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The Influence of Cryogenic Cooling on Surface Roughness in Machining of AL Alloy AA 6082

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ABSTRACT: *Surface excellence is one of the most specific necessities for machined parts. The main signal of surface excellence of machined areas is the surface roughness (R_a). In this study, the influence of the cryogenic cooling during the turning process of Al 6082 alloys on the surface roughness was investigated. The cutting tool geometry (tool nose radius and rake angle), cutting speed and feed rate factors were utilized as the main parameters. Refrigerant R134a was used for cryogenic cooling during this investigation study. The surface roughness was investigated using TiN coated carbide cutting tips type SVJCR 2020 K16 among parameters of cutting speed (75,100 and 125m/min), feed rate (0.1, 0.2 and 0.3mm/rev), depth of cut (0.5mm) and tool nose radius (0.4 and 0.8mm). This investigation was carried out to study the influence of cryogenic cooling and the cutting parameters on surface roughness of the machined surfaces. The minimum value of surface roughness obtained is 0.450µm at cutting speed of 125m/min, the feed rate of 0.1mm/rev, tool nose radius of 0.8mm, and rake angle of 6º.*

KEYWORDS: *AA6082; machinability; cryogenic cooling; surface roughness.*

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I. INTRODUCTION

Commercial Aluminum alloy 6082 (AA 6082) is medium strength alloy with acceptable formability, good weldability and superb corrosion resistance. AA 6082 is used as a structural alloy, and it is the most common alloy used for machining purposes. However, AA 6082 grade has good properties such as lightweight, corrosion resistance, ductility, formability and conductivity, but in other hand has low hardness [1], relatively lower strength, lower fatigue strength, and friction-fatigue strength [1]. Due to these properties, the working areas of AA 6063 must be chosen correctly. Al alloys are commonly used on a massive scale in many applications such as automotive industries, aerospace, ship industries and railways [1,2]. Because of the ability of machining (turning, milling, drilling,…), AA 6061 material is used to produce a lot of parts like wheels, panels, also bodies of vehicles in automotive manufacturing [3,4].

The use of cryogenic cooling for machining purposes was carried out in the1950s [5]. Cryogenic cooling is effected and quick removal method for heat generated while the machining processes and could be applied to almost types of materials [5]. In the cryogenic cooling process, the conventional cutting fluid is replaced by a cryogenic such as liquid nitrogen and CO_2, in this method usually liquefied gases, are intended into the cutting area to cool down the cutting tool and/or work piece. The cryogenic cooling liquids absorb the heat from the cutting zone and evaporate [5]. The machining by using cryogenic cooling is one of the most advantageous methods in metal cutting processes and improves the tool life; surface finish and reduce tool wear [6]. Experimental work has done by Domenico U. et al. [7] reported that the use of cryogenic cooling in machining processes significantly affects the surface integrity. In particular, cryogenic cooling conditions limit the white layer thickness and offer better surface roughness [7]. Ferri et al. [8], studied the effect of usage of cutting fluids during machining processes of the commercial aged hardened AA6082-T6 grade. They reported that the tools with the internal cooling system are very effective when compared to classic tools. Ravi et al. [9] have conducted an experimental work to optimize of turning process parameters of Al alloy 6082 using three types of cutting tools (HSS, Carbide and Cobalt tool). They have found that the optimum conditions are (900 rpm, 8º rake angle, 1.1mm depth of cut), (615 rpm, 4º rake angle, 0.9mm depth of cut) and (615 rpm, 4º rake angle, 0.7mm depth of cut) for HSS, Carbide and Cobalt tools respectively [9].

In the current study, manipulate of the cryogenic cooling with utilization of refrigerant R134a whilst the turning route of Al 6082 alloys on the surface roughness was investigated. The cutting tool geometry, cutting speed and feed rate factors were employed as the main parameters.

II. EXPERIMENTAL STUDY

I.1. Workpiece Material

Commercial Aluminum alloy grade AA 6082 T6 bars with a diameter of 30 mm were utilized in this experimental investigation. Two groups of the samples were produced. The first group is assigned to the "A" group, which was tempered to conversion heat treatment followed by an annealing process at 530-550ºC temperatures for one hour, and then cooled slowly to room temperature. By this way, the aging effect is eliminated.

