Experimental Investigation of the Optimum Turning Surface Finish of Recycled 6061 Aluminum Alloy

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Abstract - *In manufacturing industries, emphasis is placed on the suitability for the use of the parts produced. The suitability for use also depends on the parameters and machining conditions and the nature of the material used during the shaping of the parts.*

As the use of recycled materials is topical, recycled aluminum alloy 6061 is the material chosen for the study. This study consisted in optimizing the parameters and machining conditions in dry turning and with wet, to guarantee a better surface quality of the alloy.

The design of experiment method was used to analyze the data, and the desirability function for the optimization of the feed rate and the cutting speed according to the machining conditions. This study allowed the implementation of a model to obtain the optimum surface roughness, the recycled alloy 6061, if the combination of parameters and cutting conditions is respected.

Key Words: Surface roughness, cutting parameters and condition, optimization, recycled aluminum alloy

1.INTRODUCTION

Manufacturing industries are generally concerned with the quality of products from the production process. As machining is one of the processes used in these industries, it appears that the quality of the surfaces generated is one of the aspects on which the emphasis is placed. In general, the surfaces produced have some defects that can have an effect on their suitability for use (functional constraints). These defects are due to the influence of several elements during machining. Among these elements are the conditions under which machining is done (with or without lubrication), since the quality of the surface depends on it. In addition to these cutting conditions, there are others such as: cutting parameters, the nature of the machined material, the geometry of the cutting tool, vibrations ...). The combination of all these elements therefore has a considerable impact on the generated surfaces defined in terms of surface roughness, mainly the average arithmetic roughness (Ra).

This study is made to determine the optimum surface roughness (Ra), depending on the combination of parameters and cutting conditions that have a considerable influence on the quality of the surface. We can realize that several research works have been done, to study and / or optimize the parameters and cutting conditions in order to look for the best surface finish on different materials (aluminum alloys, steels). Some research focuses on the effects of cutting parameters (feed rate, cutting speed, cutting depth) and lubrication conditions (dry machining, MQL, wet) Sasi Prasath Thangamani [1]. The MQL lubrication mode, according to Sreejith [2], is a good compromise between dry machining and wet machining for better surface quality. Y. Zedan et al [3] have shown that when machining alloy 6061-T6, dry and MQL, the increase in cutting speed leads to a decrease in surface roughness, and lubrication minimizes and eliminates the deterioration of the resulting surface. Other works such as those of Kouam et al [4] during the turning of the aluminum alloy 6061-T6, have shown that surface roughness is a function of the feed rate under different lubrication conditions. The surface finish of other aluminum alloys, such as 2024-T351, 7075-T6 and 6061-T65, is more influenced by the Kamguem et al tower lead [5]. By analyzing the influence of lap advance under different lubrication conditions on surface roughness, Leppert and Tadeusz [6] indicated that increasing the lead per lap leads to increased roughness and the MQl guarantees the best surface finish.

These studies are not limited to the search for the effects of cutting parameters and conditions. There is also the optimization of these parameters and cutting conditions to know the optimum of the surface roughness. Thus, several optimization methods are used. Statistical, analytical and experimental methods were used by KH. Chibane et al [7] to combine cutting parameters, in order to obtain predictive models of the surface roughness of a 100C6 steel. Taguchi's methods and analysis of variances were also used, in the studies of Vishal F et al [8] and Bouzid et al [9] for the optimization of the influence of cutting speed, cutting depth and feed rate, on the surface roughness when turning a mild steel (0.18% carbon). Modeling and optimization techniques with a significant influence in hard turning, were presented by Sudhansu Ranjan D et al [10]. For them, the Tagichi method and that of ANOVA are the most effective in controlling the effects of process parameters on the surface finish. Among the methods used, there is the one that imposes the definition of the desirability function. This desirability function was used by Derringer [11] and Myers et al [12], to find a result that varies between two extreme values 0 and 1, and by Ramana et al [13] to perform optimal parameter adjustment to reduce surface roughness.

With regard to the roughness of recycled materials, in particular aluminum alloys, Mandatsy et al [14,15] reported a difference in surface roughness between two recycled aluminum alloys, machined under the same conditions. They indicated a very significant influence of lubrication on roughness. Mandatsy et al [16] recycled and heat-treated aluminum alloy 6061, then did dry and lubrication machining to define models for evaluating surface roughness based on the feed rate, cutting speed and hardness of the material.

