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New model end milling parameters based on screening test on aluminum alloy (aa6041)

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Abstract

The manufacturing industry aims to achieve high productivity and quality products in the production process. Many factors have direct and indirect influences on realizing the two production objectives. Among them are part geometry, process conditions, and the environment. The correct and best process selection must be made on the right machine with the optimum parameters in the machining process application. This paper presents the results of screening studies performed on a milling process involving milling parameters such as the cut speed, feeding speed, depth of cut, cutting width, and flute. The screening results aim to decide the optimal milling parameters for the process. The screening process was performed on a CNC Milling HAAS machine using aluminum alloy (AA6041) with end mill cutter HPMT 303 1000 070 and HPMT S42 1000 072 of AL SE STD Ø10 utilized in dry cutting conditions. The results of this screening process were then analyzed through ANOVA with the help of Minitab 19.0 using the Taguchi method. In this work, three sets of machining parameters obtained from the screening process were then applied in experimental work, whereby the surface finish outcomes become the basis for determining the quality of the process based on the maximum surface roughness value.

Keywords: Taguchi method; optimum machining parameters; screening operation; CNC milling; surface roughness

Abstrak

Industri manufaktur bertujuan untuk mencapai produktivitas tinggi dan produk berkualitas dalam proses produksi. Banyak faktor yang memiliki pengaruh langsung dan tidak langsung dalam mewujudkan kedua tujuan produksi tersebut. Diantaranya adalah geometri bagian, kondisi proses, dan lingkungan. Pemilihan proses yang benar dan terbaik harus dilakukan pada mesin yang tepat dengan parameter optimal dalam aplikasi proses pemesinan. Makalah ini menyajikan hasil studi penyaringan yang dilakukan pada proses penggilingan yang melibatkan parameter penggilingan seperti kecepatan potong, kecepatan pengumpanan, kedalaman potongan, lebar pemotongan, dan seruling. Hasil penyaringan bertujuan untuk menentukan parameter penggilingan yang optimal untuk proses tersebut. Proses penyaringan dilakukan pada mesin CNC Milling HAAS menggunakan paduan aluminium (AA6041) dengan pemotong end mill HPMT 303 1000 070 dan HPMT S42 1000 072 dari AL SE STD Ø10 yang digunakan dalam kondisi pemotongan kering. Hasil dari proses skrining ini kemudian dianalisis melalui ANOVA dengan bantuan Minitab 19.0 menggunakan metode Taguchi. Dalam pekerjaan ini, tiga set parameter pemesinan yang diperoleh dari proses penyaringan kemudian diterapkan dalam pekerjaan eksperimental, di mana hasil permukaan akhir menjadi dasar untuk menentukan kualitas proses berdasarkan nilai kekasaran permukaan maksimum.

Kata kunci: Metode Taguchi; parameter pemesinan optimal; operasi penyaringan; Penggilingan CNC; Kekasaran permukaan

INTRODUCTION

Various machining processes in the manufacturing industry produce high-quality products. An effective manufacturing process produces products of the proper dimensions and precision. One classical example is the milling operation, which disposes of material quickly with excellent surface finishing results. Surface finish measurement is most commonly used as an indicator to determine

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the physical quality of the product, which would then dictate whether the product is accepted or rejected [1]. The surface finishes of machined components primarily impact their performance and function [2]. Conventionally, manufacturing processes are prepared to derive the maximum productivity with minimum cost. Also, the surface quality is influenced by the deviation. If the deviation is significant, the surface will be rough; if the deviation is slight, the surface will be smooth [3].

Materials with high strength have been manufactured due to many material engineering and technology developments. Choosing an appropriate cutting tool for removing chips from these materials is an important decision affecting the machining process's overall efficiency [4]. Currently, aluminum alloys are widely used as primary materials in various parts and products, such as in the automotive industry. The aluminum alloy cutting process is a manufacturing process that is predominantly used in the automotive industry as well as for manufacturing mold and die components in the die casting process.

Milling is part of the machining process in which material is clamped in a fixture on the positioning table and feeds past a rotating cylindrical tool with multiple cutting edges. The milling cutter's perpendicular rotation works against the cutting edge's direction on the plane surfaces created through a straight milling process. The choice of cutting tool and the cutting geometry's form must be suitable and correct to alleviate the effect of the cutting force and heat caused by the machining operation. The milling process is often used for its high material removal rate.

