Effect of the Side Cutting–Edge Angle on the Surface Roughness for Aluminum 1350 in the Turning Operation by Taguchi Method

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ABSTRACT
The purpose of this work was to analyze the effect of the side cutting-edge angle on the surface roughness of aluminum 1350 in a turning operation. A Taguchi design L32 was used in this work; the control variables were spindle speed, feed rate, depth of cutting and the side cutting-edge angle. Several metal cutting experiments and statistical tests provide evidence that the side cutting-edge angle significantly affects the surface roughness with a Statistical F equal to 24.96, mainly, when the side cutting-edge angle is maintained at high level; in this study, the high level was kept to 5.0 degrees. Also, when the high level condition is kept, it causes a major variation of the residual values; consequently, the surface roughness of the workpiece falls out of the specifications demanded by customers. Moreover, the best combination of the cutting parameters for a minimum surface roughness equal to 23.5 µin was obtained. Finally, further research directions are presented.

Keywords: Side cutting-edge angle, Taguchi method, surface roughness

RESUMEN
El propósito de este trabajo fue analizar el efecto del ángulo de corte de la herramienta sobre la rugosidad superficial del aluminio 1350 en la operación de torneado. Se uso un diseño Taguchi L32 en este trabajo; las variables de control fueron velocidad del husillo, tasa de alimentación, profundidad de corte y el ángulo de corte de la herramienta. Los experimentos y pruebas estadísticas realizadas mostraron que con una F estadística igual a 24.96, el ángulo de la herramienta de corte afecta significativamente la rugosidad superficial, principalmente, cuando el ángulo de corte se mantiene a un nivel alto; en este estudio, el nivel se mantuvo a 5 grados. Además, cuando esta condición se mantiene, causa una mayor variación en los residuales; consecuentemente, la textura de la pieza de trabajo cae fuera de la especificación demandada por el cliente. Adicionalmente, se obtuvo la mejor combinación de los parámetros de corte para una mínima rugosidad superficial igual a 23.5 µin. Finalmente, se hacen algunas recomendaciones para futuras investigaciones.

1. Introduction

Surface roughness is a performance indicator of the machining processes that has received great attention during the last year. It is sometimes a design feature as important as fatigue loads, precision fits and aesthetic requirements [1]. A mathematical model traditionally used in the text books is given in Equation 1:

$$R_i = \frac{f^2}{32r} \qquad (1)$$

This model explains how the feed rate f and the nose radii of the cutting tool r affect the surface roughness **Ri**. However, it is important to consider other factors that, according to experts, significantly affect the surface roughness. A considerable quantity of investigations have been done considering other cutting parameters such as cutting speed, feed rate, depth of cutting and cutting tool geometry. Table 1 shows some works found in the literature.

Author	Control Parameters	Significant Parameters	Operation
[2] Nalbant et al.	Feed rate, depth of cut and cutting tool geometry	Feed rate and cutting tool nose	Turning
[3] Zhang et al.	Spindle speed, feed rate and cutting speed, **Noise factors**: Temperature and cutting tool wear	Spindle speed, feed rate and cutting tool wear	Milling
[4] Mohamed et al.	Cutting speed, feed rate and depth of cut	Feed rate and depth of cut	Turning
[5] Ghani et al.	Cutting speed, feed rate and depth of cut	Cutting speed, feed rate and depth of cut	Milling
[6] Puertas et al.	Cutting speed, feed rate and depth of cut	Feed rate and depth of cut	Turning
[7] P. G. Benardos & G.C. Vaniakos	Cutting speed, feed rate, depth of cut, forces, cutting tool Wear and Cutting Fluid	Feed rate, forces, depth of cut and cutting fluid	Milling
[8] Darwish	Workpiece hardness, feed rate and depth of cut	Feed rate and depth of cut	Turning
[9] Beauchamp et al.	Cutting speed, feed rate, depth of cut , radii of the cutting tool nose, long of the cutting tool and long of the work piece	Feed rate, radii of the cutting tool nose and interaction between feed rate and cutting speed.	Turning
[10] Alauddin et al.	Cutting speed, feed rate and depth of cut	Cutting speed and feed rate	Milling

Table 1. Parameters of the numerical example

Table 1 shows some works related with the study of cutting parameters such as cutting speed, feed rate, depth of cut, cutting tool geometry and other variables on the surface roughness. However, the effect of the side cutting-edge angle on the surface roughness has not been considered widely by experts and according to machinist, when the square turret is rotated to one side cutting-edge angle, the imperfect nose geometry of the cutting tool affects the roughness surface when it touches the workpiece. On the other hand, Kalpakjian [11] claims that the side cutting-edge angle affects chip formation, tool strength, and cutting forces. Nevertheless, it is important to mention that the side cutting-edge angle can significantly affect the surface roughness mainly when the workpiece is machined in a conventional lathe using a high side cutting-edge angle. Figure 1 outlines the main parts of a conventional lathe. On the other hand, Figure 2 shows the parts of the cutting tool and the location of the side cutting-edge angle in the turning operation.

