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Research Article

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Predicting the Effects of Cutting Parameters in Milling of Thin – Walled Component of Aluminum Alloy A6061 on 5 Axis CNC Machining Center

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Abstract This paper aims to analyze and evaluate the influence of cutting parameters in the surface roughness and deformation of A6061 aluminium alloy thin-walled components. A regression model among cutting parameters, surface roughness and part's deformation is based on applications of the Taguchi experiential planning method and Minitab 19 statistical analysis software. The combination of its results and application of the analysis variance method (ANOVA) provides the influence level of parameters in surface roughness and deformation in thin-walled manufacturing processes, in which solid end mill and 5-axis CNC machine are used. The result contributes to a not only theoretical and practical basis for further studies but also improvement of the machining industry.

Keywords cutting parameters, thin-walled components, surface roughness, deformation, A6061 aluminum alloy

1. Introduction

The aluminium alloy material A6061 is a long-wearing aluminium alloy which can suit with the different requirement and ability to resist good corrosion. This material weight is lighter than alloy steel about three times. Therefore, the aluminium alloy material is used to manufacture the light-heavy components.

Many components are used to manufacture the aeroplane, which needs the thin-walled and light weight. However, these components have low hardness, so the thin-walled component is easy to deform in the machining process [2-4]. Although, that component is manufactured by the CNC machine. In the processing of aluminium alloy materials, the geometry of the tool cutting greatly affects the quality of the product. Simultaneous analysis and evaluation of the cutting parameters and the geometry of the cutting tool to the cutting force when milling Al6061 aluminium material by solid end mill [1].

Therefore, the thickness is divided into many thin cutting layers, which decreases the effect of cutting force on the component deformation and hardness [5].

The thin-walled component accuracy depends on many factors such as cutting regime parameter, component deformation undercutting force, component and tool deformation undercutting temperature, cutting tool accuracy, system hardness [6]. This paper is concentrate to study the effect of cutting regime parameters to the component surface roughness and deformation of aluminium alloy material A6061.

The purpose of this paper builts the recurrent math model between the component surface roughness and deformation with three parameters of cutting velecity, tooth advance, cutting depth in center direction to the surface roughness and deformation of the thin-walled component in milling of aluminum alloy material A6061 [7]. The quality of the component surface is an important factor to estimate the production quality. The surface roughness Ra is used as an index to estimate for finishing the component surface in the machining process [8]. The cutting regime parameter is the main factor that decides the production quality.

The method to reduce the deformation under the effect of cutting force in machining the thin-walled is an indispensable problem. Many types of research show that the effect of cutting regime factor has a big effect on the thin-walled component cutting force and deformation, as shown in Figure 1.