The two main challenges of the metalworking industry are improving the quality of manufactured products and reducing the cost of production. These are possible through effectively selecting cutting parameters, tool materials, cutter geometries, material removal technology, lubricants, etc. These selections are often based on a trial and error to meet the production objectives. In this research, the Taguchi method was chosen to analyze the milling parameters in producing the minimum roughness value (Ra) of surface roughness in the milling operations [5]. Taguchi method [6] has been widely used as the primary technique for process parameter optimization, including cutting speed, feed speed, depth and width of cut, and number of tooth as described in figure 1.

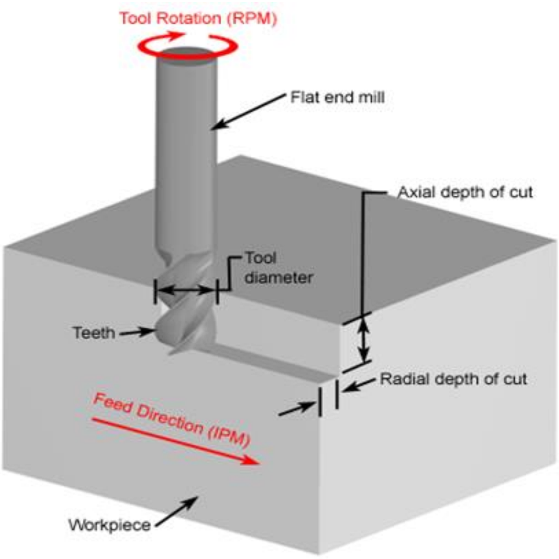

Figure 1. Straight side milling process (custompart.net)

This paper is presented as follows. The section system framework explains the overall framework of the work, including the test setup, methodology, Taguchi in Varian analysis, and experimental method, including information on material, machine capacity, and the design of the experiment. Next, it presents and discusses the experimental results. Finally, the end of the section concludes the primary findings of this work.

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SYSTEM FRAMEWORK

This section introduces the test setup and methodology comprising the Taguchi method applied and the experimental setup.

Methodology

Figure 2 shows the overall flow diagram of the experimental setup. The independent variables selected in the screening process were the cut speed, feeding speed, cutting depth, cutting width, and amount of tooth (flute). Of these five independent variables, optimum parameters are determined. These optimum parameters form the basis for developing the model that predicts surface roughness values in each experiment [7]. The optimum parameters were synthesized using the Taguchi method and analysis of the variants table in Minitab 19.0.