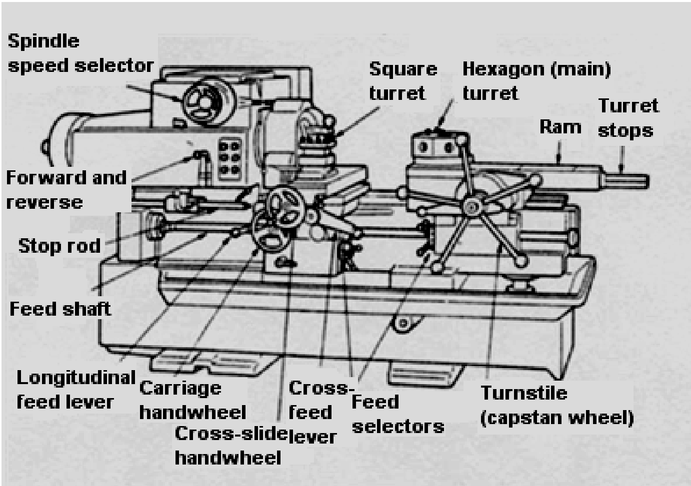

Figure 1. Parts of the Conventional.

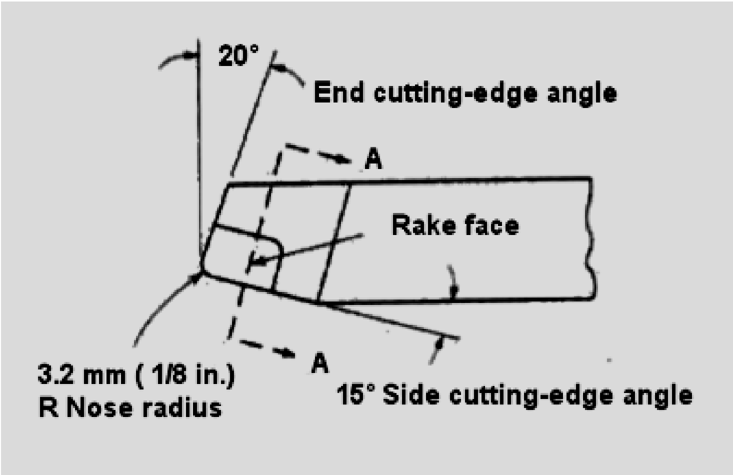

Figure 2. Parts of the Cutting Tool.

In order to analyze the effect of the side cutting-edge angle on the surface roughness, an experimental Taguchi design was used.

2. Methodology

Given that aluminum is a material with good quality mechanics, very common also in the machine-tool industry, this experimental work was carried out on specimens of Aluminum 1350 using a conventional lathe; Table 2 describes the chemical composition of aluminum.

In order to analyze the effect of the side cutting-edge angle on the surface roughness, a Taguchi design L32 with two replicates was used. The control variables were spindle speed, feed rate, depth of cut and major side cutting-edge angle, while the surface roughness was the response variable. Table 3 shows the levels of the variables used in the experiment.

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	V
1350	0.10	0.40	0.05	0.01	-	0.01	0.05	0.02+Ti	

Table 2. Chemical Composition of Aluminum 1350.

Control Variables	Low	High
Coding	1	2
Spindle speed (rpm)	625	950
Feed rate (in/min)	1.6	3.0
Depth of cut (in)	.0156	.1250
Side cutting-edge angle (degrees)	0	5.0

Table 3. Levels of the Variables Used in the Experiment.

