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Parametric Optimization of Machining Criteria for Al 6068 Aluminum Alloy using in Manufacturing Process of Aircraft *

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ABSTRACT

In the aviation industry, it is essential to use parts that are lightweight but durable, and aluminum alloys generally provides effective solutions. In manufacturing processes, automation-based production techniques and robotic and efficient processing processes such as Computer Numeric Technique (CNC) are used, and it is important to define optimum production parameters. In this study, parametric optimization values of machining criteria were developed for the milling operation of AL 6068 aluminum alloy. For this purpose, Response Surface Method (RSM) was used for optimal solutions of parametric values and evaluation of relationships. According this, optimum processing parameters were determined to be 1521 rpm revolution speed, 0.4 mm depth of cut, and 197 mm/min federate. These manufacturing parameters were evaluated. A quadratic regression equation giving the surface roughness was created for this operation. At the end of the study, some suggestions were made regarding the improvement of production efficiency based on the parameters defined.

Keywords: Surface roughness, Response Surface analysis, Al 6082, Milling

I. INTRODUCTION

With the development of material technologies, many parts can be produced from aluminum alloys in the aviation. Both lightness of aluminum alloys and their strength have made a big contribution to the development of aircrafts. Today, 70% of Boing 777 is produced from an aluminum alloy [1].

Technological change in manufacturing technologies has also provided versatile advantages. However, in some special parts manufacturing, especially thin-walled parts, gap and tolerance changes that occur in material shaping according to the original structure are seen as important problems [2,3]. The main reason for this situation may be due to processing and technology, as well as elastic deformation, which jeopardizes production accuracy in manufacturing, as an effect due to material surface roughness. In fact, all these processes are related to many criteria, from cutting parameters to toolpath strategy [4–6].

Choosing safe and light materials in the aviation industry is essential. Aluminum alloys meet these needs [7]. There are some studies on the machinability of aluminum alloys used in the aviation industry. Turning process optimization of AL6082 alloy was made by Palaniappan et al. They used the Signal/Noise analysis for the optimization process [8]. Kulkarni et al. investigated of Al7075-T6 milling operation. They used minimum quantity lubrication technique [9]. Das et al. investigated the surface roughness of aluminum alloy, and they found that surface roughness reduces via increasing spindle speed [10].

Producing low cost and desired quality parts in machining processes is one of the main factors. These two factors are directly affected by processing parameters. Machining parameters include factors such as cutting speed, feedrate, depth of cut, and the number of inserts, etc. Each machining parameter has a significant impact on the dimensional integrity and surface roughness values of the workpiece.

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Various aluminum alloys are used in the aviation industry. AL6082, one of these aluminum alloys, is used in aerospace applications due to its high corrosion resistance, high machinability, and good weldability [11–13]. Traces (surface roughness) occur on the part surface as a result of the movement of the cutting tool in the CNC milling machine. This surface roughness must be within certain tolerances. For this reason, surface roughness optimizations are made in machining operations in the literature. In this study, machining optimization of AL 6082 aluminum alloy was made by response surface methodology. Average surface roughness (Ra) was optimized, and the machining parameter's effects were defined.

II. MACHINING OF AIRCRAFT STRUCTURES

Parts are produced from different alloys depending on the usage area. Many parts made of aluminum alloys are used in various regions of the airplane. Aluminum materials are generally taken as slab and machined on CNC machines. For example, the window frame, horizontal tail plain, aircraft beam etc. parts produced by machining on a CNC milling machine. In Figure 1, a sample of commercial airline seat frame was given and in Figure 2 landing gear of a military transport aircraft was given.

Figure 1 Commercial airline seat frame [14].

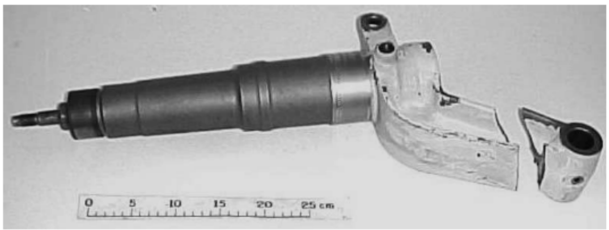

Figure 2 Landing gear of a military transport aircraft [15].

As can be seen from the figures above, these parts must be produced precisely. Nowadays, such parts are machined on CNC machines. With CNC machines, parts can be produced with a low rate of waste and with desired tolerances.