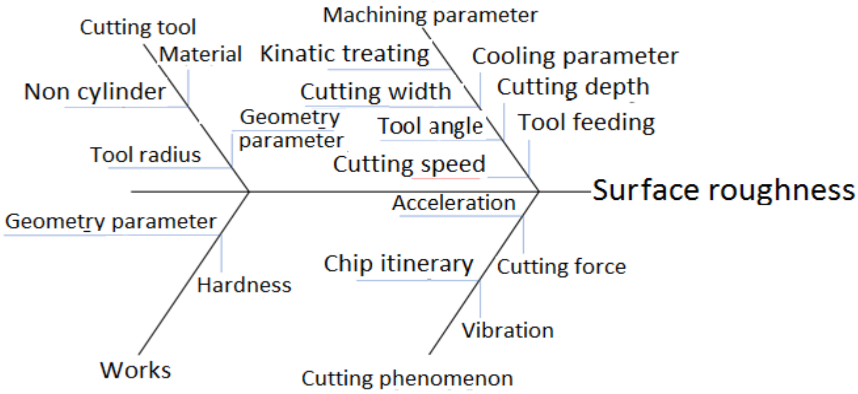


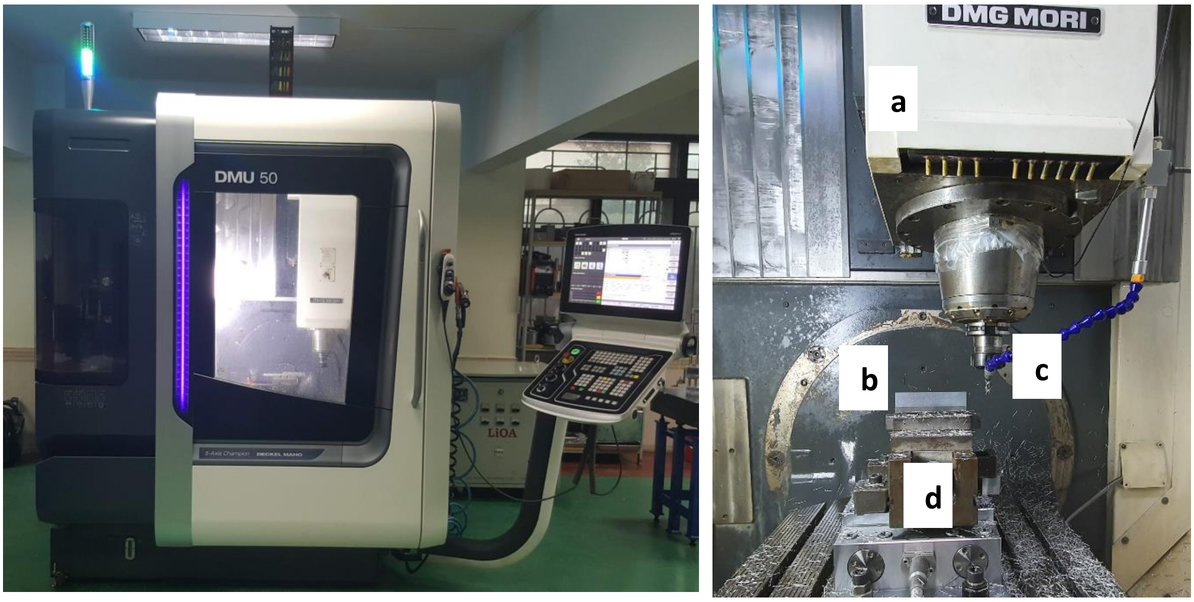
Figure 1: The effect of factors to surface roughness in machining process [9]

This research purpose to estimate the effect of the input parameters to output result by the ANOVA method, which connects to Minitab 19 software. Otherwise, the recurrent math model is built to predict the surface roughness and deformation of the thin-walled component in the milling process.

2. Surveying the Surface Roughness and Deformation in Milling of Thin – Walled Component of Aluminum Alloy A6061

2.1. Surveying condition

The five-axis machining centre CNC (DMU50) with the control system of Siemens 840D: Axis itinerary X/Y/Z =500/450/400; Axis itinerary B: -5 degree to +110 degree; Axis itinerary C: 360 degrees; Main axis motor: Main axis speed from 20 to 14.000 (round/ min.), Main axis motor capacity: 20.3 KW, Axis SK40 standard DIN69871. Working table: Axis speed B and C max: 20(round/ min.); Toolset: 16 positions; Tool length: 300; Tool weight: 6 kg; Axis moving speed; Max machining speed in axes of X/Y/Z: 30.000mm/min; Fast tool running speed in axes of X/Y/Z: 30.000mm/min.



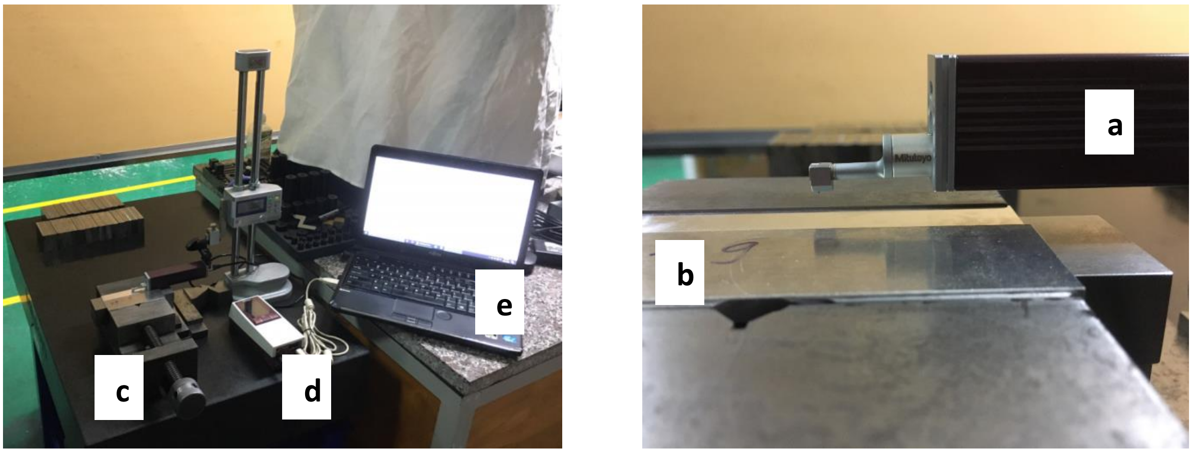
a. 5 axis CNC machine DMG DMU50
b. Experiment specimen
c. Cutting tool
d. Clamping