A commercial grade of AA 6082 T6 Al alloy is aged and hardened at 170-200 ºC in the meaning of the T6 treatment concept; these samples coded as "B" group and their chemical composition is illustrated in Table 1. Si and Mg additives prove aging hardenability effect.

Table 1. The chemical composition of AA 6082 Al alloys (wt %).

Si	Mg	Mn	Fe	Cr	Cu	Zn	Ti	Other
1.05	0.8	0.68	0.26	0.01	0.04	0.02	0.01	0.05

Tensile tests with 1 mm/min constant speed were performed for "A" and "B" samples. Tensile and hardness tests results are shown in Tables 2 and 3 for the two groups respectively. The hardness test has been performed by Microwickers hardness test machine.

Table 2. Mechanical properties of "A" samples.

Proof Stress, 0,2	87 MPa
Ultimate Tensile Stress	155 MPa
Hardness	40 HB
Elongation	% 2.2

Table 3. Mechanical properties of "B" samples.

Proof Stress, 0,2	114 MPa
Ultimate Tensile Stress	210 MPa
Hardness, HV 0,1	70 HB
Elongation	% 12

I.2. Cutting Tool

TiN-coated carbide-cutting inserts (Taegu-Tec Company) were employed in the experimental work, Table 4 shows the main geometrical aspects of the cutting inserts were used. Insert holder type SVJCR 2020 K16 grade was used while the experiments.

Table 4. Properties of the turning cutting tool insert.

Tool nose radius	0.4 and 0.8 mm
Rake angel	6° and 18°
Coating type	TiN

I.3. Cutting Parameters

CNC turning machine type TAKSAN TTC 550 was utilized for the experimental tests (10 kW power and the maximum rotation speed of 6000 rev/min). Table 5 shows the cutting parameters were used in the tests.

Table 5. Cutting parameters.

Material	AA6082
Cooling method	Cryogenic
Cutting speed, V_c [m/min]	75, 100, 125
Feed Rate, *f* [mm/rev]	0.1, 0.2, 0.3
The depth of cut, *d* [mm]	0.5
Rake angle, γ [°]	6° and 18°

Refrigerant gas R134a was utilized for cryogenic cooling. It is safe for usual usage, non/toxic, non/flammable and non/corrosive. It transforms into gas form when exposed to the environment due to the fact that its boiling temperature is -26.1Cº, Table 6 illustrates the main properties of R134a.

Table 6. Properties of refrigerant (R134a).

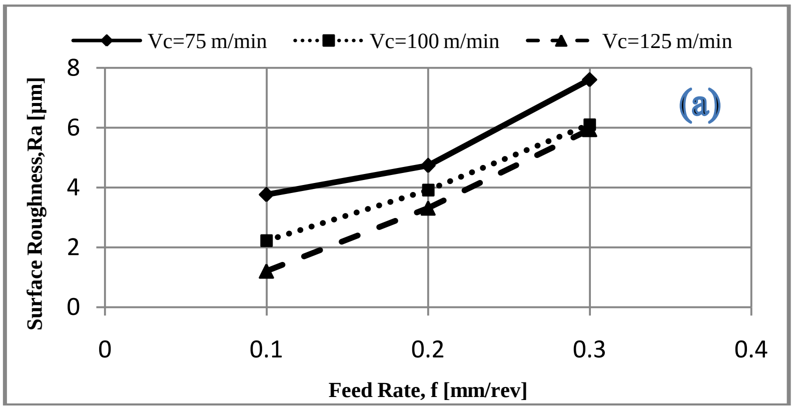
No	Properties	R-134a
1	Boiling Point	-26.1C°
2	Auto-Ignition Temperature	770C°
3	Ozone Depletion Level	0

I.4. Surface Roughness Measurements

The surface roughness (*Ra*, according to ISO 4287/1) was measured by employment of MAHR Marsurf PS1 device. Surface roughness measurements were taken to be the average value of the minimum of three measurements in different areas.

III. RESULT AND DISCUSSIONS

Surface roughness (R_a) results of the turning process for "A" and "B" samples vs. feed rate with the three different cutting speed (75, 100 and 125m/min), two different tool nose radius (0.4 mm and 0,8mm) and two different rake angles (6° and 8°) are given in figures 1-4. The figures show that the surface roughness values essentially increase with the increasing of the feed rate, tool nose radius and rake angle. The effect of feed rate is the mainly significant factor, the same result obtained by D. K. Suker et al. [10]. However, feed rate and tool nose radius are more efficient than the rake angle. Surface roughness values diminish with the increasing of cutting speed for the mutually samples. Optimal surface roughness values for "A" samples reached while using the rake angle of 18° and tool nose radius of 0.4 mm, and while utilization of the tool nose radius of 0.8 mm the surface roughness values has not observed clearly changing.



