Jurnal Dinamis (*Scientific Journal of Mechanical Engineering*)
Journal homepage: https://talenta.usu.ac.id/dinamis/

The Effect of Machining Parameters of Water Surface Tool Wear 6061be on 500 Watt Mini CNC Machining Using Straight Endmill Carbide Tool With The Taguchi Method

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ARTICLE INFO

Article history:
Received October 25th 2024
Revised November 04th 2024
Accepted December 10th 2024
Available online December 11th 2024

E-ISSN: 2809-3410

How to cite:
Richard Napitupulu, Siwan Perangin angin, Hendrik Voice Sihombing. "The Effect of Machining Parameters of Water Surface Tool Wear 6061be on 500 Watt Mini Cnc Machining Using Straight Endmill Carbide Tool With The Taguchi Method'' Jurnal Dinamis *(Scientific Journal Of Mechanical Engineering)* Vol. 12 No 2, 64-71, December. 2024.

ABSTRACT

In the modern industrial era, the turning process plays a very important role in the manufacturing sector, especially in material processing. The cutting technique of the material significantly affects the quality of the product, while the selection of cutting parameters and conditions also play a key role in the effectiveness of the process. Determining the right cutting parameters is vital to ensure optimal results, extend the life of the cutting tool, reduce production costs, reduce carbon emissions, and improve the overall efficiency of the process. In turning using a 3 Axis Mach 3 CNC Router, machining parameters and tool geometry greatly affect the work results. This study uses the Taguchi method combined with fuzzy logic to identify optimal machining parameters in order to improve the durability of the tool blade in the turning process. The experimental design was carried out using an L16 4^3 OA orthogonal array with two controlled factors, namely cutting speed and depth of cut, each at three levels. The purpose of this study is to find the best combination of these factors in high-speed turning of Aluminum Alloys 6061 material with a 3 Axis Mach 3 CNC Router machine. The results of Taguchi analysis show that the order of parameters that most influence tool life are first, cutting speed (Speed), second, feed motion (Feed), and third, depth of cut (Depth of Cut).

Keyword: CNC, Carbide Straight End Mill, Taguchi Method, Aluminum Alloys 6061

ABSTRAK

Pada era industri modern, proses pembubutan memiliki peranan yang sangat penting di sektor manufaktur, terutama dalam pemrosesan material. Teknik pemotongan material mempengaruhi kualitas produk secara signifikan, sementara pemilihan parameter dan kondisi pemotongan juga memainkan peran kunci dalam efektivitas proses tersebut. Penentuan parameter pemotongan yang tepat sangat vital untuk memastikan hasil yang optimal, memperpanjang umur alat potong, mengurangi biaya produksi, menurunkan emisi karbon, serta meningkatkan efisiensi keseluruhan proses. Dalam pembubutan menggunakan CNC Router 3 Axis Mach 3, parameter pemesinan dan bentuk geometri alat sangat mempengaruhi hasil kerja. Penelitian ini menggunakan metode Taguchi yang dipadukan dengan logika fuzzy untuk mengidentifikasi parameter pemesinan yang optimal dalam rangka meningkatkan ketahanan mata pahat pada proses pembubutan. Desain eksperimen dilakukan menggunakan larik ortogonal L16 4^3 OA dengan dua faktor yang dikontrol, yaitu kecepatan potong dan kedalaman potong, masing-masing pada tiga level. Tujuan penelitian ini adalah untuk menemukan kombinasi terbaik dari faktor-faktor tersebut pada pembubutan kecepatan tinggi bahan Aluminium Alloys 6061 dengan mesin CNC Router 3 Axis Mach 3. Hasil analisis Taguchi menunjukkan bahwa urutan parameter yang paling berpengaruh terhadap umur pahat adalah pertama, kecepatan potong (*Speed*),

http://doi.org/10.32734/dinamis.v12i2.18697

kedua, gerak pemakanan (*Feed*), dan ketiga, kedalaman pemotongan (*Depth of Cut*).