On the other hand, the results of the experimental run are given in Table 4:

Spindle speed	Feed rate	Depth of cut	Side cutting-edge angle	Surface roughness (µin)
1	1	1	1	29.25
1	1	1	1	22.75
1	1	1	2	21.75
1	1	1	2	30.75
1	1	2	1	33.50
1	1	2	1	28.75
1	1	2	2	27.50
1	1	2	2	33.25
1	2	1	1	41.75
1	2	1	1	34.50
1	2	1	2	68.75
1	2	1	2	48.25
1	2	2	1	35.00
1	2	2	1	37.25
1	2	2	2	48.00
1	2	2	2	52.75
2	1	1	1	22.50
2	1	1	1	24.50
2	1	1	2	24.50
2	1	1	2	29.00
2	1	2	1	32.75
2	1	2	1	35.75
2	1	2	2	29.75
2	1	2	2	33.25
2	2	1	1	33.00
2	2	1	1	29.50
2	2	1	2	33.75
2	2	1	2	46.00
2	2	2	1	33.50
2	2	2	1	34.00
2	2	2	2	42.50
2	2	2	2	42.75

Table 4. Results of the Experimental Run

In this way, 32 experiments were carried out with different combinations; each treatment was run randomly, the control variables were coded; thus, 2 indicated high level and 1 indicated low level. The surface roughness was measured using a stylus profilometer MITUTOYO model SURSTEST.301 and the arithmetic mean R_a was the measurement method used in the study; the reason for using this measurement method is its industrial usefulness.

3. Data analysis

Table 5 shows the analysis of variance for means. This analysis is used to determine the factors that significantly affect the surface roughness.

According to the data from ANOVA, with a confidence level equal to 90% and a P<0.10, the parameters and interactions that significantly affect the surface roughness are spindle speed, feed rate, side cutting-edge angle.

The interactions are spindle speed*feed rate, feed rate*side cutting-edge angle, feed rate*depth of cut and spindle speed*depth of cut.

Table 6 shows the analysis of variance for SN ratios.

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
SPINDLE SPEED	1	69.62	69.62	69.618	10.23	0.024
FEED RATE	1	635.99	635.99	635.985	93.47	0.000
DEPTH OF CUT	1	24.69	24.69	24.688	3.63	0.115
SIDE OF CUTTING EDGE ANGLE	1	169.81	169.81	169.813	24.96	0.004
SPINDLE SPEED*FEED RATE	1	89.66	89.66	89.657	13.18	0.015
SPINDLE SPEED*DEPTH OF CUT	1	29.23	29.23	29.228	4.30	0.093
SPINDLE SPEED* SIDE OF CUTTING EDGE ANGLE	1	16.25	16.25	16.251	2.39	0.183
FEED RATE*DEPTH OF CUT	1	54.85	54.85	54.853	8.06	0.036
FEED RATE*SIDE OF CUTTING EDGE ANGLE	1	169.81	169.81	169.813	24.96	0.004
DEPTH OF CUT* SIDE OF CUTTING EDGE ANGLE	1	10.36	10.36	10.360	1.52	0.272
Residual Error	21	34.02	34.02	6.804		
Total	31	1304.29				

Table 5. Analysis of Variance for Means.

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
SPINDLE SPEED	1	3.0027	3.0027	3.0027	14.19	0.013
FEED RATE	1	37.2036	37.2036	37.2036	175.83	0.000
DEPTH OF CUT	1	2.7108	2.7108	2.7108	12.81	0.016
SIDE OF CUTTING EDGE ANGLE	1	7.9894	7.9894	7.9894	37.76	0.002
SPINDLE SPEED*FEED RATE	1	3.4252	3.4252	3.4252	16.19	0.010
SPINDLE SPEED*DEPTH OF CUT	1	1.5814	1.5814	1.5814	7.47	0.041
SPINDLE SPEED* SIDE OF CUTTING EDGE ANGLE	1	0.2474	0.2474	0.2474	1.17	0.329
FEED RATE*DEPTH OF CUT	1	4.1681	4.1681	4.1681	19.70	0.007
FEED RATE*SIDE OF CUTTING EDGE ANGLE	1	6.9800	6.9800	6.9800	32.99	0.002
DEPTH OF CUT* SIDE OF CUTTING EDGE ANGLE	1	0.6824	0.6824	0.6824	3.23	0.132
Residual Error	21	1.0579	1.0579	0.2116		
Total	31	69.0489				

Table 6. Analysis of Variance for SN ratios.

The signal-noise (S/N) ratio is treated as a response of the experiment, which is a measure of the variation within a trial under noise factors and it contributes to reduce the variation within a trial. Therefore, in this experiment, the variables spindle speed, feed rate, depth of cut, side of cutting-edge angle and the interactions spindle speed*feed rate, spindle speed *depth of cut, feed rate*depth of cut and feed rate*side of cutting-edge angle are sources of variation. In addition, the machinist must carefully choose these cutting parameters or face an unacceptable finished surface.