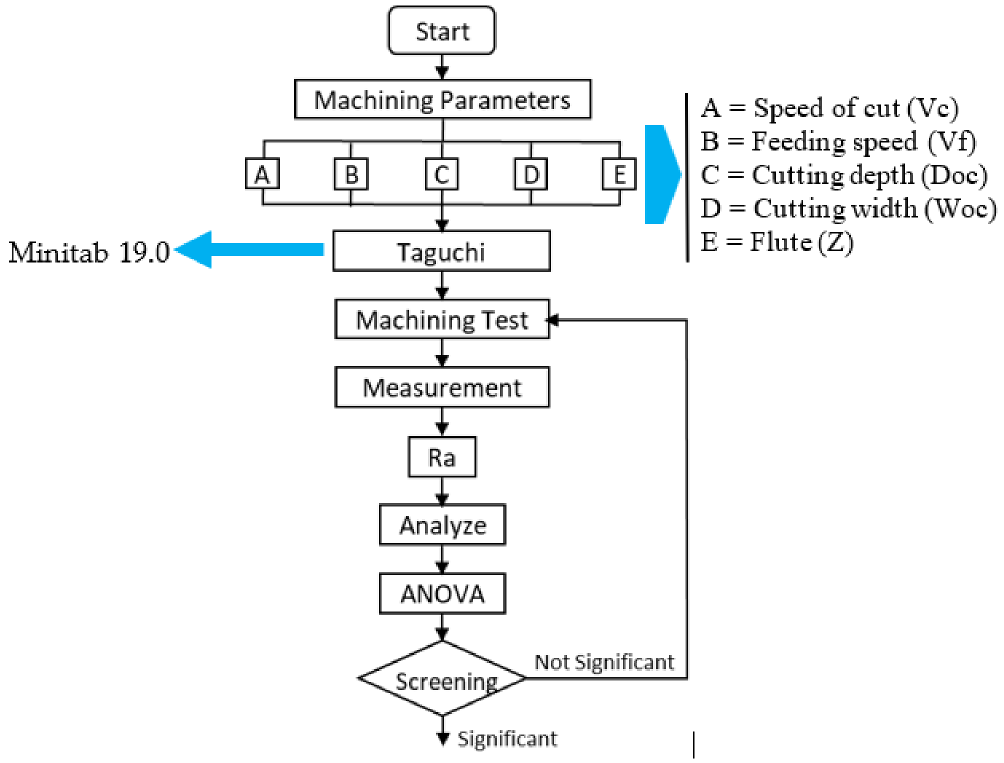

Figure 2. Experimental flow diagram for screening process

The Taguchi method [5], [6], [7] reduces the number of experiments required using orthogonal arrays and minimizes the effects of outside influences. In addition, it reduces experiment time and costs and yields the desired factors in a shorter period [8].

The average disagreement for the output response of the experimental results in each parameter context can be shown in the orthogonal array matrix (OA). This response is then analyzed through a single performance standard using the signal-to-noise (S/N) ratio. S/N ratios can be categorized as "smaller-better", "bigger-better", and "nominal-better," in which a typical response advantage category is considered [9]. The experiments require a shorter response in the surface process of swirling tool on the aluminum alloy. Therefore, the S/N ratio of “Smaller is the better” (minimize) was selected [10]. It was calculated using Equation (1) below.

$$\eta = \frac{S}{N} = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} {Y_i}^2 \right) \quad (1)$$

Where Yi is the experimental results of the data observed and n is the observation number of the experiment. The Taguchi method was applied with the Minitab software to analyze variants (ANOVA) that produced an unspoiled signal-to-noise (S/N) ratio output. This value was used to measure experimental design variations. The S/N ratio increases the control factor measured in terms of

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quality characteristics, namely the quality improvement achieved from the reduced variability. The S/N ratio characteristic was chosen according to the experiment response. For this reason, using the Taguchi orthogonal array can minimize the number of experiments [11]. Minitab 19.0 was applied with array L8*25, employing factors equal to 5 for the screening process. The screening test and Minitab 19.0 produce small run numbers, and the variant analysis (ANOVA) output was still unspoiled. By ANOVA, the effects of the cutting parameters on the workpiece's surface were determined [12]. Many researchers have been used in Taguchi to optimize several machining processes such as milling, turning, drilling, etc. [13]. The regression analysis of Ra values versus cutting speed (Vc), feeding speed (Vf), depth of cut (Doc), width of cut (Woc), and flute (Z) is given by,

$$Ra = -0.017 - 0.002310V_c + 0.000289V_f + 0.695D_{oc} + 0.0215\mathrm{Woc} + 0.0415\mathrm{Z} \quad (2)$$

Figure 3 illustrates the typical probability plot of the roughness value, which describes the relation between the cut speed, feeding, depth and width of cut, and tooth amounts.

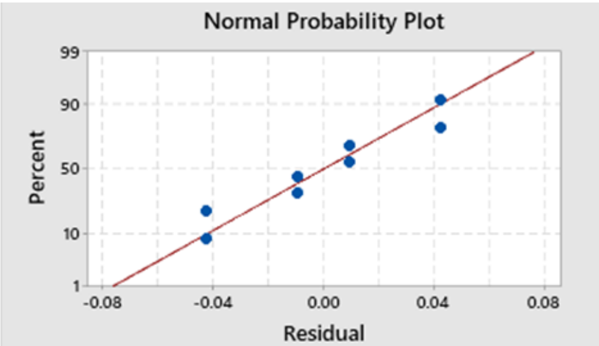

Figure 3: Normal probability

The results showed no outliers. The normal probability plot indicated normal data distribution, while the variables influenced the process's response. The Ra equation then represents the results of Figure 4. The surface roughness value (Ra) was measured using a roughness tester, and the response Material Removal Rate (MMR) was calculated below [14].

$$\boldsymbol{MMR} = \frac{(\boldsymbol{Wi} - \boldsymbol{Wf}).\mathbf{1000}}{(\boldsymbol{Dw}.\boldsymbol{t})} \quad (3)$$

Wi is the first weight in grams, Wf is the last weight in grams, t is the machining time in minutes, and Dw is the Aluminium Alloy density in gr/cm3. The specimen's chemical composition was obtained using Optical Emission Spectroscopy in WAS Foundry Master with ASTM E 1251 standard. The specimen material was identified as AA6041 based on the Designation of International Alloy and Chemical Composition for Wrought Aluminum and Aluminum Alloy with the chemical composition listed in Table 1. This specimen was selected because it has good mechanical properties and is often used in automotive and aerospace components.

