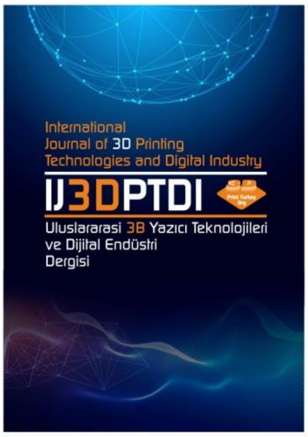

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EVALUATION OF SURFACE ROUGHNESS IN DRILLING OF AA 7075 T6 PLATE WITH DIFFERENT CUTTING TOOL GEOMETRIES WITH EXPERIMENTAL, STATISTICAL AND DEFORM 3D SIMULATION

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ABSTRACT

The basis of the study is to examine the average surface roughness (Ra) value resulting from drilling AA 7075 T6 plates with drills with different point angles (ε) and under different cutting parameters. However, two different point angles (118° and 135°), three different cutting speeds (Vc) (40, 60 and 80 m/min) and three different feeds (f) (0.04, 0.08 and 0.12 mm/rev) were preferred in the experiments. The effect of cutting and tool geometry parameters on Ra was digitized by performing an ANOVA analysis. It was determined that Ra increased with the increase of Vc, ε and f. The parameter with the most significant effect on Ra was Vc with 49.10%, followed by ε with 30.52% and f with 13.67%, respectively. In order to examine the reasons for the increase in Ra value more effectively, drilling simulations were carried out under different cutting parameters using Deform 3D software. The simulation estimated temperature, cutting force and damage during drilling. The predicted results and the factors on Ra were revealed. In the experiments carried out with the drill with a tip angle of 135°, it was estimated that the temperature, the temperature, the cutting force and the damage value along the Z-axis were higher than the drill with a tip angle of 118°.

Keywords: AA 7075 T6 Plate, Drilling, Drill Bit Point Angle, Surface Roughness, Simulation of Deform 3D.

1. INTRODUCTION

In addition to being light, aluminium alloys play an essential role in developing aerospace, aviation, weapons and defence industries, thanks to their superior mechanical properties. Due to the increasing use of aluminium alloys, their machinability is often the subject of research. The behaviour of aluminium alloys in machining differs from other metallic materials. Since aluminium alloys show a smearing behaviour in the machining process, they adhere to the cutting tools and play an essential role in increasing the surface roughness and reducing the life of the cutting tool. 7xxx series aluminium alloys contain 4-8% Zn and 1-3% Mg and are particularly interested in aircraft, aerospace and automotive industries since they have higher hardness and strength than other aluminium alloys (Smith, 2001; Yurdakul et al., 2002). ; Wu et al., 1997; Heinz et al., 2000; Ferrer, 2001; Rendigs, 1997). (Çakır et al., 2012) conducted hole drilling experiments in two different aluminium materials, AA 7075 and AA 6013, with two-edged HSS and carbide drills, using four different cutting speeds and four different feed rates. The forces and moments in the cutting tool were measured. In addition, the experiments were carried out in full factorial order, and the results were interpreted by analysis of variance. According to their results, it was determined that the increase in the feed rate increased the thrust force and moment, while the workpiece material was not as effective as the cutting parameters. They also concluded that the cutting tool type and feed significantly affect the thrust moment. (Kushnoore et al., 2016) evaluated the thrust force and moment when drilling AA 6061 material and the hole quality. Carbide drills were used in the experiments. They used the L_{27} orthogonal array experimental design. The effects of thrust force, moment, cutting speed and feed on hole diameter deviations were analyzed by developing the RSM technique. The adequacy of the proposed models were tested with ANOVA. Optimum parameter levels for thrust, torque and circular error were obtained using the Taguchi signal-to-noise ratio technique. As a result, they determined that circular errors are affected mainly by drill diameter, cutting speed and feed. In another optimization study, AA 7075 material was drilled, and the Ra parameter was measured. The experimental setup was planned in Taguchi L_{16} array. When the optimum values obtained are examined; It has been determined that the surface roughness gives the best results at 20 m/min, the first level of cutting speed, 0.06 mm/rev, the first level of feed rate, and 118°, the first level of the tip angle (Erkan and Yücel, 2018). Various studies have investigated the effect of machining parameters on thrust force and diameter deviations for drills with different tip angles. The results show that low feed rate and low cutting speeds are suitable for dry machining of AA 6061. An application of Taguchi and response surface methodologies has been made to minimize circular error and thrust in AA-7075 drilling. Optimization results showed that it is necessary to use a combination of low cutting speed, low feed and large point angle to minimize diameter error and thrust (Kılıçkap et al., 2010). The role of different coatings, point angle and cutting parameters in the hole quality formation in the drilling of AL-6061 alloy was investigated. It was concluded that the cutting parameters affected the hole quality differently. They achieved effective results by using low cutting speed and feed. Drilled using different materials with several cutting conditions, cutting speed and feeds showed that circularity errors were highly dependent on material properties, drill geometry and cutting condition (Kurt et al., 2008).

