Middle-East Journal of Scientific Research 31 (1): 01-08, 2023
ISSN 1990-9233
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DOI: 10.5829/idosi.mejsr.2023.01.08

Analysis of the Effects of Cutting Parameters on Surface Roughness in the Machining of Aluminum Alloys

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Abstract: In this study, the effects of cutting parameters such as tool rake angle and cutting speed on the surface roughness were investigated. For this purpose, the effects of different alloy types, AA2011 and AA7075, rake angle and cutting speed on the surface roughness were investigated statistically. Test setup determined to remove the chips by giving the cutting tool both positive and negative rake angles was used in the machinability. Statistical Analysis was carried out in the SPSS package program in order to determine the effects of alloy type, rake angle and cutting speed on the surface roughness values obtained by the experiments. It was found that surface roughness (Ra) values of alloys decreased with increasing rake angle according to the using Analysis. According to the variance analysis, the effects of the effects of alloy type, cutting speed, rake angle and their interactions on Ra values were statistically significant.

Key words: Aluminum Alloys · Rake Angle · Surface Roughness · Statistical Analysis

INTRODUCTION

Aluminum and aluminum alloys are the most used in today's industry after iron and steel. Despite the lighter that Aluminum has higher strength properties than structural steels. Aluminum has good electrical and thermal conductivity and it has the high heat and light reflectivity too. In addition, it's very good corrosion resistance and ease of casting and shaping enable it to be used in many service areas [1].

The surface roughness is the most important machining parameter that used to determines the quality of the materials. The ability of the machine parts working, which perform the desired function for a long time and with minimum energy consumption, in contact with each other depends on the surface roughness and dimensional accuracy of the parts.

The fatigue strength, corrosion resistance and tribological properties of the material have been affected by changing surface quality [2]. Therefore, measurement and characterization of surface roughness is important for the optimization of machining processes.

There are many factors affecting the machining of aluminum alloys, as in other machining processes. The rake angle has enormous effects on the cutting forces and Built-Up Edge (BUE) during machining of aluminum [3, 4]. If a large rake angle increases, machining of materials easier by the contact surface between the cutting tool and the work-piece. On the other hand, a large rake angle has a negative effect on the strength of the insert.

It’s stated that increases rake angle increases, the wear of tip area of the cutting tool increases. In order to prevent these formations, the rake angle should be selected at optimum values [5]. Mizutani *et al.* [6] stated that on aluminum alloys, it was concluded that with the increase of hardness, the surface roughness decreased and Built-Up Edge (BUE) formation disappeared. It was also reported that lower surface roughness values were obtained when machining by used positive rake tools (5° and 7.5°) alloys with high hardness values [3]. Jeelani and Musial [4] determined that used a tool with a positive rake angle between 10°- 30°, with the increase of the rake angle in the positive direction the formation of

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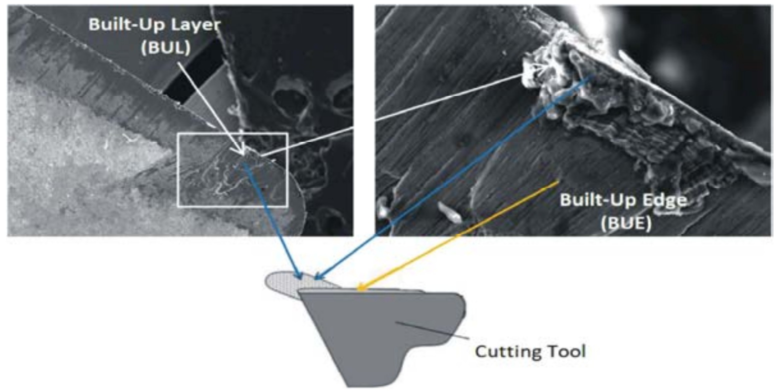

Fig. 1: Formation of Built-Up Edge (BUE) and Built-Up Layer (BUL)

BUE decreases and thus the surface roughness decreases. The other important factor is the cutting tool wear mechanisms, one of them is the adhesion wear mechanism that occurs especially in the machining of ductile materials. Adhesion wear generally occurred as the work piece material is attached to the cutting tool surface [7].

It is seen in Figure 1, the adhesion of the work piece material to the rake surface of the tool in the machining process is known as Built-Up Edge (BUE). It is mostly formed in the processing of ductile materials. The thin layer formed by welding the cutting tool rake surface over a large area is called the Built-Up Layer (BUL). The reason of the formation of BUE and BUL on the cutting tool is temperature and excessive pressure in the cutting tool during the chip removal depending on the cutting parameters. These formations also depend on the chemical structure of the work piece in the cutting tool [8, 9].