During the cutting process in the CNC milling machine, surface roughness occurs on the cut surface due to the movement of the cutting tool. Surface roughness is one of the indicators of the usability of the parts. Roughness on the surface can not only look bad but also reduce the strength by creating a notch effect. It is desired that the surface roughness be as low as possible. Therefore, sometimes polishing operation can be performed after the machining operation (Figure 3).

Figure 3 Machined and polished views of turbine blade [1].

For industrial producers, the polishing operation creates an additional cost. Optimization of the cutting parameters is needed to avoid this cost. Thus, the desired surface roughness can be achieved during processing on CNC milling machine without polishing operation. In this study, parameter optimization has been made to minimize the surface roughness.

III. SETUP AND METHODOLOGY

In this study, AL6082 aluminum alloy was machined by HAAS TM-1HE CNC milling machine. Firstly, parts were cut to 30mm*30mm. Later, they were machined by Ø6mm HSS end mill. All cutting operations were done with the tool 10 mm below the part top surface.

When the literature is searched, it is understood that the rotation speed of the cutting tool (RPM), the pass amount (Ap), and the feedrate (F) are generally used as parameters in machining operations [16–18]. These parameters were also considered in this study. The rotation speed of the cutting tool in 1 minute (RPM), the depth of cut (Ap), and the movement speed of the cutting tool in 1 minute (F) were selected as parameters.

Three different levels are determined for each parameter. The experimental setup was given in Table 1. A view of the machining operation was given in Figure 4.

Figure 4 Cutting process

Table 1 Experimental Setup

Experiment No	Rpm	Ap	F
1	1650	0.4	100
2	800	0.8	100
3	2500	0.8	100
4	1650	0.4	300
5	1650	0.8	200
6	1650	1.2	100
7	800	0.4	200
8	2500	0.8	300
9	800	0.8	300
10	1650	1.2	300
11	2500	1.2	200
12	800	1.2	200
13	1650	0.8	200
14	2500	0.4	200
15	1650	0.8	200

The surface roughness of the parts parallel to the cutting process was measured three times. Later, average surface roughness (Ra) was determined by calculating their averages. A view of the measuring process was given in Figure 5.

Figure 5 Measuring of surface roughness

The response surface method is an optimization method that enables the optimization of experimental results starting from the experiment design. The response surface method is widely used in experimental studies for parameter optimization [19–21]. Response surface method includes the design of the experiment set that will provide reliable measurement of the answer variable, the establishment of the model that will provide the best fit to the data collected according to the experiment set, and the determination of the factor levels that give the optimum response value [22]. In this method, the regression analysis of the experimental results is made. Then variance analysis is done. And finally, the optimum parameter levels are determined. The flow diagram of the response surface method was given in Figure 6. In this study, response surface analysis was made with the help of Minitab 18 software.

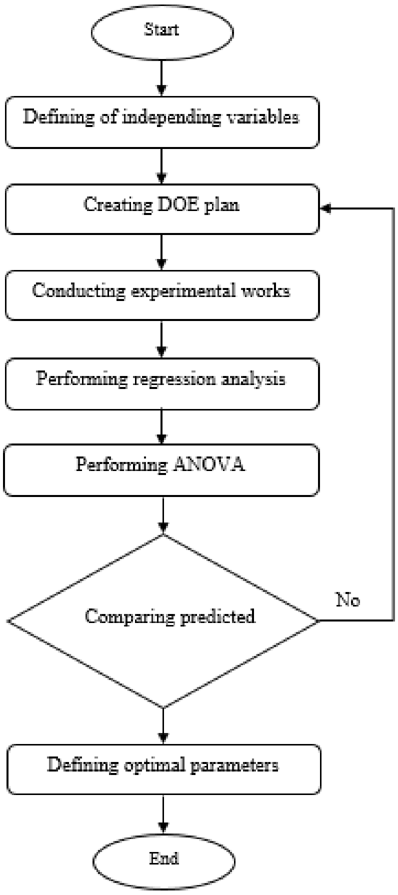

Figure 6 Flow diagram of response surface method.

The response surface method aimed at optimizing the effects of independent variables on the dependent variable [23]. This method is used to analyze and model the relationship between experimental parameters and results, and to determine the optimum parameter level [24]. In this study, the effects of the parameters on the surface roughness were investigated using the response surface method.