In another study, a new method was designed for the selection of optimum machining parameters during drilling, and its performances were investigated. The study is about the multiple performance optimizations of the machining of 7075 aluminium alloy during the drilling process. The drilling parameters used for this experiment are; cutting speed, including feed rate and drill bit, and the two output parameters are surface roughness and material removal rate. Experiment results were collected and analyzed in Minitab17 statistical software. Analyzes of variance were used to determine the most crucial control factors affecting surface roughness and material removal rate. ANOVA determined that cut depth and cut speed play an essential role in producing a higher material removal rate. It has also been found that the cutting speed plays a vital role in creating lower surface roughness (Gopalakrishan et al., 2018). AA 7075 – T6 aluminium alloy was subjected to continuous drilling tests with K 20 quality carbide tools under dry drilling conditions. While the cutting speed (V) was kept constant in the experiments, the feed rate (f) and drill bit point angle (ɵ) parameters were changed within certain limits, and the effects of these factors on the surface roughness, feed force and tool tip temperature were determined experimentally. It has been determined that the temperature values measured from the pre-drilling samples are significantly reduced compared to the conditions without pre-hole for the same material in the current literature. It was determined that the tooltip temperatures decreased depending on the increasing feed rate and drill bit angle values. It was observed that the average surface roughness values of the samples increased with the feed rate and drill bit point angle (Çaydaş and Çelik, 2017).

In the present study, drilling tests of AA 7075 T6 plates were carried out with drills with different point angles under different cutting parameters. The average surface roughness (Ra) values of the drilled surfaces were measured with the help of a profilometer. The effective parameters on Ra were determined by performing regression analysis, and a mathematical equation was formed. The influencing parameters were digitized with the help of ANOVA analysis. By making deformation simulation estimations, the effective parameters on Ra made sense.

2. EXPERIMENTAL METHOD

The SEYKOÇ Aluminium company supplied the AA 7075 T6 material used in the experiments. The plates are 30 mm thick and milled on the drilled face square. The chemical components of AA 7075 T6 material are shown in Table 1.

Table 1. Chemical content of AA 7075 T6 material.

Element	Fe	Si	Cu	Mn	Mg	Zn	Cr	Zi+Ti	Other	Al
Rate (%)	0.5	0.5	1.2-2.0	0.3	2.1-2.9	5.1-6.1	0.18-0.28	0.25	0.15	Remainder

AA 7075 material has been subjected to T6 heat treatment. T6 thermal cycle consists of a solution heat treatment followed by a water quenching and then an age hardening (or precipitation hardening). Solution heat treatment dissolves intermetallic phases. It allows the eutectic Si to become spherical, increasing the ductility of the alloy (Ogris et al., 2002; Sjölander and Seifeddine, 2010). The time for solution treatment is strongly dependent on the microstructural scale (Sjölander and Seifeddine, 2010), ranging from a few minutes up to several hours (Zhang et al., 2002; Han et al., 2014; Tillova et al., 2018). Its yield strength is between 460-505 MPa, its tensile strength is between 530-570 MPa, and its hardness value is between 140-160 Brinell. The drills that created the holes have two different point angles (118° and 135°) obtained from Taegutec. Drill bits with a diameter of 8 mm are made of HSS material and are Titanium Nitride (TiN) coated. HSS steel coated with 2.5µ TiN. DELTA SEIKI CNC - 1050 A - CNC vertical machining centre with 11 kW engine power and a maximum spindle speed of 10.000 rpm was used in the experiments. AA 7075 plates attached to the machine tool clamp were drilled with HSS-TiN coated drills with point angles of 118° and 135°. All experiments were carried out under dry machining conditions. The cutting and tool geometry parameters used are shown in Table 2.