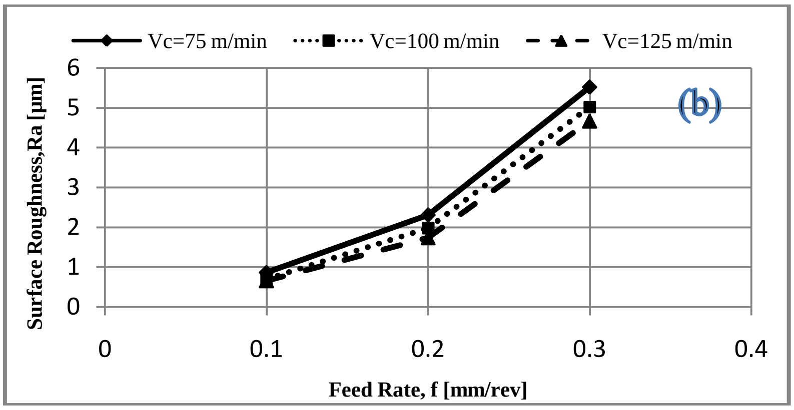


Fig. 1. Surface roughness vs. feed rate for "A" samples (tool nose radius 0.4 mm); (a) Rake angle of 6°, (b) Rake angle of 18°.

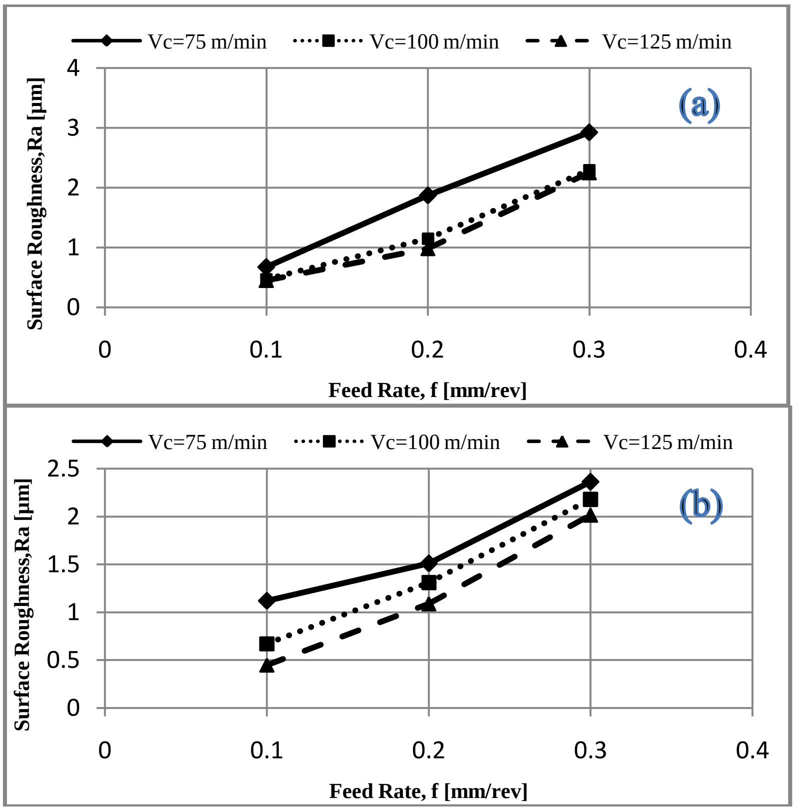
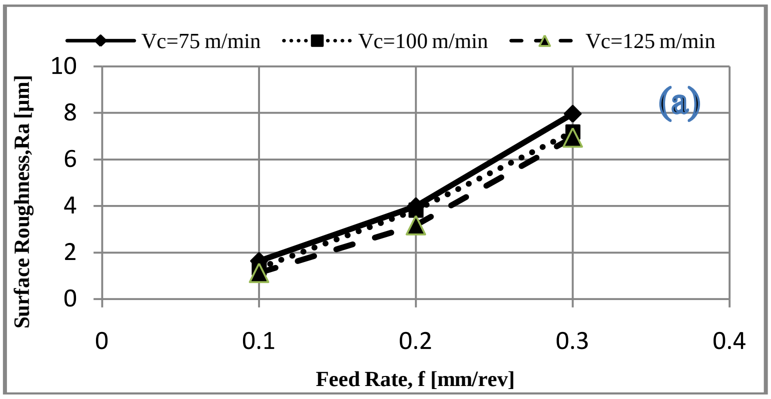


Fig. 2. Surface roughness vs. feed rate for "A" samples (tool nose radius 0.8 mm); (a) Rake angle of 6°, (b) Rake angle of 18°.