Kata kunci: CNC, *Carbide Straight End Mill*, Metode Taguchi, Paduan Aluminium 6061

1. Introduction

The cutting process using a lathe is one of the most important processes in the manufacturing world [1]. Where the cutting process using machines such as lathes, milling and so on is included in dry machining but in recent years machining techniques have been developed using coolants to increase machining effectiveness such as minimum quantity lubrication (MQL), near dry machining (NDM) and high pressure coolants HPC [2] [3]. In today's world in the manufacturing sector, turning plays an important role among all other cutting methods. Material cutting techniques are one of the things that determine the important quality of the product, while cutting parameters and conditions also play an important role in the machining process [4]. It is very important to determine the appropriate cutting and machining condition parameters, to achieve the required material feed rate Material Removal Rate (MRR) and also the optimal material cutting rate value can be achieved with the right machining parameters [5]. Today's rapidly changing manufacturing environment requires the application of optimization techniques in metal cutting processes to effectively respond to intense competition and to meet the increasing demand for customized quality products (low cost, high quality, easy to deliver) in the market [6]. CNC or Computer Numerically Controlled is a machining process widely used in aviation, aerospace, automobile manufacturing, and other high-precision industrial production fields, which has become an important basic processing equipment or machine in modern industrial production. Using CNC has been proven to increase production efficiency in a production unit up to 5-10 times that of ordinary machine tools. This greatly saves labor costs and reduces equipment and capital investment [7] [8]. Selecting effective cutting condition parameters is very important to ensure product quality, extend tool life, reduce production costs, reduce carbon emissions, and improve production efficiency [9]. In CNC turning operations, machining parameters and tool geometry play an important role, Optimization of machining parameters improves the economic value of machining and also increases product value.

Design of experiment (DOE) is an important process to improve the design settings of manufactured goods that can be utilized to reduce the cycle time required to improve new methods [10]. The Taguchi optimization method is a proven effective method to obtain optimal cutting condition values in CNC machining processes [11] [12]. Taguchi developed a robust manufacturing system, insensitive to environmental variations, machines, and daily and seasonal wear. His approach optimizes performance characteristics through process parameter settings and reduces the sensitivity of system performance to sources of variation. With that, the Taguchi method has become a powerful method in the design of experimental methods especially for machining processes [13] [14]. Previous studies have comparatively used response surface methodology and the Taguchi method to conclude that low temperature cutting conditions significantly reduce power consumption compared to dry and wet cutting conditions. Previous studies have shown the effect of machining parameters on surface roughness during the milling process of Al6061 - T6 Alloy material using the Taguchi method. The results show that the Taguchi design successfully optimizes machining parameters for tool wear (Ra) and tool wear (Vb). Spindle Speed parameter is the parameter that most influences surface roughness compared to feed rate and Depth of Cut [15][16]. In this study, Taguchi method with fuzzy logic is used as an efficient approach to determine the optimal machining parameters for CNC turning parts to optimize Surface Hardness on Workpieces. The experimental design uses an L16 (43) OA orthogonal array for 3 controllable factors, namely, speed (Speed), depth of cut (Depth of Cut) and feed rate (Feed), each at 4 levels to find the optimal combination of factors and levels in high-speed CNC turning of Aluminum AI6061BE. Single-response optimization is carried out using the Taguchi method. For multi-response cases, fuzzy logic units (FLU) are used to convert four correlated responses into a single response called comprehensive output size (COM). Later, analysis of variance (ANOVA) is used to determine the most influential high-speed CNC rotation parameters for the Tool wear variable (Vb).

2. Method

In this study, the workpiece to be machined is Aluminum type AI6061BE with dimensions of 300 mm x 300 mm and a thickness of 20 mm which is depicted in Figure 2.1. The composition of AI6061BE can be seen in table 2.1 and table 2.2. The experiment was conducted at Universitas HKBP Nommensen, Faculty of Engineering, Mechanical Engineering Study Program.

2.1. Experiment Details

CNC milling operation is done using a 3 Axis Mach 3 CNC Router machine. The spindle motor has a power of 500 Watts and a spindle speed range of 2000 to 5000 rpm. Endmill Cutting Bit Type with 2 Flutes with a diameter of 6 mm Carbide type non Coating HRC40 Chisel Bit Image Seen in Figure 2.1.

a

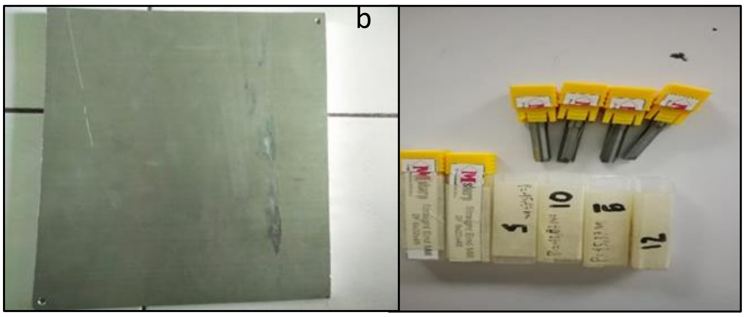

Figure 2.1 (a) Alumunium AI6061BE; (b) Straight End Mill

The SRT6210 Digital Surface Roughness tester was used for surface roughness measurement. The tool wear analysis was carried out at 300X magnification using a Taguchi L^{16} (4^3) OA Digital Zoom USB Microscope used to design the experiment. The experimental setup is shown in Figure 2.2.