Figure 2: 5 axis CNC machining center DMG DMU50

Cutting tool: Using the hardness alloy materialYG-1®E5D70100*3 with the tool diameter (d) = 10 mm. Number of tool blade: (F) = 3, Length of tool blade: (L_1) = 27 mm, Total tool length: (L) = 75 mm, angle of tool blade: (α) = 45 ^{0,} radius of tool: R < 0,1 mm.

Figure 3: Cutting tool

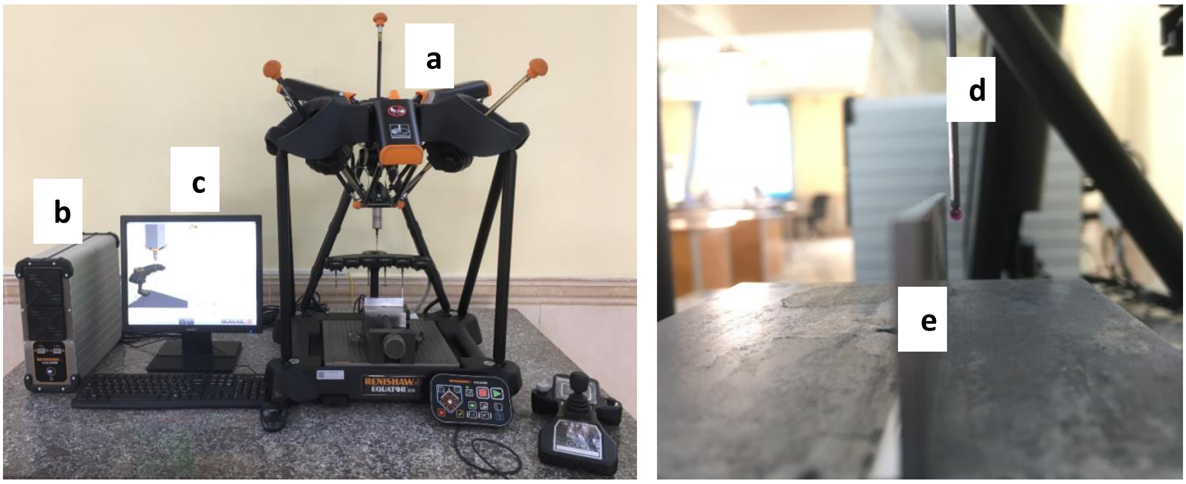
Roughness measurement equipment: The surface roughness R_a is measured by machine MITUTOYO-Surftest SJ-210 Portable Surface Roughness Tester. The software SurfTest SJ USB Communication Tool Ver5.007 is used to show the R_a in criteria ISO 1997. Each experimental specimen is measured three times. Their average value is used to analyze and calculate the experimental result.



a. Roughness measurement machine
b. Experimentspecimen
c. Clamping system
d. Data treating
e. Laptop

Figure 4: Roughness measurement equipment system

Deformation measurement equipment: The deformation in the y-direction is measured by RENISHAW EQUATOR™ 300 Versatile gauge. Each experimental specimen is surveyed for 10 points with two values of z-direction. Their average value for each value of z is used to analyze and calculate the experimental result.



a. RENISHAW EQUATOR™ 300 Versatile gauge equipment
b. Control equipment
c. Monitor
d. Measurement rod
e. Works

Figure 5: Comparision measurement equipment

Machining component: Aluminum alloy material A6061 LxWxH=100x50x4(mm). Aluminium alloy material components A6061is shown in Table 1.