Özlü *et al.* [10] investigated that the effects of cutting parameters on the surface roughness in the turning of AA6061 alloy with uncoated and coated via TiB2. According to the result of them the levels of optimum cutting parameters were determined for the best machined surface roughness. Yaka [11] investigated the surface roughness of aluminum 5000 alloy and produced by recycling the casting method values by used Taguchi Analyze. Also, the same author stated that the most important factor on the surface roughness is feed rate.

Oral *et al*. during the milling process, the effects of mechanical vibrations in the cutting tool on the surface quality were investigated experimentally. Titanium (Ti6Al4V) work piece was used in the tests. The test parameters were determined by full factorial method by taking 4 different cutting speed (Vc m/min), 4 different feed rate (f mm/rev) and constant cutting depth (ap/mm). Regression analyze was performed for the average surface roughness values obtained from the tests [12].

Meral *et al*. [13] drilled uncoated and TiAlN coated HSS drills in 6, 8, 10 mm diameters of AISI 1050 steel. The effects of feed rate, cutting speed, drill diameter and drill type on surface roughness (Ra) and feed forces were investigated by ANOVA Analysis.

Kasım *et al.* [14] investigated that the effects of cutting speed, feed rate and depth of cut on the surface roughness of Inconel 718 when milled under minimum quantity lubrication. The effects of the relationship between the control variables and the response on the surface methodology (RSM) was determined by used Box-Behnken design and experimentally too. It's was showed that the interaction between the feed rate and the radial depth of cut was the primary factor controlling surface roughness.

Multilayer coated carbides, cermets and alumina inserts of different tool geometries were experimented using three different levels of cutting speed, feed rate and depth of cut. To determine the influence of cutting fluids during machining, three classes of cutting fluids were used. As output parameters, surface roughness, flank wear, temperature, machining time and metal removal rate were considered. The influence of all the cutting (input) parameters on each of the output parameters was determined by using the ANOVA technique [15].

Bakar *et al*. [16] investigated that the performance of conventional and The High Pressure Water Jet Assisted Machining (HPWAM) methods in the machining by used Ti-6Al-4V titanium alloy. The evaluation parameters were selected tool life, wear mechanisms, surface roughness and chip formation. The results showed that improved tool life as much as 195% HPWAM better than conventional methods.

It is understood from the studies in the literature that the rake angle and cutting speed have an effect on the surface roughness in the machining of ductile materials. However, it is seen that there is not enough number of studies in the literature in which the rake angle, cutting speed and the chemical composition of the alloy material, especially the effect on the surface roughness are examined by multiple variance analysis. In this study, the effect of rake angle and cutting speed change on the surface roughness in machining AA2011 and AA7075 alloys with uncoated carbide cutting tool was investigated statistically with the Analysis of Variance.

MATERIALS AND METHODS

Preparation of Experimental Samples: The test samples used in the study were cylindrical AA2011 and AA7075 aluminum alloys, which are widely used in the machining industry. Test specimens were prepared by using 100 mm diameter AA2011 and 70 mm diameter AA7075 aluminum. A center hole was drilled at the one surface of the test sample attached between the chuck and the tailstock on the CNC lathe.

In the experiments, Kennemetal product CCGT120404 coded K313 quality uncoated carbide cutting tool and SCLC2525 M12 coded 95° approach angle tool holder were used. Cutting tools normally have a rake angle of 15°. During the experiments, the rake angles were adjusted to the values determined in the negative and positive directions with an adjustable system [17].

The cutting parameters have been determined according to the material structure of aluminum alloys, the recommended cutting parameters in the processing of aluminum alloys, the cutting tool, the conditions of the CNC lathe and ISO 3685 [11, 18-20]. Different machining conditions were determined to determine the roughness values by experiments. These parameters are given in Table 1.

Table 1: Cutting tool and cutting parameters

Tool holder	: SCLCR 2525M12
Cutting tool	: CCGT 120404 (K313 grade)
Insert nose radius (r-mm)	: 0.4
Rake angle (γ- °)	: -5, 0, 5, 10, 15, 20
Cutting parameters	
(V - m/min)	: 400, 450, 500, 550, 600
(f - mm/rev)	: 0.25
(a- mm)	: 2.5

Methods: The chemical compositions of these materials were determined by performing spectral analyzes (Table 2). In addition, Brinell hardness values were measured by using the INSTRON WOLPERT. Mahr Perthometer M1 device was used for surface roughness of test samples that AA 2011 and AA 7075 aluminum alloys. The average surface roughness value (Ra) measured by three repetitions for each condition was used to the evaluation of the surface roughness. In the roughness measurements, the ambient temperature was accepted as 20 ±1 °C, the cutting length was chosen as 0.8 mm and the sampling length as 5.6 mm.