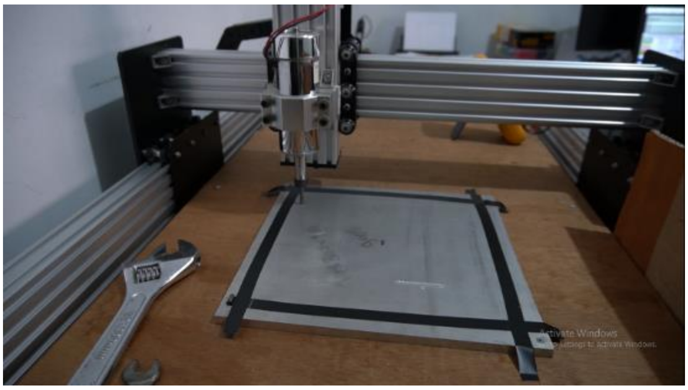

Figure 2.2 Mini Mach3 500 watt CNC Milling Machine

2.2. Taguchi Method

The Taguchi method is a widely used approach for optimizing process parameters based on experimental data. In this research, the analysis was carried out using Taguchi's Signal-to-Noise (S/N) ratio method [14]. To evaluate the performance characteristics, the "smaller is better" criterion was chosen as the optimal quality characteristic for assessing surface roughness (Ra) and tool wear (Vb). These two parameters are among the most commonly utilized and recognized in the field of machining. The relationship between these factors is expressed by the equation below

Nominal is the best : $\frac{S}{N} = -10 \log \frac{y^2}{s^2}$ *(1)*

Lower is the best : $\frac{S}{N} = -10 \log \frac{y^2}{s^2}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y^2}\right)$ *(2)*

Lower is the best : $\frac{S}{N} = -10 \log \frac{y^2}{s^2}\frac{1}{n}\left(\sum_{i=1}^{n}\frac{1}{y^2}\right)$ *(3)*

To obtain variables with optimum values in this test, in this case surface roughness (Ra) and tool wear (vb), equation (3) is selected, namely Lower is the best [14].

Table 2.1 Material Composition of AI6061BE [13]

Bahan	**Al**	**Si**	**Mg**	**Fe**	**Ti**	**Mn**	**Ni**	**Zn**	**Cu**	**Cr**	**Pb**
AI6061BE	93.69	0.4	0.8	0.7	0.15	0.15	0.02	0.25	0.15	0.04	0.01
		0.8	1.2						0.14	0.35	

Table 2.2 AI6061BE Material Specification [13]

Properties	Value
Tensile Strength	Min 265 (N/mm^2)
Elongation	Min 8 %
Density	2.7 g/cm^3
Young's Modulus	68.9 GPa

Table 2.3 Machining Parameters

Input Parameter	Unit	Level 1			
		1	2	3	4
Speed	rpm	2000	3000	4000	5000
Feed	mm/min	40	50	60	70
Depth Of Cut	mm	0.10	0.13	0.15	0.18

3. Result and Discussion

From the analysis run by minitab software with the Taguchi method displayed in the table The smaller the better is considered in the Response table for the SN ratio as presented in Table 3.1, Table 3.3 and Table 3.4. The difference between the highest and lowest average values of each factor is called Delta. Minitab shows the Delta ranking position. Rank 1 as the first highest value, Rank 2 as the second highest award, and shows the impact or influence of machining parameters on the response factor or in this case is tool wear (Vb).

As observed in Table 3.3, the spindle speed (Speed) emerges as the most significant factor, as it holds the top rank. It is followed by feed rate (Feed) in second place, and depth of cut (DOC) in third. In this study, the ranking of factors influencing surface roughness for AI6061BE material is Feed > Speed > Depth of Cut. The Main Effect Plot for the S/N ratio of uncoated tools, shown in Figure 3.2, illustrates the impact of each factor on the response characteristics, including the signal-to-noise ratio and standard deviation.

The P Value determines the significance of the parameter. The smaller the P value, the greater the impact on the tool wear response variable during this study. The results obtained for surface roughness are described in Tables 3.2 and Table 3.3.