Figure 6: Aluminum alloy experiment specimen A6061

Table 1: Aluminum alloy material components A6061 (%)

Si	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Al**
0.4 – 0.8	0.7	0.15 – 0.4	0.15	0.8 – 1.2	0.04 – 0.35	0.25	0.15	Remaining

Table 2: Technical characteristics of aluminum alloy A6061

Characteristics	**Value**	**Characteristics**	**Value**
Melting temperature (^{0}C)	582 - 652	Elastic module (Gpa)	68,9
Thermal tranfering coefficent (W/m.K)	167	Electric charge(Ω.m)	3.99e-006
Thermal capacity(J/g-^{0}C)	0.896	Pending capacity (Mpa)	96.5
Weight (kg/m^3)	2.7	Traning capacity(Mpa)	276
Hardness (HB)	95	Poisson system	0.33

2.2. Analyze and estimate the experimental result

The set of an experimental parameter includes f_z, a_r. The experimental method of Taguchi $L_9$with three different levels is used to analyze, predict the surface roughness and deformation in shape meaning. The too material of hardness alloy YG-1 E5D70100*3 for final time machining of aluminium alloy A6061in the limit as follows:

- The cutting velocity V on the high-speed milling machine in the range: 120÷256 m/ min;
- The cutting depth in the direction a_r: 0.1÷1.75 mm;
- The advance f_z in the range: 0.01÷0.17 mm/tooth.

Base on the method Taguchi for choosing the experiment with three degrees as in Table 3.

Table 3: Input parameters and experimental study

TT	Parameter	Level 1	Level 2	Level 3
		-1	**0**	**1**
1	Cutting velocity (V_c) [m/min]	100	170	240
2	Tooth advance (f_z) [mm/tooth]	0.02	0.06	0.1
3	Cutting depth in axis direction (a_r) [mm]	0.5	1	1.5

The experimental study for three input parameters which each parameter has three different level. The most suitable diagram ($L_9 – 3^3$) includes nine experiments that are chosen to study the effect of three cutting regime parameters such as cutting velocity, tooth advance, cutting depth in the centre directly to the surface roughness and deformation of the thin-walled component in milling.

Table 4: Roughness and deformation measurements result

Order	Code variable			Experimental parameter			Surface roughness R_a	Deformation df [mm]
	X_1	X_2	X3	V_c [m/ min]	f_z [mm/tooth]	a_r [mm]		
1	-1	-1	-1	100	0.02	0.5	0.15	0.028
2	-1	0	0	100	0.06	1	0.39	0.048
3	-1	1	1	100	0.1	1.5	0.84	0.056
4	0	-1	0	170	0.02	1	0.19	0.033
5	0	0	1	170	0.06	1.5	0.37	0.056
6	0	1	-1	170	0.1	0.5	0.84	0.048
7	1	-1	1	240	0.02	1.5	0.13	0.033
8	1	0	-1	240	0.06	0.5	0.39	0.052
9	1	1	0	240	0.1	1	0.83	0.067

2.2.1 Analyzing the component surface roughness

The method ANOVA is used to analyze the effect of parameters in table 5, which shows that the tool advance f_z has the most effects on the component surface roughness after machining about 99.70 %, cutting depth in centre direction (a_r) gets about 0.11%, the effect of cutting speed (V_c) gets about 0.054%, the effect of other parameters gets about 0.125 % which are determined by ANOVA method as shown in table 5.

Table 5: Analysis result ANOVA for surface roughness

The number of obs:	9			R-squared:	0.9696	
Root MSE:	0.12466			Adj R-squared:	0.8785	
Source	**Sum of squares**	**Degree of freedom**	**Mean square**	**F-value**	**Prob > F**	**Percent contribution (%)**
Model	0.69958	6	0.11659			
V_c	0.000422	2	0.002111	0.44	752.74	0.054
f_z	0.719288	2	0.359644	752.74	0.001	99.69
a_r	0.000822	2	0.0004111	0.86	0.005	0.11
V_c *f_z	0.000955	2	0.0004777			0.021
Error	0.000956	0				0.125
Total	0.721489	8	0.090186			100.000

The recurrent equation about the effect of cutting regime parameters to the component surface roughness after machining presents the effect of every single parameter and each other influence. Table 5 shows the input parameter, which is estimated by the ANOVA method.