Higher surface roughness (R_a) values were obtained when using higher rake angle with tool nose radius of 0.8 mm for "B" samples, and the higher values of surface roughness for "A" samples observed while using the tool nose radius of 0.4 mm and rake angle of 6°. "B" samples showed small changes in surface roughness values for both tool nose radius (0.4 and 0.8 mm) with the three levels of cutting speed. It is observed from Fig.1(a) that as the cutting speed increases from 75 m/min to 125 m/min, the surface roughness reduces for the three levels of feed rate while using rake angle of 6°. The above trend of decreasing the surface roughness with an increase in cutting speed is because of the thermal softening effect. Further when using rake angle of 18° the outcomes of surface roughness remained closed to each other.

Pervious figures show that the increasing in the feed rate causes an increase in surface roughness, this related to the fact that the increasing of friction action between workpiece and tool cutting edge. In addition, the tool nose radius has a large effect on surface roughness; as the tool nose radius increases as the surface roughness increases. An increase in the cutting speed reduces the surface roughness; this could be linked to the thermal softening influence during machining [10].



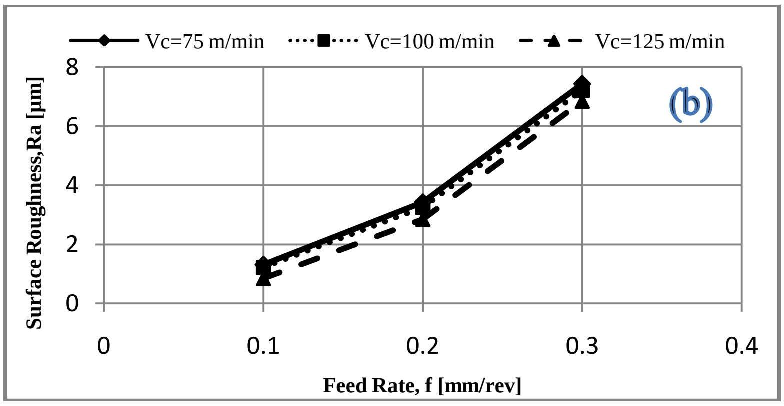
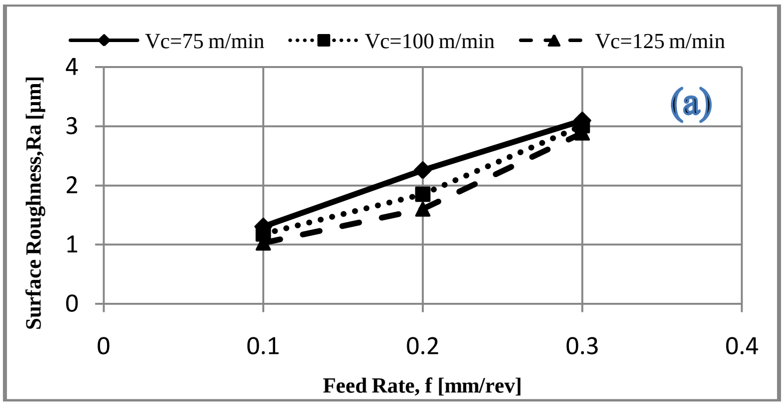


Fig. 3. Surface roughness vs. feed rate of "B" group samples (tool nose radius 0.4 mm); (a) Rake angle of 6°, (b) Rake angle of 18°.