The experiments were ensured to be under the same conditions by using a new cutting tool for each experiment. After each experiment, the machine was stopped and the cutting speed and rake angle values were adjusted again and a total of 60 experiments were carried out.

Data for each test were statistically analyzed. The analysis of variance (ANOVA) was used ($\alpha<0.05$) to test for significant difference between factors. When the ANOVA indicated a significant difference among factors, the compared values were evaluated with the Duncan test to identify which groups were significantly different from other groups.

RESULTS AND DISCUSSION

Results of Chemical Properties and Hardness Values: Aluminum alloys with different compositions have been developed to be used in various requirements in the manufacturing industry. Aluminum alloys show different physical, mechanical and technological properties depending on the alloy element and its ratios. The results showed that the values of BSN changed between 88 and 125. The highest BSN was obtained from AA 2011 samples as 125, the lowest values of those were obtained from AA7075 samples as 88, respectively. In aluminum alloys, 2xxx series alloys are known as aluminum-copper alloys and 7xxx series alloys are known as aluminum-zinc-magnesium-copper alloys [1]. The chemical analysis of AA 2011 and AA 7075 aluminum alloy are shown in Table 2.

As seen in Table 2, while the main component element of the AA2011 alloy is Cu (5.58%), the main component elements of the AA7075 alloy are Zn (4.97%), Mg (2.11%) and Cu (2%). It' seen that these rates are in agreement with the literature.

Table 2: Chemical compositions of the test materials (%)

Alaşım Tipi	Si	Fe	Cu	Mn	Mg	Zn	Ni	Cr	Pb	Sn	Ti	Sb	Al
AA2011	0.158	0.324	5.580	0.002	0.002	0.025	0.012	0.014	0.459	0.015	0.008	0.003	93.39
AA7075	0.240	0.255	2.000	0.260	2.110	4.970	0.015	0.150	0.013	0.005	0.025	0.003	89.96

Table 3: Surface Roughness Values (Ra)

		AA2011		AA7075	
Rake angle (°)	Cutting speed (m/min)	Mean	Std. Deviation	Mean	Std. Deviation
-5	400	5.442	0.179	5.493	0.098
	450	5.317	0.174	6.081	0.120
	500	5.672	0.102	5.599	0.079
	550	5.449	0.131	6.819	0.043
	600	5.138	0.086	6.935	0.086
0	400	6.349	0.211	5.805	0.100
	450	5.069	0.159	5.049	0.120
	500	5.527	0.166	4.230	0.137
	550	4.249	0.117	5.069	0.097
	600	5.039	0.117	6.025	0.069
5	400	5.035	0.200	5.144	0.136
	450	4.992	0.251	5.008	0.083
	500	5.602	0.186	4.739	0.083
	550	5.078	0.132	4.689	0.074
	600	4.778	0.110	5.632	0.065
10	400	4.994	0.192	5.196	0.043
	450	5.371	0.167	5.554	0.073
	500	5.309	0.197	5.074	0.080
	550	4.402	0.115	5.223	0.077
	600	5.088	0.146	4.861	0.049
15	400	5.482	0.192	4.489	0.112
	450	4.361	0.188	5.345	0.052
	500	4.359	0.122	4.842	0.076
	550	4.239	0.115	4.574	0.045
	600	4.309	0.186	4.217	0.054
20	400	4.183	0.154	4.264	0.104
	450	3.823	0.249	3.903	0.069
	500	4.358	0.146	3.718	0.074
	550	3.909	0.126	4.278	0.070
	600	4.137	0.068	3.959	0.134

Findings of Surface Roughness: Cutting speeds and rake angles of machining AA2011 and AA7075 aluminum alloy were 400, 450, 500, 550, 600 (m/min) and six -5, 0, 4, 10, 15, 20 (°) respectively. The surface roughness was very the most common tests and it was used as a determiner of the many applications. While the lowest value for surface roughness value of test samples was 3.71 (AA7075: 20° rake angle and 450m/min cutting speed), the highest value for surface roughness value of test samples was 6.93 (AA7075: -5 degrees rake angle and 600 m/min cutting speed). The mean and standard deviation values of the surface roughness values (Ra) obtained from the test samples are given in Table 3.