Figure 7 is a comparison of the measurement result from the experiment and component surface roughness after machining. The actual result is quite near to the measurement result. Value R^2 of the recurrent equation has a roughness value of about 96.96%. Therefore, this math recurrent equation is the most suitable for three parameters of cutting velocity, cutting depth and tool feeding. The output parameter is surface roughness.

$$\begin{cases} Ra = 0.209 - 0.00057V_c + 9.98f_z - 0.548a_r - 0.0184V_c * f_z + 0.00196V_c * a_r + 2.50f_z * a_r \\ R^2 = 96.96\%, \quad R^2_{Ajd} = 87.85\% \end{cases} \quad (1)$$

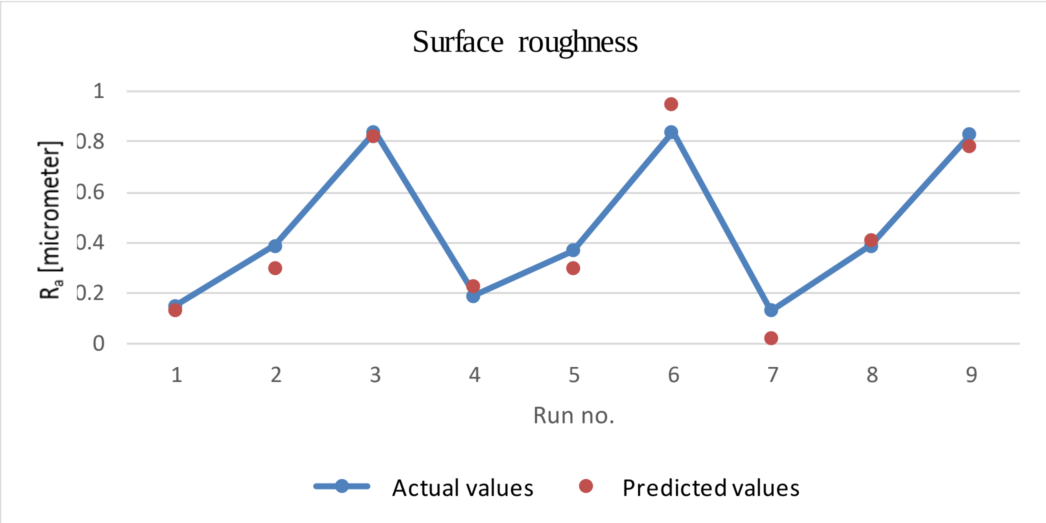


Figure 7: Experimental measurement result and roughness prediction R_a

2.2.2 Deformation analysis

The method ANOVA is used to analyze the effect of parameters in table 6, which shows that the tooth tool advance (f_z), which has the most effects on the component deformation about 82.81%, cutting depth in centre direction (a_r) gets about 5.78%; cutting speed (V_c) gets about 5.38%, which are determined by ANOVA analysis table as shown in table 6.

Table 6: Analysis result ANOVA for the component deformation

Number of obs:	9		R-squared:		0.9609	
Root MSE:	0.00512		Adj R-squared:		0.8437	
Source	**Sum of squares**	**Degree of freedom**	**Mean square**	**F-value**	**Prob > F**	**Percent contribution (%)**
Model	0.001241	8	0.90186105	16.22	0.0000	
V_c	0.000072	2	0.000036	0.44	752.74	5.38
f_z	0.001110	2	0.000555	752.74	0.001	82.81
a_r	0.0000775	2	0.000039	0.86	0.005	5.78
Error	0.000956	0				6.03
Total	0.721489	8	0.090186105			100.000

The recurrent math equation about the effect of cutting regime parameters to the component deformation after machining presents the effect of every single parameter and each other influence of the input parameter, which is estimated by the ANOVA method as shown in table 6.

The comparison of the experimental result from the experiment and deformation prediction value is shown in Figure 8. The prediction result is quite near the measurement result. Value R^2 of the recurrent equation has a surface roughness value of about 96.09%. Therefore, this math recurrent equation is the most suitable for three input parameters of cutting velocity, cutting depth and tool feeding. The output parameter is the component deformation.

$$\begin{cases} D_f = 0.028 + 0.000055 V_c - 0.279 f_z + 0.0611 a_r + 0.00352 V_c * f_z - 0.000233 V_c * a_r \\ \qquad -0.100 f * a_r \\ R^2 = 96.09\%, \quad R^2_{Ajd} = 84.37\% \end{cases} \quad (2)$$