IV. RESULTS AND DISCUSSION

The surface roughness of the parts was measured three times. The arithmetic means of the measurement results were calculated. Measurement results were given in Table 2. Standard deviations of 3 measurements were also given in the table. The largest standard deviation is 0.095. This shows that the measurements are reliable.

Table 2 Measurement results

Exp. No	Measurement No			Ra (µm)	Standard deviation
	1.	2.	3.		
1	0.701	0.693	0.658	0.684	0.019
2	1.156	1.378	1.205	1.246	0.095
3	1.749	1.569	1.629	1.649	0.075
4	0.607	0.559	0.617	0.594	0.025
5	0.712	0.759	0.830	0.767	0.049
6	0.841	0.833	0.831	0.835	0.004
7	0.562	0.649	0.630	0.614	0.037
8	1.275	1.160	1.291	1.242	0.058
9	1.609	1.607	1.541	1.586	0.032
10	0.541	0.472	0.579	0.531	0.044
11	0.610	0.695	0.658	0.654	0.035
12	1.170	1.037	1.081	1.096	0.055
13	0.457	0.575	0.449	0.494	0.058
14	0.852	0.739	0.843	0.811	0.051
15	0.655	0.814	0.760	0.743	0.066

The smallest surface roughness was obtained in experiment 13. In this experiment 1650 rpm, 0.8mm Ap, and 200 mm/min F were used. Machined part's surfaces were given in Figure 7. The photos were taken with a 32-megapixel camera. The defects on the surfaces of parts with large surface roughness such as Experiment 9, Experiment 3 and Experiment 2 can be seen.

Surface plot of parameter effects was given in Figure 8. While intermediate values of federate (F) and revolution speed (Rpm) according to the figure reduce the surface roughness, the opposite effect occurs in the depth of cut (Ap). There is a critical level in the depth of cut. Working at this critical threshold level (about 0.8 mm), a worse surface roughness result. When working below this critical threshold, surface roughness decreases. On the other hand, values close to the medium level in feedrate and revolution speed create a better surface roughness.

The use of high feedrate causes the formation of high shear forces and low shear angle [25]. This negatively affects the surface quality. Increasing depth of cut also increases the surface roughness [26].

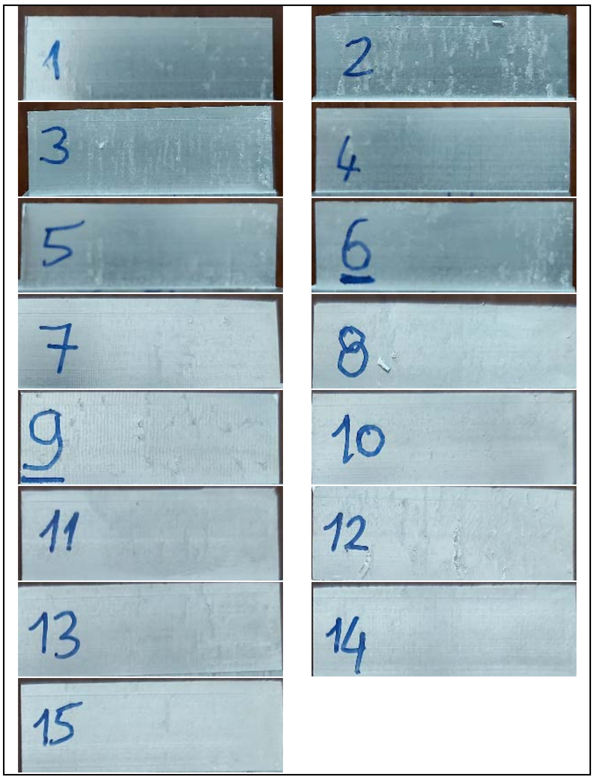

Figure 7 Machined surfaces.