It is seen that the surface roughness values improve with the increase of the rake angle [3, 4, 21-23]. Variance Analysis results of surface roughness values obtained from AA2011 and AA7075 alloys at different rake angles and cutting speeds are given in Table 4.

According to the results of variance analysis the types of the alloy, cutting speed, rake angle were found to have significant effects on surface roughness properties of test samples ($p<0.05$). it was determined that the interaction of alloy type and rake angle, cutting speed and rake angle, alloy type, cutting speed and rake angle on the surface roughness values were a significant difference at 95%, also.

According to the variance analysis, the effects of the types of the alloy, cutting speed, rake angle on surface roughness values were statistically significant. Duncan test results conducted to determine the importance of the differences between the groups are given in Table 5.

Table 4: Analysis of Variance Results

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	88.388[a]	59	1.498	88.035	0.00
Intercept	4466.174	1	4466.174	262453.139	0.00
Alloy type -A	1.131	1	1.131	66.471	0.00
Cutting speed -B	2.083	4	0.521	30.608	0.00
Rake angle -C	52.298	5	10.460	614.656	0.00
A * B	7.128	4	1.782	104.722	0.00
A * C	3.824	5	0.765	44.938	0.00
B * C	11.935	20	0.597	35.068	0.00
A * B * C	9.988	20	0.499	29.348	0.00
Error	2.042	120	0.017		
Total	4556.604	180			
Corrected Total	90.430	179			

a. R Squared = .977 (Adjusted R Squared = .966)

Table 5: Duncan test results

AA2011					AA7075				
Experiment Conditions		N	Ra	HG	Experiment Conditions		N	Ra	HG
Cutting speed (m/min)	550	18	4.554	A	Cutting speed (m/min)	500	18	4.7	A
	600	18	4.782	B		400	18	5.065	B
	450	18	4.822	B		550	18	5.108	BC
	500	18	5.137	C		450	18	5.156	C
	400	18	5.247	D		600	18	5.271	D
Rake angle (°)	20	15	4.081	A	Rake angle (°)	20	15	4.0224	A
	15	15	4.549	B		15	15	4.693	B
	10	15	5.032	C		5	15	5.042	C
	5	15	5.097	C		10	15	5.181	D
	0	15	5.246	D		0	15	5.235	D
	-5	15	5.403	E		-5	15	6.185	E

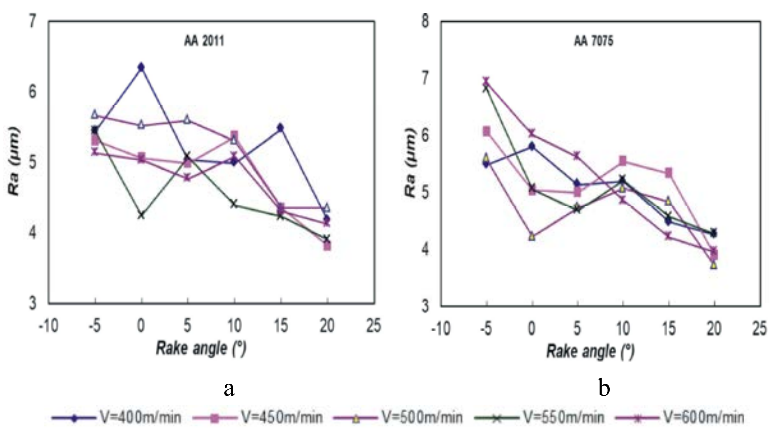

Fig. 2: The effects of rake angle on the surface roughness

According to the Duncan test results, it was observed that the roughness values decreased with the increase in the rake angle, which is the one of the cutting parameters. It was determined that the roughness values obtained at the rake angle of 10-5° for the AA2011 alloy and 10-0° for the AA7075 alloy were in the same homogeneity group. With increasing cutting speed, Ra values partially decreased for AA2011, but this situation is not AA7075 alloy. The cutting speeds were within the ranges recommended of the tool manufacturer and the changes in the machining conditions of the aluminum were limited. The effects of cutting parameters on the surface roughness were given in Figure 2a-b and Figure 3a-b.