Given that the purpose of this study is related to the effect of the side cutting-edge angle on the surface roughness, the following statistical analysis was done with respect to this cutting parameter. Figure 3 outlines the surface roughness behavior under two levels of side cutting-edge angles; therefore, Figure 3 indicates that there is a higher surface roughness when a workpiece is machined using a high side cutting-edge angle than when is machined with a low side cutting-edge angle. This behavior could be due to the vibration of the machine when it is used to high side cutting-edge angle during the turning process.

Figure 4 outlines the residual behavior of the data versus the side cutting- edge angle under two levels of side cutting-edge angles.

According to Figure 4, the variation of the residual values is most noteworthy at high side cutting-edge angles; therefore, under this machining condition, it is very probable that some machined parts will fall out of the specifications demanded by customers and, consequently, will be rejected. This is due to the wide variation caused by the high side cutting-edge angle. On the other hand, the interaction between feed rate*side cutting-edge angle significantly affects the surface roughness when the feed rate and the side cutting-edge angle are kept at high level. This is due to the vibration caused by the forces generated at high levels during the cutting process.

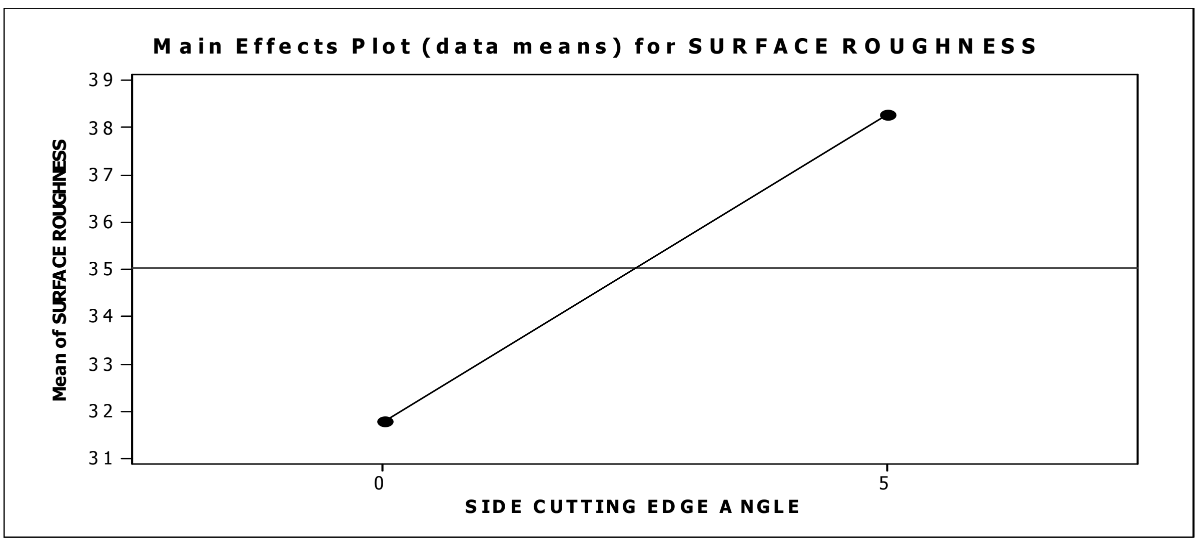

Figure 3. Side Cutting-Edge Angle Effect Plot for Surface Roughness.