In order to continue the research in the same axis, but with recycled aluminum alloys, we use the study of Mandatsy et al [16]. In this study, they recycled by foundry the machining chips of aluminum alloy 6061. Some of these alloys obtained were heat treated to T6, others remained without heat treatment. They limited themselves to presenting roughness assessment models according to the most influential cutting parameters and conditions. This study therefore complements the optimization of the same parameters and cutting conditions in order to define a model for evaluating the optimum of surface roughness when turning untreated and treated recycled 6061 aluminum alloys.

This study includes a part on the experimental procedure and the material used, another part on the results and discussion, and finally a conclusion to close the study.

2. PROCEDURE EXPERIMENTALE

Figure 1 shows the three steps that make up the experimental procedure put in place to conduct the study. The first step was to apply the design of experiments (response surface method). The experimental designs were used to determine the relationship between the feed rate (f), the cutting speed (Vc), the lubrication mode (dry machining, wet machining) and the surface roughness (Ra), and then to define the models for assessing the surface roughness. The second step was to optimize the feed rate, cutting speed and lubrication conditions to have the optimums of surface roughness (maximizing and minimizing). Using the definition of the desirability function, as derringer [11] and Myers et al [12], the optimal values of the feed rate and the cutting speed according to the lubrication mode were obtained. In the end, the third stage focused on machinability testing. The results of the optimization were taken into account to generate surfaces, whose surface roughness was measured, in order to compare the results with the previous steps.

The data from a design of experiment (response surface) carried out by Mandatsy et al [16] were used to carry out this study.

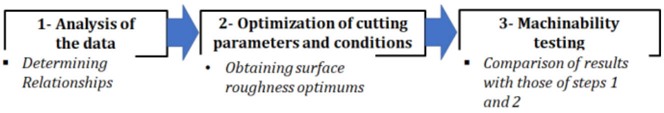

Fig-1 : Steps constituting the experimental procedure

Statgraphics software, software for design experiments, was used to analyze the data and perform the optimization. A multi-response optimization study by the desirability function was done to determine the combination of feed rate and cutting speed. This combination makes it possible to find the optimum (maximum and minimum) surface roughness of treated and untreated recycled 6061 alloys (obtained dry machining and wet machining). The desirability function was used considering that all surface roughness's have the same importance.

This study required the use of recycled aluminum alloys (untreated recycled 6061 alloy and T6-treated recycled 6061 alloy) produced by Mandatsy et al [16]. In this study, these alloys were designated as follows:

- Untreated recycled 6061 alloy : 6061-RNT
- Recycled 6061 alloy treated with T6: 6061-RT

The optimized values of the feed rate and the cutting speed were taken into account, to be introduced into the models of Mandatsy et al [16] in order to calculate the surface roughness. Then, machinability tests were done based on optimized the feed rate and cutting speed, and to measure surface roughness. For machinability tests, a turning machine was used, for dry machining and wet machining. Surface roughness measurements, a rugosimeter equipped withSurfPack-SJ data acquisition software, was used.

3. RESULTATS ET DISCUSION

Table 1 contains values of the surface roughness of each alloy obtained after each test (machining at a cutting depth of 0.6 mm) according to the cutting parameters considered (lap advance 0.05 – 0.13 – 0.2 mm/rev, cutting speed 100 – 155 – 210 m/min) and the cutting conditions considered (dry machining and wet machining).

Table -1: Surface roughness values at a cutting depth of 0.6 mm (Mandatsy et al [16])

		Dry machining		**Wet machining**	
f	**Vc**	**6061 R**	**6061 R-T6**	**6061 R**	**6061 R-T6**
0.2	**155**	4.771	3.856	2.618	1.5
0.05	**210**	3.336	1.971	1.69	0.866
0.13	**100**	3.907	2.662	1.91	1.108
0.2	**100**	4.513	3.724	2.506	1.375
0.05	**155**	2.83	1.889	1.67	0.873
0.05	**100**	2.602	1.867	1.633	0.824
0.13	**210**	4.611	3.703	2.1	0.951
0.13	**155**	3.801	3.655	1.9	0.965
0.2	**210**	5.023	3.976	2.879	1.479
0.13	**155**	3.801	3.655	1.9	0.966
0.13	**155**	3.801	3.655	1.9	0.968
0.13	**155**	3.801	3.653	1.9	0.965
0.13	**155**	3.803	3.655	1.904	0.965
0.13	**155**	3.801	3.655	1.906	0.965
0.13	**155**	3.801	3.657	1.9	0.968