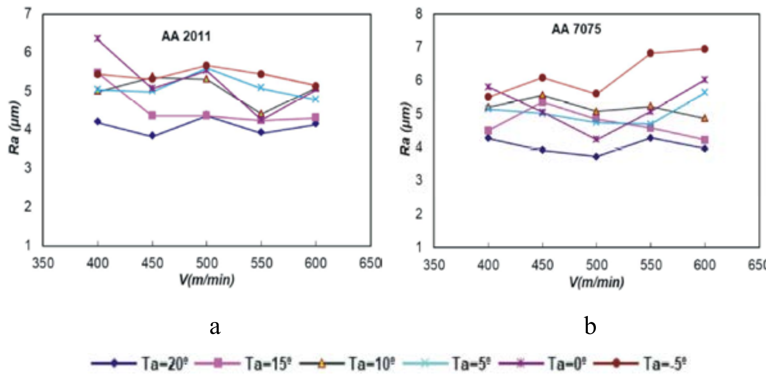

Fig. 3: The effects of cutting speed on the surface roughness

It's seen that the surface roughness values of test samples decreased with increasing rake angle (Figure 2a). When the rake angle was increased from -5° to 20°, the surface roughness (Ra) of A2011 alloy decreased nearly 25% at all values of cutting speed. The lowest average surface roughness values at all rake angles were obtained at the cutting speed of 550m/min.

On the other hand, it can be said that when the rake angle increased from -5° to 20°, the average surface roughness (Ra) values of AA7075 alloy decreased approximately 35%. The lowest surface roughness values were achieved at 500m/min cutting speed at all selected rake angles. It can be explained that due to the positive effect of increasing the rake angle on friction and tool temperature, the formation of BUL and BUE decreased.

It's mentioned that BUL and BUE formation has been occurred at low rake angles. It is thought that the tool rake surface has an irregular structure due to the formation of BUL and BUE at low rake angles, the average surface roughness values increased [3, 4].

It can be shown that Ra values which were obtained at 5 degrees for both alloys were quite high compared with the other rake angles. When the rake angle was increased from -5° to 0° and 0° to 5°, the Ra values nearly 13% anf 3.8% decreased, respectively for AA7075 alloy. Besides, when the rake angle was increased from -5° to 0°, the Ra values nearly 2.6 % decreased for AA2011 alloy. Low surface roughness values were obtained from using rake angles of 15° and 20° for both alloys. The surface roughness values of AA7075 alloy are lower than AA2011 alloy especially at 20° rake angle. When effects of cutting speed on Ra values were examined the (Figure 3a-b), no significant change was observed in surface roughness values with increasing cutting speed at AA2011 alloy. But, it can said that the roughness surface values ??increased with the increased of cutting speed at low rake angles of AA7075.

It is concluded that machining of ductile materials with low rake angle is not within acceptable limits; besides, Ra values are unstable. In addition, it can be said that the cutting speed has no effect on the surface roughness value since the cutting speeds for aluminum selected within the ranges determined by the tool manufacturer. The compared to surface roughness values obtained at the same rake angle and cutting speeds both aluminum alloys, the Ra values were obtained of AA7075 the more than AA2011 alloy due to the amount of BUL and BUE formation of AA7075, which has the ductility and low hardness [6].

Low surface roughness values are required in material processing. It is seen that the lowest values of surface roughness are achieved at the 20° rake angle and 550m/min cutting speeds for AA2011 alloy and 500m/min for AA7075 alloy. These determined conditions can be expressed as optimum parameters.

CONCLUSION

In this study, the effects of rake angle and cutting speed change on the average surface roughness in machining of AA2011 and AA7075 alloys with uncoated carbide cutting tool were investigated statistically. The following deductions are summarized in below according to the results obtained;

- It was determined that Ra values were decreased with increasing rake angle and there was no significant change in Ra values with increasing cutting speed as a result of this experimental study.
- When the effect of the rake angle on the surface roughness is generally evaluated, it is seen that the lowest surface roughness values at the machining of test samples are achieved in 20° rake angle and 550m/min cutting speed for AA 2011 alloy and 500m/min for AA 7075 alloy.

- The compared to surface roughness values obtained at the same rake angle and cutting speeds both aluminum alloys, the Ra values were obtained of AA7075 the more than AA2011 alloy.
- The surface roughness values were obtained at the rake angle of 10-5° for the AA2011 alloy and 10-0° for the AA7075 alloy and they were seen at the same homogeneity group.
- According to the results of variance analysis the types of the alloy, cutting speed, rake angle were found to have significant effects on surface roughness properties of test samples ($p<0.05$).

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