Table 1: Chemical composition of aluminum

Element	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Ni	Pb	Zn
Wt (%)	96.3	0.103	0.24	0.138	2.31	0.109	0.639	0.014	<0.005	0.004	0.005

A 3-axis milling machine HAAS VF-1D was employed to experiment using end mill cutter HPMT 303 1000 070 and HPMT S42 1000 072 of AL SE STD Ø10 utilized in dry cutting condition at 750 rpm value according to the tool geometry and work piece [15]. The experimental design aimed to

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determine the influence of machining parameters on the surface roughness, which was investigated through variations in spindle speeds, feeding speed, and cutting depth. The Taguchi method was applied using the orthogonal array to observe the involved parameters with fewer experiments, thus reducing the effects of factors that cannot be controlled. In addition, this method provides a simple, efficient, and systematic approach to determine the optimal machining parameters in the manufacturing production process. The first step was identifying the quality characteristics and selecting the machining parameters. The machining parameters selected were the cutting speed (Vc), feed speed (Vf), cutting depth and width (Doc), and an additional parameter, the tool geometry.

Table 2 lists the range of selected parameters based on the manufacturer's recommendations. Next, the experiment's design (DOE) was performed using Minitab 19.0 with array L8*25 employing factors equal to 5.

Table 2: The parameters of the milling process

Process Parameters	Level		Units
	Low	High	
Cutting speed (V_c)	100	220	m/min
Feeding speed (V_f)	150	1681	mm/min
Depth of cut (D_{oc})	0.1	0.5	mm
Width of cur (W_{oc})	4	6	mm
Flute (Z)	3	4	

The Taguchi array results were produced based on data From table 3, which is listed in table 4. L8 is the orthogonal array selected for the milling process at high speed. The machining parameters of the various columns of the orthogonal array were assigned with the OA matrix. The surface roughness of the machined surface was influenced by the machining parameters such as speed, feed, flute, depth**,** and cutting width. Here, the five parameters were considered**,** and each parameter was set at four levels in Taguchi. Table 3 tabulates the machining parameters.

Table 3: Parameters of milling process

Run	V_c (m/min)	V_f (mm/min)	D_{oc} (mm)	W_{oc} (mm)	Z
1	100	150	0.1	4	3
2	100	150	0.1	6	4
3	100	1681	0.5	4	3
4	100	1681	0.5	6	4
5	220	150	0.5	4	4
6	220	150	0.5	6	3
7	220	1681	0.1	4	4
8	220	1681	0.1	6	3

RESULTS AND DISCUSSION

The surface roughness values (Ra) were measured as the experiments' output using the WAS Foundry Master with an ASTM E 1251 standard surface measurement instrument with a stylus probe type (Handy Surf). Table 4 lists the surface roughness values obtained for each run. The results in Table 4 show that the sixth experiment produced the best surface roughness value at a cutting speed of 220 m/min, a feed speed of 150 mm/min, a cutting depth of 0.5 mm, a cutting width of 6 mm, and a flute at 3. Meanwhile, the fourth experiment produced the highest roughness value at 100 m/min, feed speed at 1681 mm/min, cutting depth at 0.5 mm, cutting width at 6 mm, and flute at 4.

The P-values and the F-Value in Tables 5 and 6 present the effectiveness of each condition in influencing the characteristics of the related responses within a limited range. Table 5 lists the parameter coefficients that produced minimum surface roughness**,** while Table 6 presents the analysis of variance. It shows the regression variable to predict the minimum roughness value (Ra). Figure 4 then shows the Pareto chart**,** while Figure 5 illustrates the different residual plots for

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Ra. In this screening test, the feeding speed was the best parameter element, followed by the cutting speed, cutting depth, cutting width, and the number of flutes.