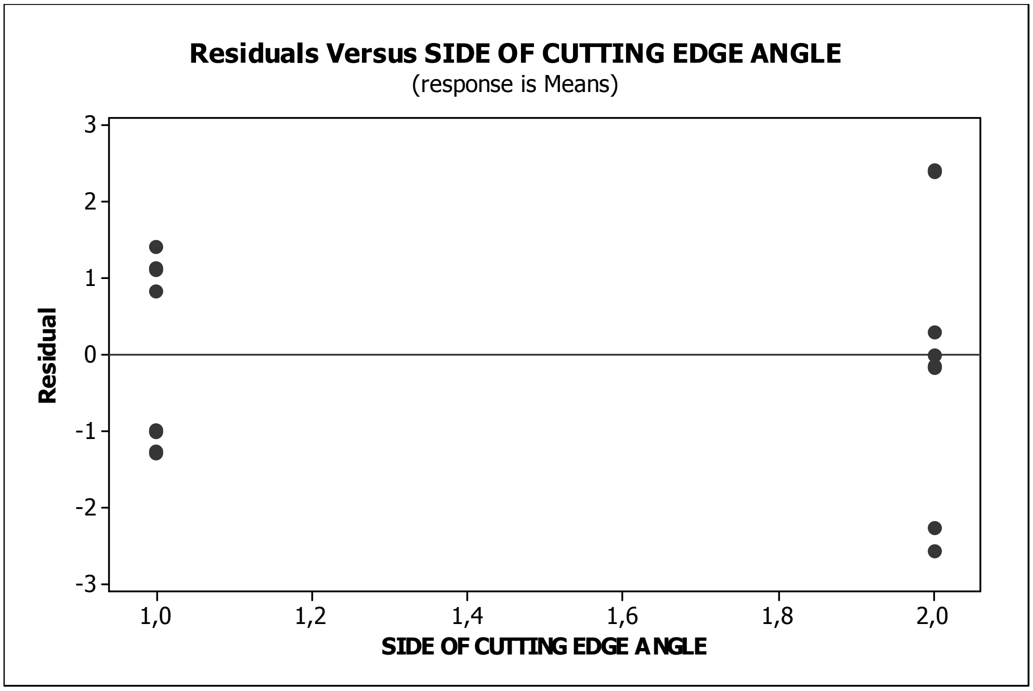

Figure 4. Residual vs Side Cutting-Edge Angle.

Figure 5 outlines the interaction plot of cutting parameters on the surface roughness.

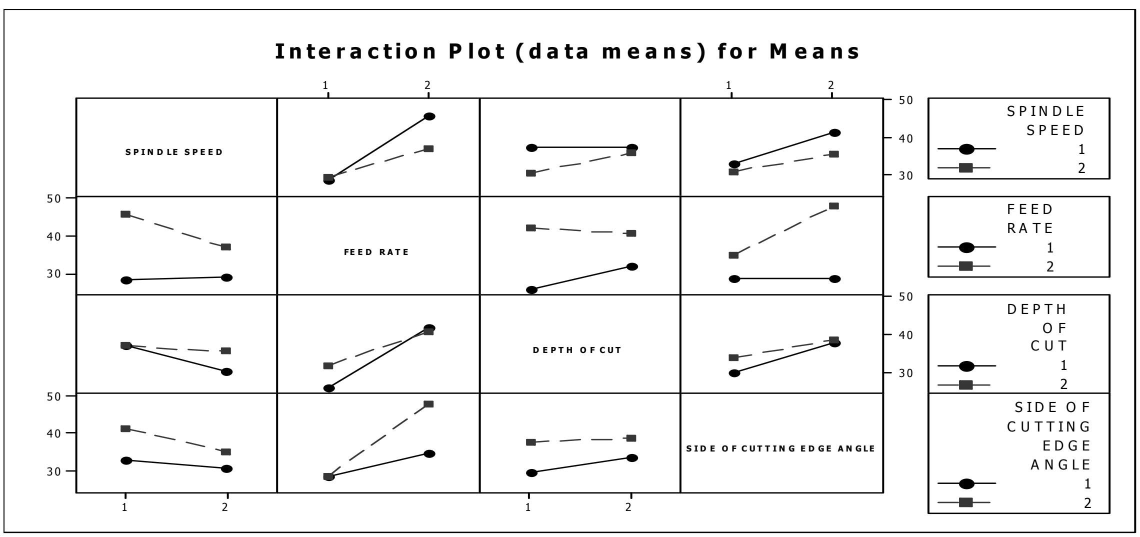

Figure 5. Interaction Plot for Surface Roughness.

Finally, the surface roughness minimum is obtained by the gradient descendant method with the following combination of cutting parameters:
Spindle speed =950 rpm, feed rate =1.6 in/min, depth of cut=0.0156 in, side cutting-edge angle = 0 degree. This combination gives a surface roughness equal to 23.5 µin.

4. Conclusions and recommendations

• The side cutting-edge angle significantly affects the surface roughness; this could be due to the imperfect geometry of the cutting tool nose. Therefore, the surface roughness is affected when the cutting tool touches the workpiece at a different side cutting-edge angle. Also, the interaction feed rate*side cutting-edge angle also affects the surface roughness.
• There is a major residual variation when the workpiece is machined to high side cutting-edge angle; therefore, this condition can cause a wide variation regarding the specifications demanded by customers
• Others parameters that significantly affected the surface roughness were feed rate, spindle speed and interactions spindle speed*feed rate, spindle speed*depth of cut and feed rate*depth of cut
• In further works, it will be important to analyze the effect of the side cutting-edge angle on the surface roughness for other work materials.

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