Table 2. Cutting parameters were used in the experiments.

Drill Bit Material	**Point Angle (ε), °**	**Cutting Speed (Vc), m/min**	**Feed (f), mm/rev**
HSS-TiN	118	40	0.04
	135	60	0.08
		80	0.12

The experiments were carried out in a clamp rigidly attached to the machine tool table. The experimental setup is shown in Figure 1.

The average surface roughness of the drilled holes was measured with the Mahr Marsurf PS10 profilometer.

Average surface roughness values measured from machined hole surfaces are given in Table 3.

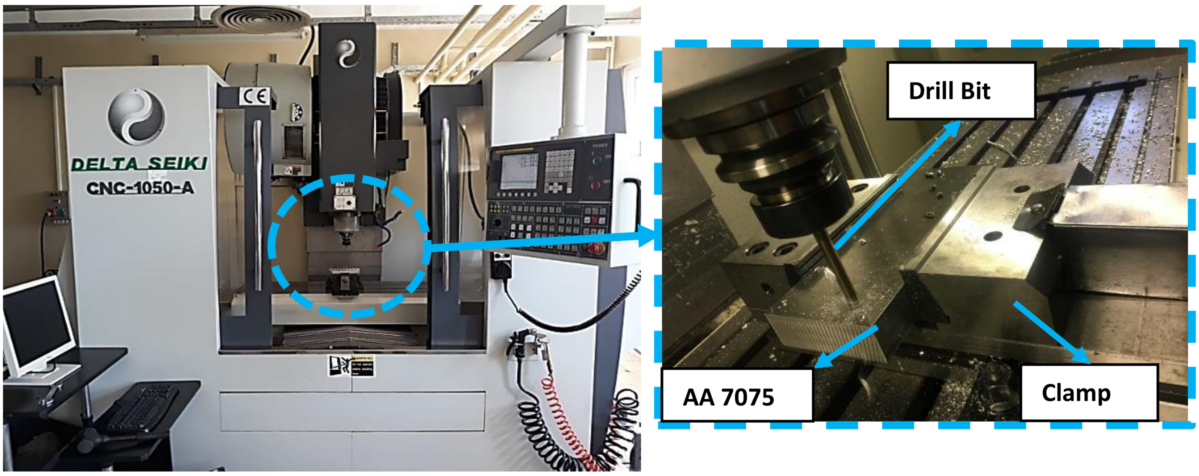


Figure 1. Experimental setup.

Table 3. Measured Ra values.

No	Point Angle, ε , °	Cutting Speed, Vc, (m/min)	Feed, f (mm/rev)	Ra, (µm)
1	118	40	0.04	1.025
2	118	40	0.08	1.273
3	118	40	0.12	1.578
4	118	60	0.04	1.775
5	118	60	0.08	2.145
6	118	60	0.12	2.255
7	118	80	0.04	2.055
8	118	80	0.08	2.369
9	118	80	0.12	2.674
10	135	40	0.04	1.381
11	135	40	0.08	1.839
12	135	40	0.12	2.285
13	135	60	0.04	2.630
14	135	60	0.08	3.100
15	135	60	0.12	3.354
16	135	80	0.04	2.955
17	135	80	0.08	3.423
18	135	80	0.12	3.884

3. STATISTICAL ANALYSIS

Regression and ANOVA analyzes were used to determine the effect of control parameters on Ra. Analyzes were performed in Minitab 20 software. Figure 2 shows the effect of control factors on Ra graphically.

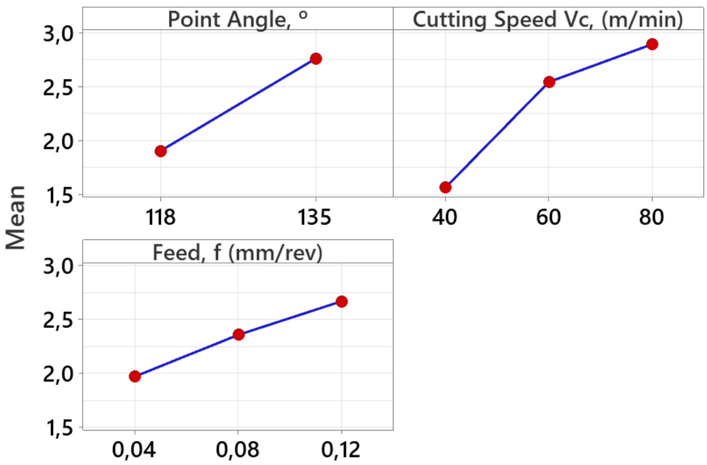


Figure 2. Main effect plots for Ra

When Figure 2 is examined, it is observed that the Ra parameter increases with the increase of ε, Vc and f.