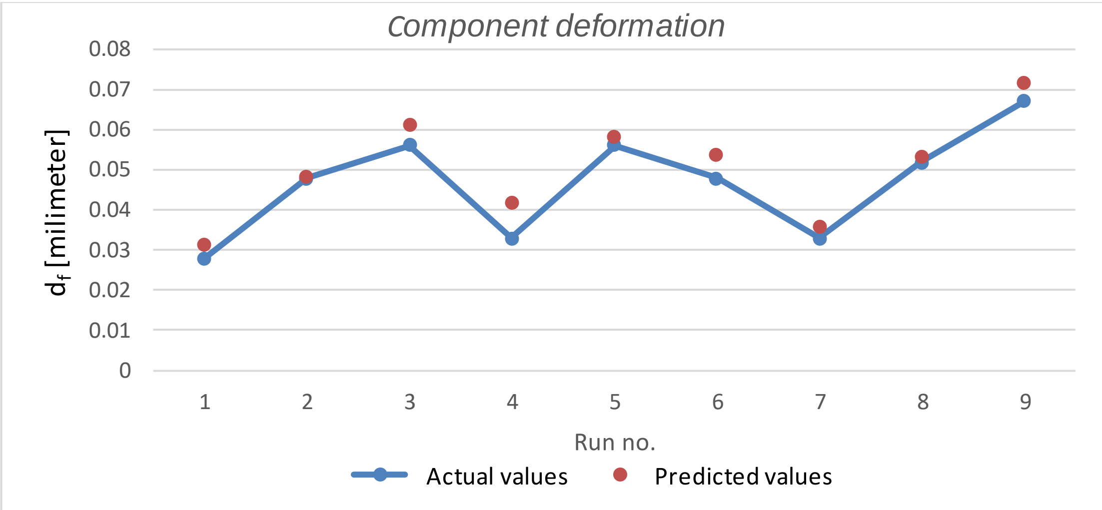


Figure 8: Experimental measurement result and cutting force prediction

3. Determining the most suitable value in the survey region

3.1. The output parameter of surface roughness (R_a)

The Minitab 19 software and Taguchi method are used to analyze the effective degree of cutting velocity V_c, tool advance (f_z) and cutting depth (a_r) to surface roughness (R_a) as shown in Table 7.So, the plot estimates the effect degree of cutting regime to surface roughness (R_a) as shown in Figure 9. The effect of tool advance (f_z) to surface roughness is the biggest in the surveying region when increasing the tool advance from degree1 , respectively 0.02 (mm/tooth) to degree 3 respectively 0.1 (mm/tooth) and value (R_a) also increases quickly from 0,156 μm to 0,8367 μm.

Similarly, the roughness also increases from 0,46 μm to 0,4667 μm khi when increasing velocity (V_c) from degree1 to degree2, but when continuing increasing velocity to degree 3, the roughness decreases to 0,45 μm. Similarly, value R_a also increases from 0.46 μm to degree 0.47 μm when a_r increases from degree1 to degree2 and then the roughness decreases when a_r increases. Therefore, the effect of the tool advance parameter on the surface roughness is the biggest when it increases from 0.02 (mm/tooth) to 0.1 (mm/tooth) and (R_a) increases from 0,156 μm to 0,8367 μm. Otherwise, the two remained parameter have the same small effect in comparison with (f_z).

Table 1: The effect of surveying parameters on surface roughness (R_a)

Level	**V_c**	**f_z**	**a_r**
1	0.46	0.156	0.46
2	0.4667	0.3833	0.47
3	0.45	0.8367	0.4467
Delta	0.0167	0.68	0.0232
Rank	3	1	2