The analysis of ANOVA has allowed to have models adjusted according to the form of the relation 1. (1)

$$Y = a_0 + \sum_{i=1}^{k} a_i X_i + \sum_{i=1,\, j\neq 1}^{k} a_{ij} X_i X_j + \sum_{i=1}^{k} a_{ii} X_{i^2} + \varepsilon$$

- With *Y* variable explained, X_i explanatory variable, X_iX_j interaction between explanatory variables, effect of the variable, a_{ii} effect of the quadratic term relative to i, a_{ij} effect of the interaction between i and j, ε term of unobservable errors of the model

The statistics R^2 for each alloy are very close to the value of 1. So, we have:

- R^2 explains 98.061% variability in the surface roughness of the alloy 6061-RNT, dry machined.
- R^2 explains 94.934% variability in the surface roughness of the alloy 6061-RT, dry machined.
- R^2 explains 99.654% variability in the surface roughness of the alloy 6061-RNT, wet machined
- R^2 explains 95.835% variability in the surface roughness of the alloy 6061-RT, wet machined.

Themodels obtained are slightly different from those of Mandatsy et al [16]. This difference is due to the fact that some values had been increased. Models 2 to 5 are those selected to be applied in the calculation of surface roughness. This analysis showed that the wet machining improves the surface finish. The improvement in surface finish is also related to the high hardness, the reduction of the feed rate and the nature of the alloy.

- Alloy 6061-RNT dry machined.

$$\begin{aligned} Ra &= 2.93921 + 19.6932 * f \\ &-208813.10^{-7} * Vc - 21.2695 * f^2 \\ &-133351.10^{-7} * f * Vc + 9185.10^{-8} * Vc^2 \end{aligned} \qquad (2)$$

- Alloy 6061-RNT wet machined

$$\begin{aligned} Ra &= 2.36409 - 7.13284 * f \\ &-7811.10^{-6} * Vc + 43.4722 * f^2 \\ &+19559.10^{-6} * f * VC + 234711.10^{-10} * Vc^2 \end{aligned} \qquad (3)$$

- Alloy 6061-RT dry machined.

$$\begin{aligned} Ra &= -1.8079 + 32.9551 * f \\ &+276009.10^{-7} * Vc - 86.9991 * f^2 \\ &+112776.10^{-7} * f * Vc - 799873.10^{-10} * Vc^2 \end{aligned} \qquad (4)$$

- Alloy 6061-RT wet machined

$$\begin{aligned} Ra &= 1.13654 - 4.88892 * f \\ &-154568.10^{-8} * Vc + 33.533 * f^2 \\ &+313341.10^{-8} * f * Vc + 359822.10^{-11} * Vc^2 \end{aligned} \qquad (5)$$

3.1 Optimization of cutting parameters

In order to optimize the surface roughness of alloy 6061-RNT (dry machined and with abundant lubrication) and alloy 6061-RT (dry machined and wet machined), the elemental desirability function (d_i) was used to maximize (relationship 6) and minimize (relationship 7).

$$d_i = \frac{y - y_{\max i-}}{y_{\min i+} - y_{\max i-}} \qquad (6)$$

$$d_i = \frac{y - y_{\min i-}}{y_{\max i+} - y_{\min i-}} \qquad (7)$$

With *Y* max – highest value of the response that is not suitable, *Y* mini + lowest value that is suitable, *Y* mini –

lowest value that is not suitable, *Y* maxi + strongest value of the response that is suitable

A common weight of 1 and a common impact of I=3 are considered, to make the combination of the advance per lap and the cutting speed, with the aim of simultaneously optimizing all surface roughness. Since optimization is multi-response, overall desirability (D) was defined according to elementary desirability. The overall desirability that presents a compromise between the advance and the cutting speed is calculated by the relationship 8.

$$D = \sqrt[n]{\prod_{i=1}^{n} d_i} \quad (8)$$

To maximize, the optimum value of desirability is 0.996044 for alloy 6061-RNT and 0.974986 for alloy6061-RT. The contour overlay graphs, Figures 2 and 3 show that the best points aren't at f = 0.2 mm/rev and Vc = 210 m/min. This gives:

- Alloy 6061-RNT, the optimum surface roughness is 5.132 µm for dry machining and 2.88 µm for wet machining (chart 1). Alloy 6061-RT, the optimum surface roughness is 4.049 µm for dry machining and 1.466 µm for wet machining (chart 2).