Analysis of variance was performed to determine the effect of the variables on the surface roughness. ANOVA results are shown in Table 4.

Table 4. ANOVA results of Ra.

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	3	10.0771	93.28%	10.0771	3.35903	64.73	0.000
Point Angle, ε	1	3.2958	30.51%	3.2958	3.29578	63.51	0.000
Cutting Speed,Vc	1	5.3050	49.10%	5.3050	5.30500	102.24	0.000
Feed, f	1	1.4763	13.67%	1.4763	1.47631	28.45	0.000
Error	14	0.7265	6.72%	0.7265	0.05189		
Total	17	10.8035	100.00%				

When Table 4 is examined, the P values show the significance level of each variable on the results, the total of SD squares, and the mean of the MS squares, while the F values and percent effect rates are also included. P values that could not be included in the table were less than 0.05. It was determined that the variable that had the most significant effect on the surface roughness was the cutting speed (Vc) with 49.10%, and then the point angle (ε) had an effect of 30.51%, and the feed rate (f) had an effect of 13.67%, respectively. The equation in which the Ra output can be calculated mathematically because of the regression analysis is given in Equation 1.

$$Ra=-6.731+0.05034\,\varepsilon+0.03324\,Vc+8.77\,f \quad (1)$$

4. DEFORM 3D SIMULATION

By using the 3D cutting module of Deform 3D software, simulations of drilling were made in different parameters. Simulation steps with Deform 3D are given in Figure 3.

