mm/rev (b) feed rate=0.1 mm/rev, feed rate=0.125 mm/rev, (d) feed rate =0.15 mm/rev

Fig 2 shows that the flank wear in zero rake angles is higher than in-6 and -12 rake angle.

2.3 Tool life estimation

The wear rate is increased with the time, and then the tool life will be $\Delta Vb = r_w \Delta t$ then $L = VB/r_w$ where ΔVb the increment of flank wear, r_w is the wear rate increase, Δt is the cutting time, Vb is the limited flank length allowed and L is the tool life. Fig 3 shows the tool life estimation in max Vb $_{max}$ =0.3 mm with three different rake angles (0, -6, and -12) and four different feed rate.



R: rake angle (degree), f: feed rate (mm/rev)

Figure 3: tool life (min) constant cutting depth (0.15 mm), constant cutting speed (325 m/min)

Fig 3 shows the different tool life in different rake angle and feed rate. The tool life in the zero rake angles is lower than the tool life in the negative rake angle. it was also mentioned that the lower feed rate gave higher tool life.

Analysis of variance

The analysis of variance (ANOVA) is a statistical method of decomposing in different components the variance of a response variable (Montgomery et al., 2004). The analysis of variance (ANOVA) was employed to analyze the effect of negative rake angle in high cutting speed on the surface roughness and tool life. The ANOVA output and the calculated F-ratios are shown in Table 4 for each significant effect. It was selected the 0.05 level for testing the significance of the main effects. The analysis of variance revealed a significant difference in all these parameters. Tables 1 and 2 show the ANOVA analysis. It can be observed that feed rate was the most significant parameter affecting surface roughness, as expected from theory.

Table 1: ANOVA table for surface roughness

Response		Ra				
	Sum of		Mean	F	p-value	
Source	Squares	Df	Square	Value	Prob > F	
Model	7.430782	7	1.06154	99.4051	< 0.0001	significant
A-Machining length	0.209575	1	0.209575	19.62512	< 0.0001	
B-Feed rate	1.404094	1	1.404094	131.4826	< 0.0001	
C-Rake angle	0.286183	1	0.286183	26.79883	< 0.0001	
AB	0.268859	1	0.268859	25.17659	< 0.0001	
AC	0.827627	1	0.827627	77.50094	< 0.0001	
BC	0.445696	1	0.445696	41.73605	< 0.0001	
C^2	0.481788	1	0.481788	45.11576	< 0.0001	
Residual	1.19604	112	0.010679			
Cor Total	8.626823	119				

Table 2: ANOVA table for the flank wear length

Response	1	VB				
	Sum of		Mean	F	p-value	
Source	Squares	Df	Square	Value	Prob > F	
Model	0.38093	8	0.047616	457.5281	< 0.0001	significant
A-Machining length	0.037919	1	0.037919	364.3476	< 0.0001	
B-Feed rate	0.008091	1	0.008091	77.74249	< 0.0001	
C-Rake angle	0.047564	1	0.047564	457.0236	< 0.0001	
AB	0.005122	1	0.005122	49.21912	< 0.0001	
AC	0.007414	1	0.007414	71.23423	< 0.0001	
BC	0.00407	1	0.00407	39.11144	< 0.0001	
A^2	0.00084	1	0.00084	8.07548	0.0053	
C^2	0.058151	1	0.058151	558.7512	< 0.0001	
Residual	0.011552	111	0.000104			
Cor Total	0.392482	119				

Table 3 concluded the Statistical analysis results;

Table 3: Statistical analysis results

	Surface roughness	Flank wear
R-Squared	0.861358	0.970567
Adj R-Squared	0.852693	0.968445
Pred R-Squared	0.837816	0.964761
Adeq Precision	45.70746	89.41255

Figure 4 and Figure 5 show the effect of feed rate and negative rake angle in three dimentions on the roughness and the flank wear respectiviely