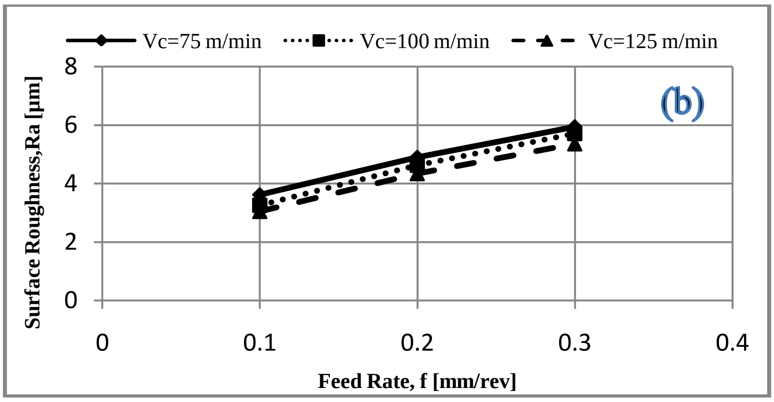


Fig. 4. Surface roughness vs. feed rate of "B" samples (tool nose radius 0.8 mm); (a) Rake angle of 6°, (b) Rake angle of 18°.

Figures 3 and 4 show the variation of surface roughness values for the various cutting speeds, feed rates, tool nose radius and rake angle during turning of “B” samples. Machining of the “B” samples using 0.4 mm tool nose radius has affected surface roughness in a bad way and the worst with higher feed rate. In some cases, cryogenic machining has negative effects, which reduce the cutting zone temperature and in turn this leads to diminishing the heat-softening phenomenon [6]. In addition, “B” samples show a decrease in surface roughness during using of (18^o) rake angle.

IV. TAGUCHI METHOD ANALYSIS

Taguchi method uses the signal-to-noise ratio (S/N ratio) to measure the quality characteristic deviates from the desired value. The smaller are the better characteristics type of S/N ratio was used in this statistical analysis. The experimental results are transformed to S/N ratios, the parameter with the higher differentiation between the mean of S/N ratios is the most significant control parameter.
Table 7 shows the ranks of the parameters resulted by S/N ratio for different parameter levels for surface roughness for “A” group samples.

Table 7. S/N ratios response table (smaller is better) of surface roughness for “A” samples.

Levels	Feed rate	Cutting speed	Tool nose radius	Rake angle
1	1.371	-7.248	-9.018	-6.553
2	-5.846	-4.822	-1.652	-4.118
3	-11.531	-3.935		
Delta	12.902	3.313	7.366	2.435
Rank	1	3	2	4

Table 8. S/N ratios response table (smaller is better) of surface roughness for “B” samples.

Levels	Feed rate	Cutting speed	Tool nose radius	Rake angle
1	-3.888	-10.206	-9.865	-7.948
2	-10.008	-9.664	-9.262	-11.179
3	-14.795	-8.821		
Delta	10.907	1.386	0.603	3.231
Rank	1	3	4	2

Table 7 shows that the most significant parameters affect the surface roughness for “A” samples which are the feed rate followed by tool nose radius, cutting speed and rake angle. The ranks of the parameters resulted by S/N ratio for different parameters levels for “B” samples are presented in Table 8; the most significant parameters affect the surface roughness for “B” samples are the feed rate followed by rake angle, cutting speed and the last is tool nose radius.

V. CONCLUSIONS

In this study, the refrigerant gas (R134a) was used for cryogenic cooling during the turning process of two samples of annealed AA 6082 and aged samples of AA 6082 T6. The influence of cryogenic cooling on the surface roughness was investigated. The following conclusions can be drawn based on the results of the experimentation:

(1) Cryogenic cooling is an environment friendly and has the largest impact on the improvement of surface finish.
(2) Increasing the feed rate causes an increase in surface roughness values because of the increasing of rubbing between the workpiece and cutting tool. Even the tool nose radius has a great effect on surface roughness. An increase in the tool nose radius increases the surface roughness.
(3) An increase in the cutting speed reduces the surface roughness; this is related to the thermal softening effect.
(4) Machining of the “B” samples, using of the 0.4 mm tool nose radius has affected surface roughness in a bad mode.
(5) The minimum value of surface roughness obtained is 0.450μm during the using the cutting speed of 125m/min, the feed rate of 0.1mm/rev, tool nose radius of 0.8mm, and rake angle of 6^o.
(6) The Taguchi method was used to conclude most favorable machining parameters: for “A” samples the most significant parameters affect the surface roughness are the feed rate followed by tool nose radius,

cutting speed and then rake angle. While for "B" samples the most significant parameters affect the (R_a) is the feed rate followed by a rake angle and cutting speed then tool nose radius.

In general, the "A" samples showed better surface roughness compared to the "A" samples.

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