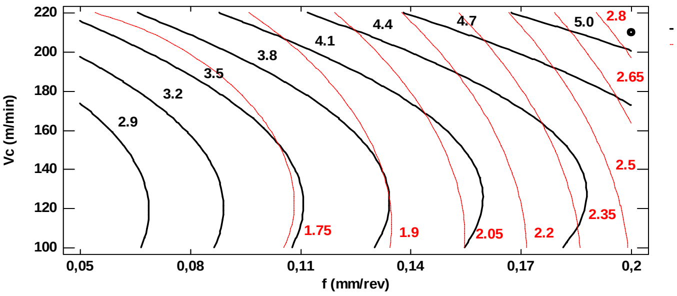

Chart-1 : Overlay graph showing the optimum surface roughness of alloy 6061-RNT

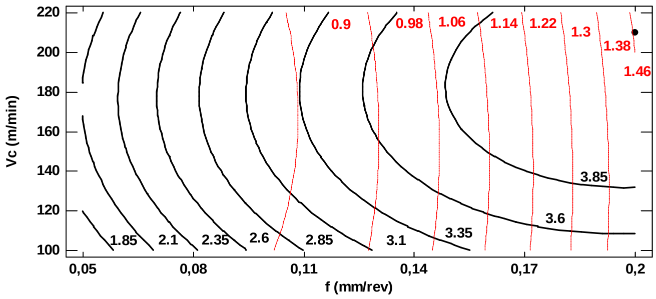

Chart-2 : Overlay graph showing the optimum surface roughness of alloy 6061-RT

To minimize, the optimum value of desirability is 0.9980022 for alloy 6061-RNT and 0.962218 for alloy6061-RT. The contour overlay graphs, Figures 4 and 5 show that the best points are at f = 0.05 mm/rev and Vc = 118.5 m/min (for alloy 6061 R) and 121.42 m/min (for alloy 6061-RT). This gives:

- Alloy 6061-RNT, the optimum surface roughness of 2.6 µm for dry machining and 1.63 µm for wet machining (chart 3). Alloy 6061-RT, the optimum surface roughness of 1.86 µm for dry machining and 0.86 µm for wet machining (chart 4).

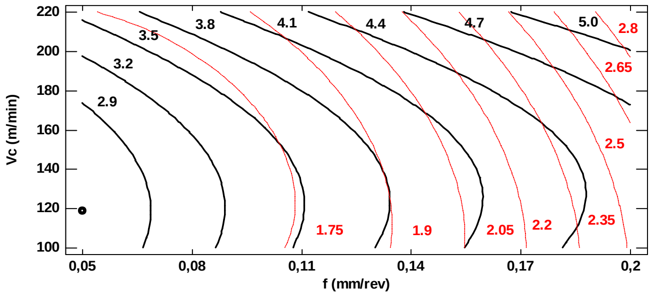

Chart-3 : Overlay graph showing the optimum surface roughness of alloy 6061-RNT

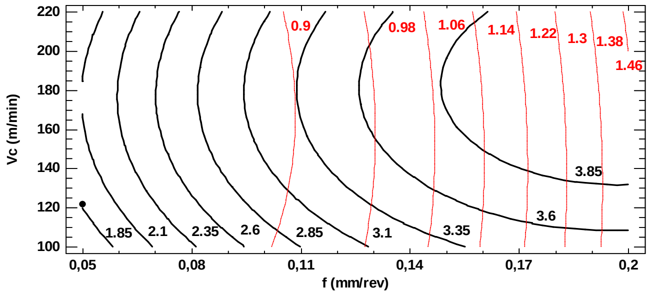

Chart-4 : Overlay graph showing the optimum surface roughness of alloy 6061-RT

3.2 Surface roughness calculations

To find the calculated values of surface roughness, models 2 to 5 were used. This calculation consisted in introducing into these models the optimized values of the feed rate and the cutting speed.

In the case of maximizing surface roughness, we have f = 0.2 mm/rev and Vc = 210 m/min for alloy 6061-RT and alloy 6061-RNT. The results are:

- Ra = 5.132 µm dry and Ra = 2.88 µm wet for alloy 6061-RNT.
- Ra = 4.049 µm dry and Ra = 1.466 µm wet for alloy 6061-RT.