Table 4: The parameters of milling process

Run	V_c	V_f	D_{oc}	W_{oc}	Z	R_a
1	100	150	0.1	4	3	0.117143
2	100	150	0.1	6	4	0.116667
3	100	1681	0.5	4	3	0.753043
4	100	1681	0.5	6	4	0.922286
5	220	150	0.5	4	4	0.126286
6	**220**	**150**	**0.5**	**6**	**3**	**0.108857**
7	220	1681	0.1	4	4	0.272571
8	220	1681	0.1	6	3	0.292857

Table 5: Parameter coefficients

Term	Coef.	SE Coef.	T-Value	P-Value	VIF
Constant	-0.017	0.201	-0.09	0.939	
Vc	-0.002310	0.000362	-6.38	0.024	1.00
Vf	0.000289	0.000028	10.19	0.009	1.00
Doc	0.695	0.109	6.39	0.024	1.00
Woc	0.0215	0.0217	0.99	0.428	1.00
Z	0.0415	0.0435	0.95	0.441	1.00

Table 6: Analysis of varian

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	5	0.707505	0.141501	37.45	0.026
Vc	1	0.153615	0.153615	40.66	0.024
Vf	1	0.392412	0.392412	103.86	0.009
Doc	1	0.154355	0.154355	40.85	0.024
Woc	1	0.003682	0.003682	0.97	0.428
Z	1	0.003441	0.003441	0.91	0.441
Error	2	0.007557	0.003778		
Total	7	0.715061			

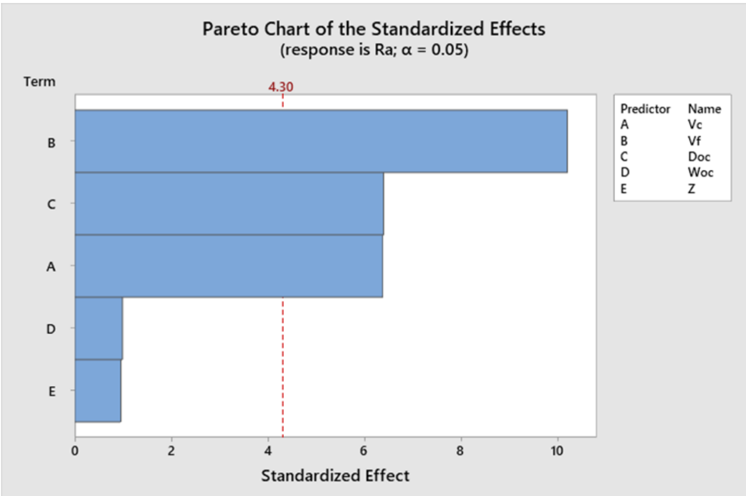

Figure 4: Pareto chart for sequence of best machining parameters

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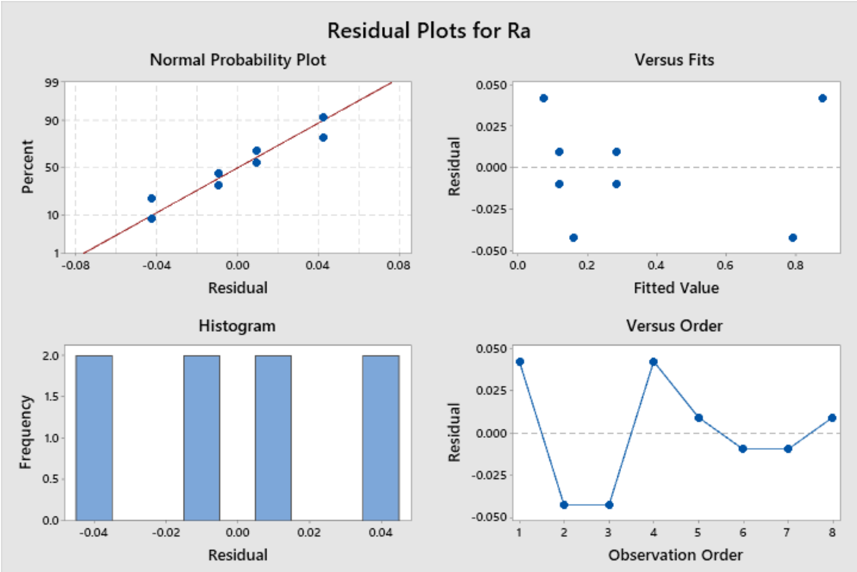

Figure 5: Different residual plots for Ra

Figure 6 shows a 3D contour plot of roughness value versus cutting speed and depth. It presents a roughness value (Ra) that the high Ra places in cutting depth of 0.5 mm in maximum cutting depth and cutting speed of 100 m/min in minimum cutting speed. While the low Ra points to minimum cutting depth and minimum cutting speed, it also points to maximum cutting depth and maximum cutting speed.