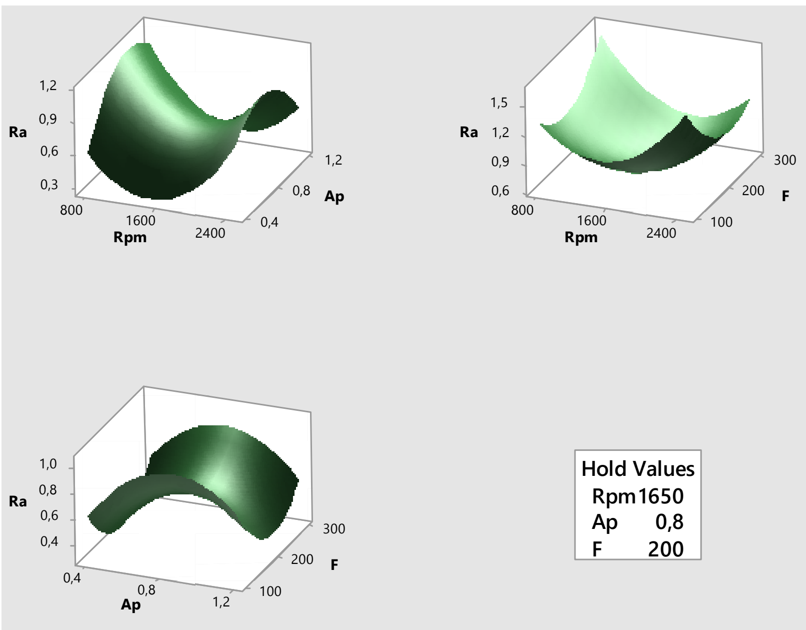

Figure 8 Surface plot of parameter effects

The optimization plot obtained from the surface response method analysis was given in Figure 9. According to the optimization chart, the best surface roughness occurs when using 1521 rpm revolution speed, 0.4 mm depth of cut and 197 mm/min federate.

The regression equation obtained as a result of the analysis made with the response surface method is given in Equation 1.

$$Ra = 0.825 - 0.001258 * Rpm + 4.392 * Ap - 0.00848 * F + 0.000001 * Rpm^2 - 2.012 * Ap^2 + 0.000032 * F^2 - 0.00047 * Rpm * Ap - 0.000002 * Rpm * F - 0.00134 * Ap * F \quad (1)$$

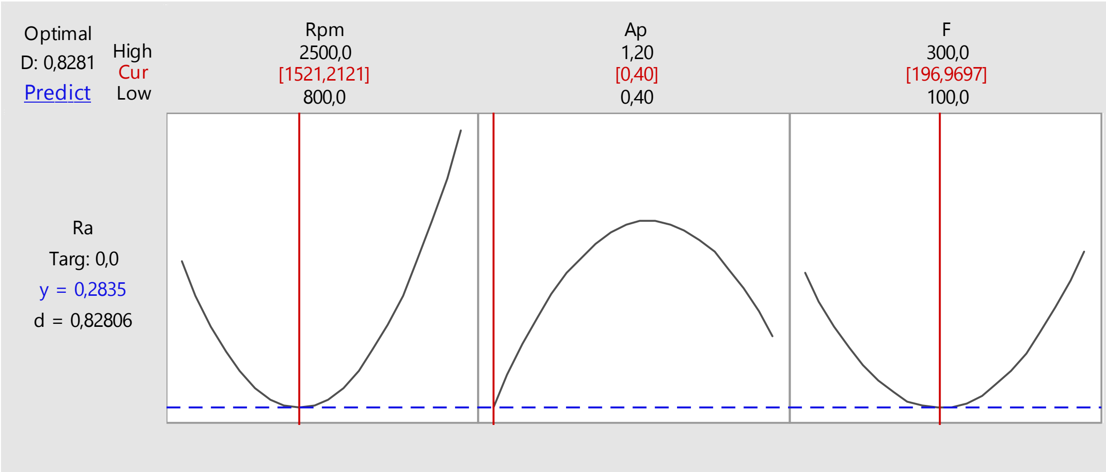

Figure 9 Optimization plot

According to Viletta et al., surface roughness in the aviation industry must be within class N7 (0.8 µm <Ra <1.6 µm) [27]. When Table 2 is examined, it is seen that all surface roughness obtained in this study meet the N7 standard. This shows that the study results can be used industrially.

V. CONCLUSIONS

In this study, surface roughness optimization of AL 6068 aluminum alloy's milling operation was made. The response surface method was used as an optimization method. Second-order regression equation was created for surface roughness. Optimum parameter levels were determined. Thus, cutting process accuracy improved. The following results were reached in this study:

- A second-order regression equation is developed that can be used to predict surface roughness.
- Optimum machining parameter levels: 1521 rpm revolution speed, 0.4 mm depth of cut and 197 mm/min federate.
- When there is no harmony between cutting parameters, visible defects may occur on the part surface.
- Too small and too large feedrate have a negative effect on the surface roughness.

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