In the case of minimizing surface roughness, we have f = 0.05 mm/rev, Vc = 118.5 m/min for alloy 6061-RNT and, f = 0.05 mm/rev Vc = 121.42 m/min for alloy 6061-RT. The results are:

- Ra = 2.607 µm dry and Ra = 1.633 µm wet for alloy 6061-RNT.
- Ra = 1.867 µm dry and Ra = 0.862 µm wet for alloy 6061-RT.

3.3 Measurement of surface roughness

The machinability tests (the trolley operation with a cutting depth equal to 0.6 mm) were carried out using as cutting parameters, the optimized values of the feed rate and the cutting speed, according to each case. Each test carried out, in dry machining and wet machining, required the use of a type of cutting tool (CPGT09T308HP, positive uncoated cut of grade KC5410, rε = 0.8 mm, α = 11°). After making three identical samples of each (length of 200 mm, diameter of the piece 50 mm), an average roughness of over face was made.

Tables 2 and 3 present respectively the optimum values of surface roughness measured when maximized and minimized.

Table -2: Optimum values of maximized roughness

	Paramètres de coupe		Ra (µm) Maximisée	
	f	Vc	Dry	Wet
6061-RNT	0.2	210	5.153	2.861
6061-RT	0.2	210	4.065	1.453

Table -3: Optimum values of minimized roughness

	Paramètres de coupe		Ra (µm) Minimisée	
	f	Vc	Dry	Wet
6061-RNT	0.05	118.5	2.617	1.63
6061-RT	0.05	121.42	1.887	0.859

These experimental results were compared with those calculated on the basis of models 2 to 5 and those of optimization. Charts 5 to 8 are graphs that show the differences between these results. On these graphs, there is a clear difference between the results, although this difference is very small.

When maximizing the roughness of the dry machined alloy 6061-RNT, chart 5 shows that the optimized surface roughness values (Ra = 5.132 µm) are identical to the calculated surface roughness values (Ra = 5.132 µm). On the other hand, they are different from the values of the surface roughness measured after machining (Ra = 5.153 µm). There is a slight difference denoted Δ (Δ=+0.021).

When machining is done wet machining, the optimized surface roughness values (Ra = 2.88 µm) are also identical to the calculated surface roughness values (Ra = 2.88 µm). On the other hand, they are different from the values of the surface roughness measured after machining (Ra = 2.861 µm). There is a slight difference denoted Δ (Δ=-0.019).

When maximizing the roughness of the dry machined alloy 6061-RT, chart 6 shows that the optimized surface roughness values (Ra = 4,049 µm) are identical to the calculated surface roughness values (Ra = 4,049 µm). On the other hand, they are different from the values of the surface roughness measured after machining (Ra = 4.065 µm). We see a slight difference denoted Δ (Δ=+0.016). When machining is done wet machining, the optimized surface roughness values (Ra = 1.466 µm) are also identical to the calculated surface roughness values (Ra = 1.466 µm). On the other hand, they are different from the values of the surface roughness measured after machining (Ra = 1.453 µm). There is a slight difference denoted Δ (Δ=-0.013).

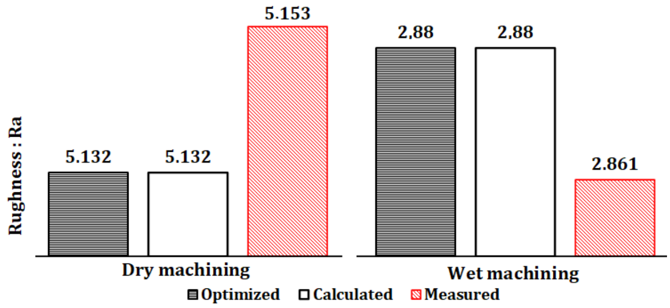

Chart-5 : Surface roughness values optimized for alloy 6061-RNT.

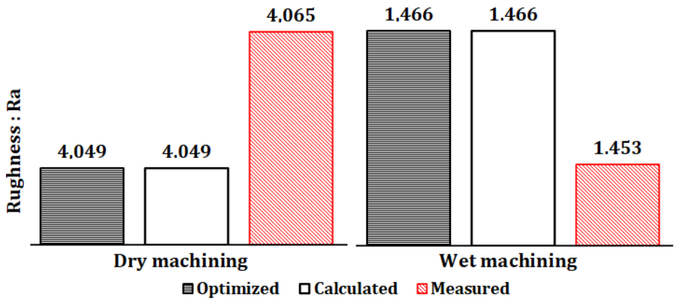

Chart-6 : Surface roughness values optimized for alloy 6061-RT.