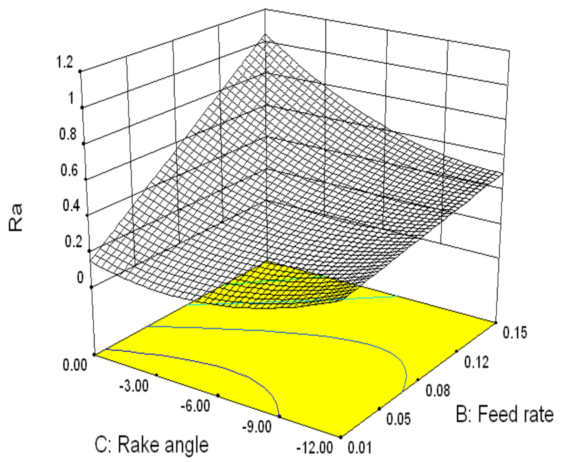


Figure 4: 3D surface roughness

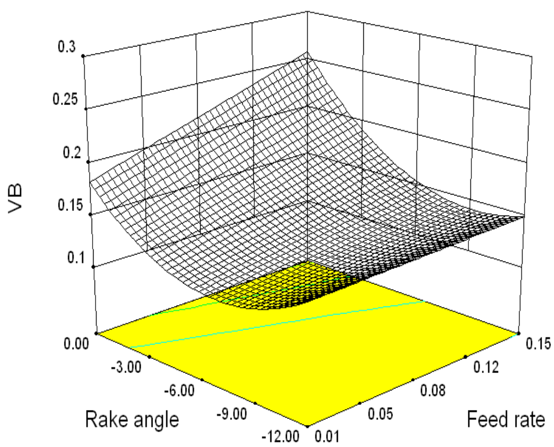


Figure 5: 3D flank wear length relationship

The perturbation plots are generated by software to recognize the effect of each factor on the measured parameters. Figure 6 and Figure 7 show the perturbation plot of the surface roughness and flank wear length

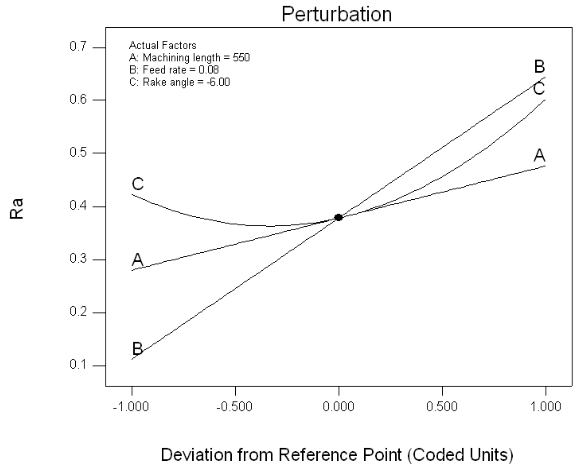


Figure 6: perturbation plot of the surface roughness

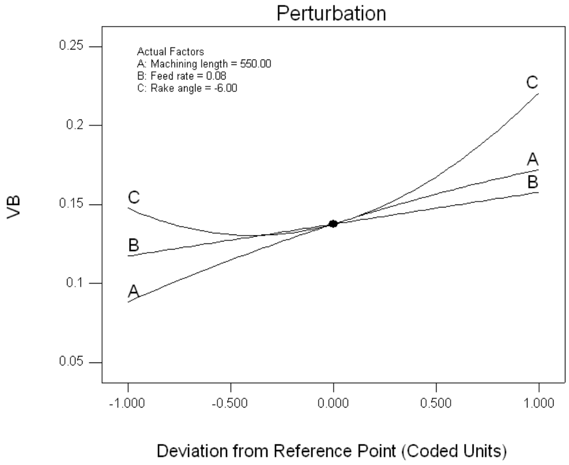


Figure 7: perturbation plot of the flank wear length

Figure 6 shows that the feed rate is the most significant factor on the surface roughness, increasing the negative direction of rake angle, is slightly increased the surface roughness. Figure 7 shows that all factors have a negative effect on the flank wear length. Increasing the feed rate and negative rake angle increase the flank wear. However, the cutting speed is the most significant factor on the flank wear followed by the feed rate, while the rake angle reduces the flank wear until a specific point then starts to increase.

Analysis and discussion

The results of the experiment work show that;

1. The roughness in zero rake angle after 300 mm of the cutting length starts to increase as shown in fig 1(a, b, c and d). This is due to the increasing of the flank wear length as shown if fig 2(a, b, c and d), because when the flak wear increase the radius of the cutting tool will increase so according to the formula $R_a = f^2/32r$.
2. The roughness is increasing with the increasing of feed rate as expected from the theory as shown in fig 1(a, b, c and d).
3. The flank wear length is decreasing in negative rake angle as shown in fig 2 because of the initial shock of work to tool is on the face of the tool and not on the point or edge, this will lead to increasing the life of the cutting tool (fig 3).

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