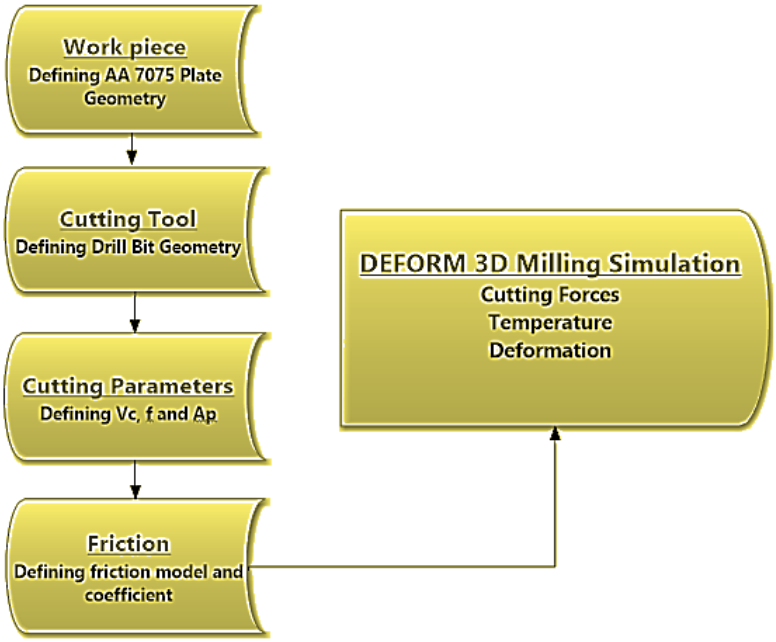


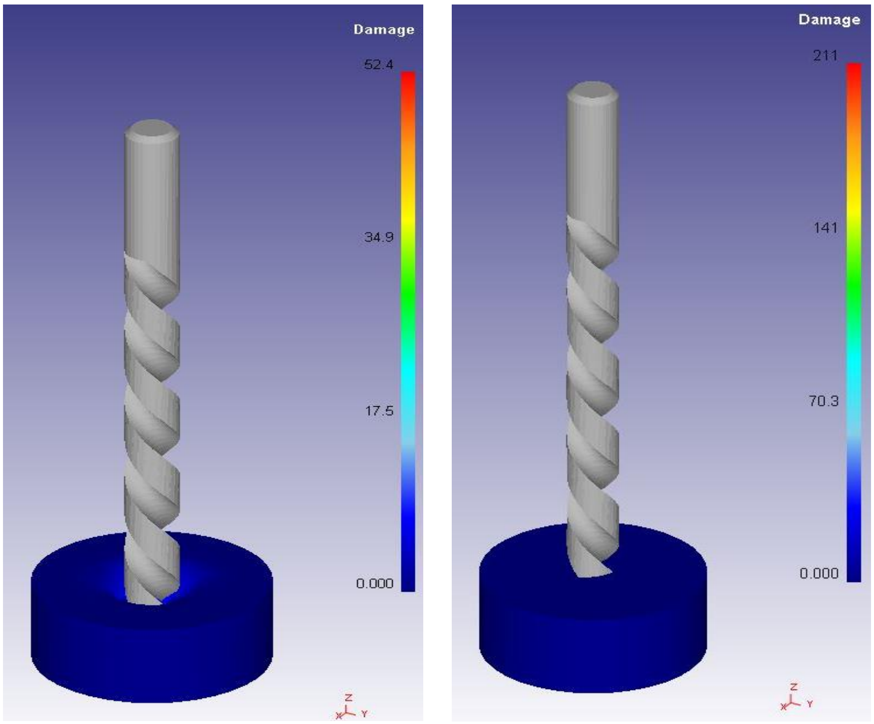
Figure 3. Deform 3D simulation steps.

The workpiece AA 7075 material was selected from the software's library. A triangular mesh is knitted on the selected material. The Mesh number is 16000. The cutting tool was also selected from the software library. The TiN coating thickness of the drill is defined as 2.5 µm in the software. The tip angle of the selected drill (118° and 135°) was customized according to the experiment. The mesh of the drills consists of 16000 triangles. The simulation was carried out at 40 m/min cutting speed and 0.12 mm/rev feed using drills with 118 and 135 degree tip angles. The depth of cut (Ap) was determined as 10 mm in the simulation. In the last step before the simulation, the Usui tool wear model shown in Equation 2 is defined.

$$\frac{dW}{dt} = A\,\sigma_n\,V_s\,exp(-B/T) \quad (2)$$

In Equation 2, *T* is the shear temperature, σn is the normal stress, *Vs* is the shear rate, and *B* is the constant.

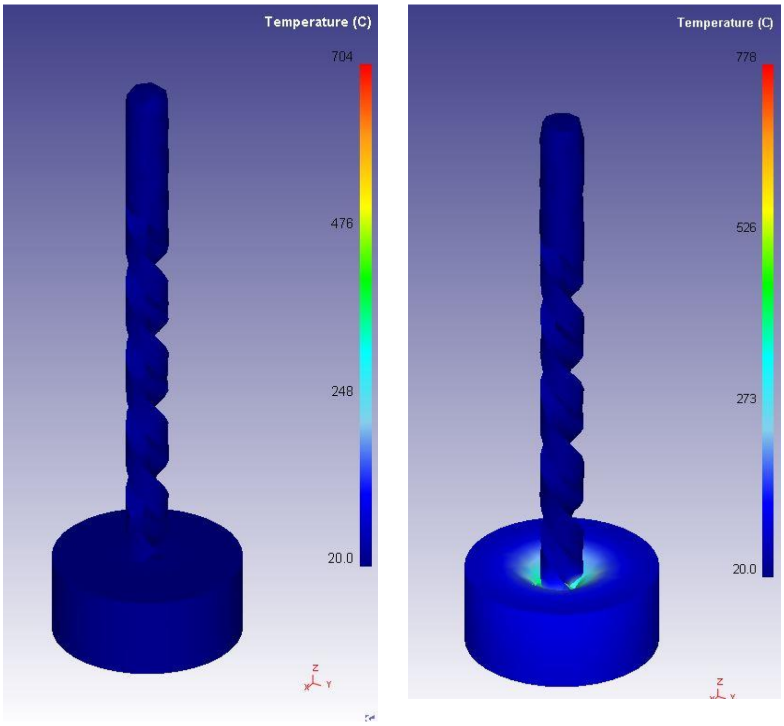
The results of the simulations, such as damage, temperature and force, were examined. In Figure 4, the damage estimates of the simulation performed using drills with 118°, and 135° tip angles, a cutting speed of 40 m/min, and a feed of 0.12 mm/rev are given. given. The cutting force occurring in the Z-axis was estimated at about 10 mm and presented in the graph.