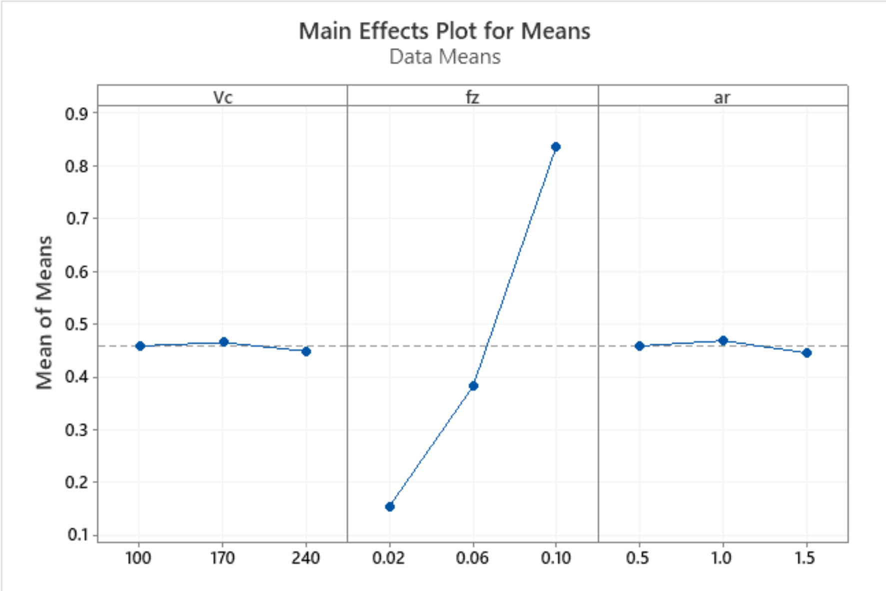


Figure 91: The effect of each parameter on surface roughness

3.2. The output parameter of component deformation (d_f)

Table 8: The effect of surveying parameters on surface roughness R_a

Level	V_c	f_z	a_r
1	0.044	0.03133	0.04267
2	0.04567	0.052	0.04933
3	0.05067	0.057	0.4833
Delta	0.00667	0.02567	0.00667
Rank	3	1	2

Similarly, for analyzing the effective degree of cutting velocity V_c, tool advance (f_z) and cutting depth (a_r) to component deformation (R_f) as shown in Table 8. So, the plot estimates the effect degree of cutting regime to component deformation (R_f) as shown in Figure 10. The effect of tool advance (f_z) to component deformation (R_f) is the biggest in the surveying region when increasing the tool advance from 0.03 (mm)to degree 0.02 (mm/tooth) and from 0.057 (mm)to degree 0.1 (mm/tooth). The effect of (a_r) to surface roughness (R_a) is the second big after the tool advance (f_z), and the effect of (V_c) is the smallest.

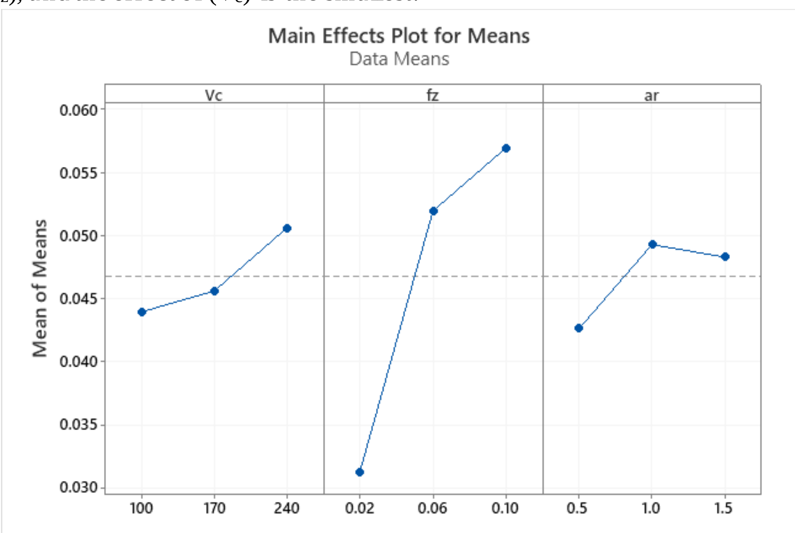


Figure 102: The effect of each parameter on the deformation of the component

Moreover, when increasingvelocity (V_c) from 100 (m/minute) atdegree 1 to 170 (m/minute) atdegree 2;240 (m/minute) atdegree3, that component deformation decreases from 0.044 (mm) to 0.05 (mm). The component deformation decreases from 0.04267 (mm) to 0.4933 (mm) when cutting depth a_r increases from 0.5 mm degree 1 to 1.0 mm degree 2 and the cutting depth (a_r) continue increasing to degree3 which the value of component defomation decreases to 0.04833 (mm).

4. Conclusion

This paper performs to survey and analyze the effect of cutting regimen parameters (V_c, f_z, a_r) when milling the aluminium alloy A6061. The Taguchi method is used to design and estimate the experimental result. The Minitab 19 software is used to build the recurrent math model with the input and output parameters are machining component surface roughness and deformation. The result shows that the surface roughness R_a is correlative with the value of the tool tooth advance f_z (99.70%), cutting depth in centre direction a_r (0.11%), cutting velocity V_c (0.054). Machining deformation degree D_f is correlative with the effect of the tool tooth advance f_z (82.81%), cutting depth in centre direction a_r (5.78%), cutting velocity V_c (5.38%). From the above result, the machining method and regime can apply in the product machining industry from the correlative material.

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