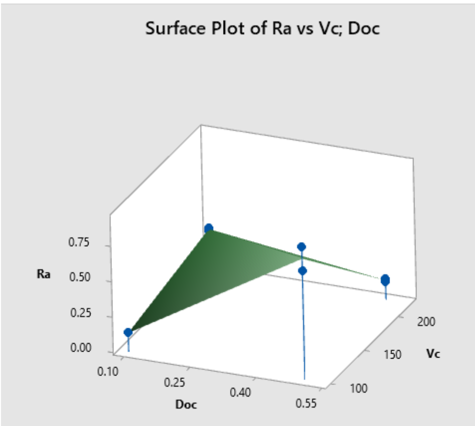

Figure 6: Contour plot of Ra based on cutting speed and cutting depth

Figure 7 denotes the 3D plot of roughness value versus feeding speed and cutting depth. It shows the roughness value (Ra) that the high Ra places in cutting depth at 0.5 mm in maximum cutting depth and feeding speed of 1681 m/min in maximum feeding speed while low Ra places in all cutting depth ranges and minimum feeding speed.

Figure 8 explains the effect of the speed of cut, feed rate, depth of cut, width of cut, and flute on the surface roughness value. Results showed that faster cutting speed produced smaller Ra values while feeding speed shows smaller Ra values at low feeding speed. A small cutting depth produced smaller Ra values on the cutting width and flute number. Hence, the speed of cut (Vc) in m/min, feed rate (Vf) in mm/min, and depth of cut (Doc) in mm were identified as the main parameters.

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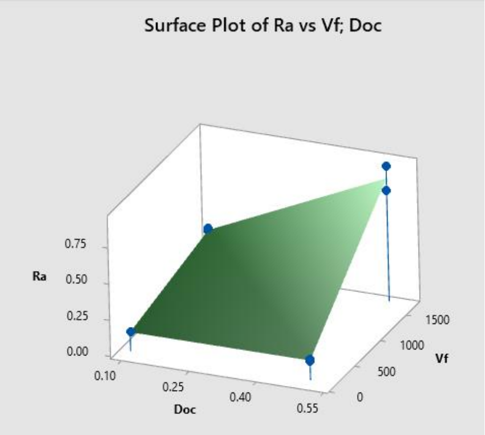

Figure 7: Contour plot of Ra based on feeding speed and cutting depth

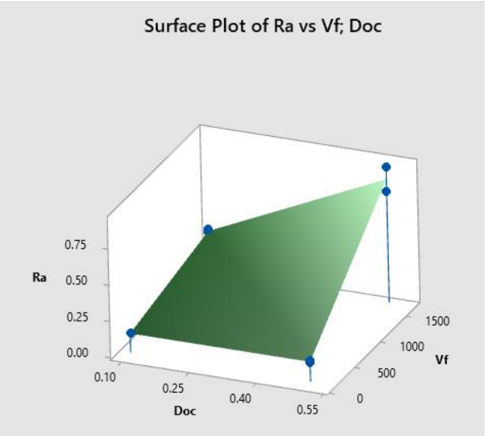

Figure 8. Main effects for Ra

CONCLUSION

A screening test is the best way to define the optimum end milling parameters in a CNC Milling process considering parameters such as cut speed, feeding speed, depth of cut, and width of cut and flute. The best surface roughness measured at 0.1088 µm was recorded for the cut speed of 220 m/min, feeding speed of 150 mm/min, depth of cut of 0.5 mm, width of cut of 6 mm, and flute of 3. The data was analyzed through ANOVA using Taguchi and Minitab 19.0 based on the F-Value and P-Value. The best of three achievement sequences of machining parameters were the feeding speed, cutting speed, and cutting depth, respectively. The optimum machining parameters from the screening test in the best order were the cutting speed, feeding speed, and depth of cut for HPMT S42 1000 072 of AL SE STD Ø10 in dry condition. Therefore, the optimal machining parameters suggested are a cut speed at 100 - 220 m / min, a feeding speed at 150 - 1681 mm/min, and a depth of cut at 0.1 - 0.5 mm. These three machining parameters would become the optimum parameters in the machining process for best surface finish quality and value.

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