When minimizing the roughness of the dry-machined alloy 6061-RNT, chart 7 shows that the optimized surface roughness values (Ra = 2,607 µm) are identical to the calculated surface roughness values (Ra = 2,607 µm). On the other hand, they are different from the values of the surface roughness measured after machining (Ra = 2.617 µm). There is a slight difference denoted Δ (Δ=+0.01). When machining is done wet machining, the optimized surface roughness values (Ra = 1.633 µm) are also identical to the calculated surface roughness values (Ra = 1.633 µm). On the other hand, they are different from the values of the surface roughness measured after machining ((Ra = 1.63 µm). There is a slight difference denoted Δ (Δ=-0.003).

When minimizing the roughness of the dry-machined alloy 6061-RT, chart 8 shows that the optimized surface roughness values (Ra = 1.867 µm) are identical to the calculated surface roughness values (Ra = 1.867 µm). On the other hand, they are different from the values of the surface roughness measured after machining (Ra = 1.887 µm). We dare a slight difference denoted Δ (Δ=+0.02). When machining is done wet machining, the optimized surface roughness values (Ra = 0.862 µm) are also identical to the calculated surface roughness values (Ra = 0.862 µm). On the other hand, they are different from the values of the surface roughness measured after machining (Ra = 0.859 µm). There is a slight difference denoted Δ (Δ=-0.003).

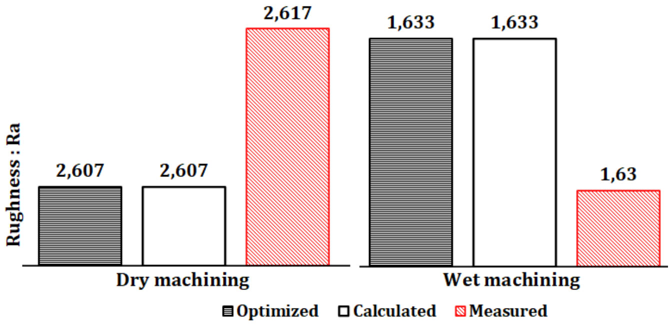

Chart-7 : Surface roughness values optimized for alloy 6061-RNT.

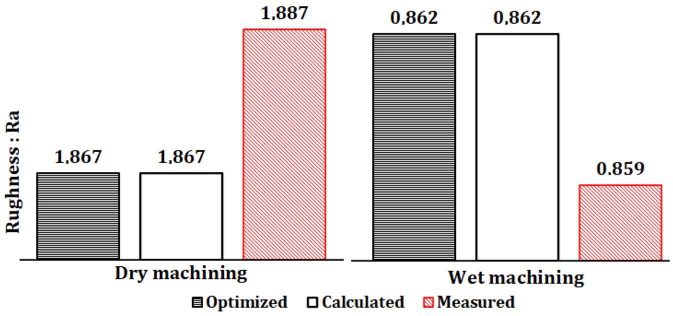

Chart-8 : Surface roughness values optimized for alloy 6061-RT.

In addition to the study by Mandatsy et al [16], the variation Δ is added to models 2 to 5, to evaluate the surface roughness of aluminum alloys 6061-RNT and 6061-RT when machined dry or wet machined. Model 9 can therefore be considered.

$$Ra = Ra_{opti} \pm \Delta \quad (9)$$

+Δ will apply to both recycled aluminum alloys when machined dry, and −Δ when wet machined.

4. CONCLUSIONS

At the end of this study, it appears that the machining of two aluminum alloys 6061-RNT and 6061-RT is possible when there is a combination of parameters and cut conditions by applying model 9.

- If it is necessary to maximize the surface roughness, it is possible to combine the feed rate (0.2 mm/rev) with the cutting speed (210 m/min) to have an optimum surface roughness by dry machining and wet machining.
- If it is necessary to minimize the surface roughness, it is possible to combine the feed rate (0.05 mm/rev) with the cutting speed (118.5 m/min) to have an optimum surface roughness (alloy 6061-RNT) and the feed rate (0.05 mm/min) with the cutting speed (121.42 m/min) to have an optimum roughness (alloy 6061-RT by dry machined and wet machining.

This study also indicated the influences of lubrication and alloy type on surface roughness. In any case, wet machining improves the surface finish well regardless of the material. The surface finish of alloy 6061-RNT is significantly better than that of alloy 6061-RT.

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