(a) (b)

Figure 4. Damage rate simulation estimates of the drilling simulation a) ε=118°, b) ε=135°

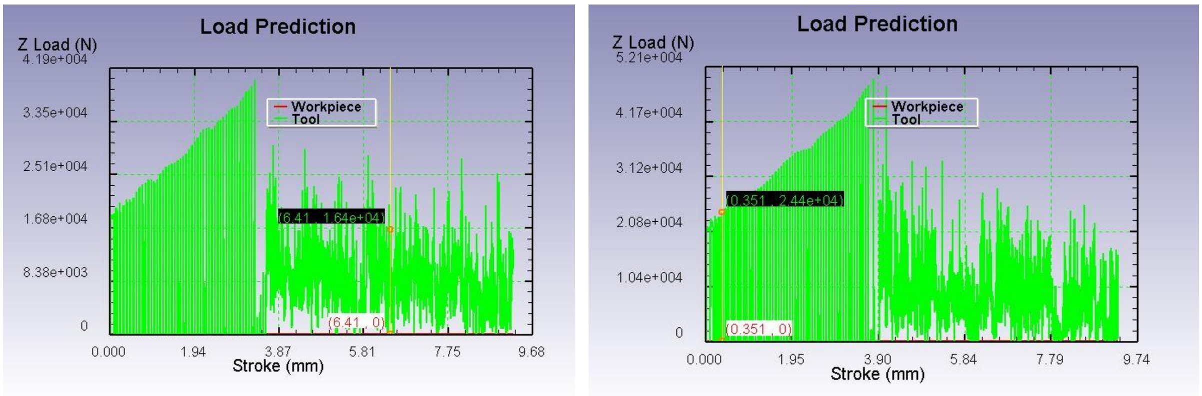
Figure 4 (b) shows that a drill with a point angle of 135° can cause a maximum of 211 damage, and in Figure 4 (b) a drill with a point angle of 118° can cause a maximum of 52.4 damage. In Figure 5, the temperature estimates of the drilling simulation are given.



(a) (b)

Figure 5. Temperature estimates of the drilling simulation a) ε=118°, b) ε=135°

Figure 5 (b) shows that a drill with a point angle of 135° can reach a maximum temperature of 778 °C, and Figure 5 (a) a drill with a point angle of 118° can reach a temperature of a maximum of 704 °C. In Figure 6, the cutting force estimates of the drilling simulation are



(a) (b)

Figure 6. Cutting force estimates of the drilling simulation a) ε=118°, b) ε=135°

Figure 6 (b) shows that a drill with a point angle of 135° produces a maximum cutting force of 284 N, and in Figure 6 (a) a drill with a point angle of 118° produces a maximum cutting force of 228 N.

When all these results are examined, the drill with a point angle of 135° creates greater cutting force, temperature, and damage value, allowing the drilled surface to be rougher.

5. CONCLUSIONS

AA 7075 material was machined with drills with 118° and 135° point angles under different cutting parameters. Ra parameters of the machined surfaces were measured. However, the parameters that have the most significant effect on the Ra parameter were determined with the help of ANOVA analysis. In addition, drilling was simulated with Deform 3D software. The simulation estimates supported experimental results. The obtained results can be listed as follows.

- Ra parameter increased with the increase of cutting speed in both drill bits.
- The increase in feed increased on Ra in the experiments with both drill bits.
- Ra increased proportionally with the increase of the point angle.
- As a result of the ANOVA analysis, it was determined that the most significant effect on the Ra parameter was Vc with 49.10%, f with 30.51% and ε 13.67%.
- It was determined that the simulation made with Deform 3D under 40m/min cutting speed and 0.12 mm/rev feed parameter predicts 228 N cutting force, 704 °C temperature and 52.14 damage value for 118° drill bit.
- It has been determined that the simulation made with Deform 3D under 40m/min cutting speed and 0.12 mm/rev feed parameter predicts a cutting force of 284 N, a temperature of 778 °C and a damage value of 211 for a 135° drill bit.
- It was obtained from the 3D simulations of Deform, where the Ra value was negatively affected by the increase in temperature and cutting force.
- 3D drilling simulation has been successfully applied for both drill geometries.
- Slight point angle, low feed and low cutting speed are recommended for better surface roughness.

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