Table 3.1 Table Anova I

S	R-Sq	R-Sq(adj)
5.6412	71.60%	29.01%

From Table 3.2 and Table 3.3, based on the P value ratio, it shows that the parameter that most affects tool wear in this study is s (Speed). The second is Feed and the third is depth of Cut. Upon reviewing the data in Table 3.2, it is evident that the R-Sq value remains at 71.60%. This indicates that the connection between the machining parameters and the response variables requires further investigation. To achieve a higher degree of accuracy, a larger sample size should be considered to increase the R-Sq value to a range of 80% to 90%. Figure 3.1 shows the setup experimentent.

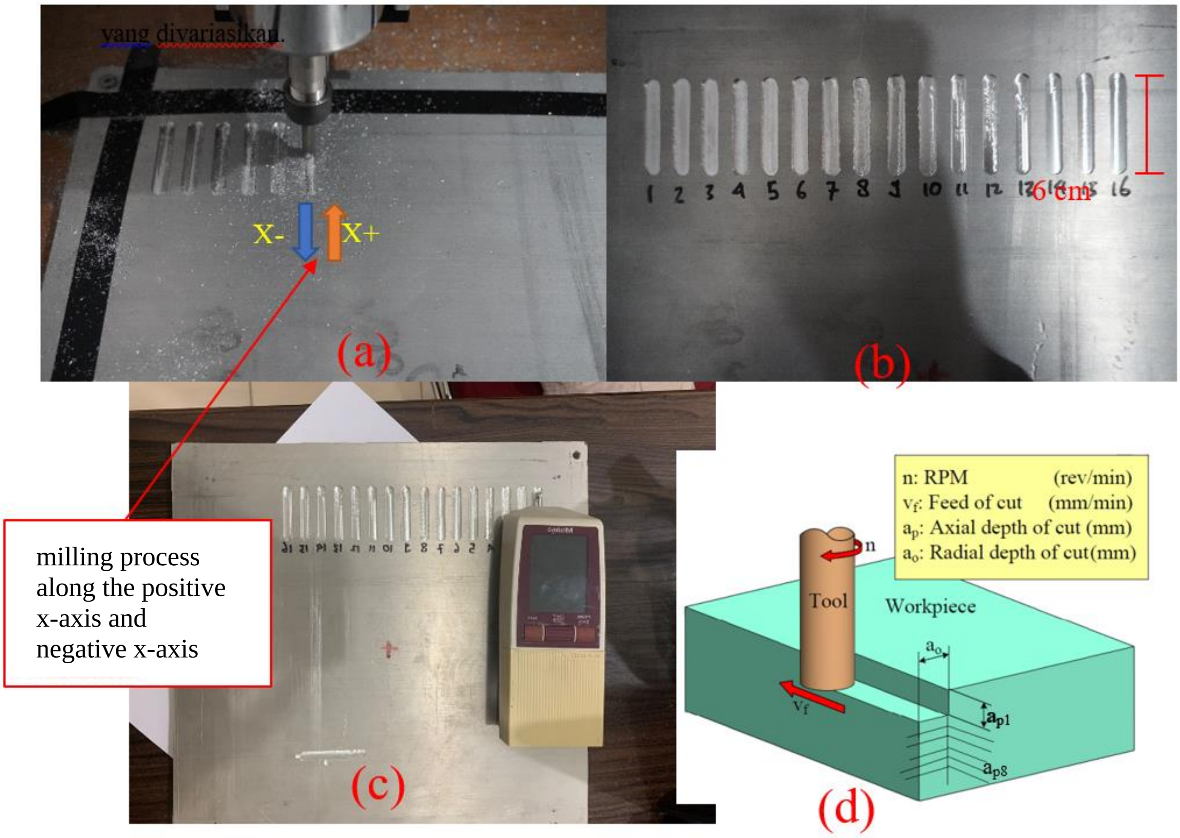

Figure 3.1 Setup experiment

Table 3.2. Surface roughness Ra and tool wear (Vb) results

No Experiments	Spindel Speed	Feed (mm/min)	*Depth Of Cut* (mm)	Ra (Micron)	Vb (Micron)
1	2000	40	0.100	2889	0.16
2	2000	50	0.125	1409	0.06
3	2000	60	0.150	3107	0.07
4	2000	70	0.175	7848	0.32
5	3000	40	0.100	3056	0.06
6	3000	50	0.125	1787	0.09
7	3000	60	0.150	1993	0.10
8	3000	70	0.175	4142	0.22
9	4000	40	0.100	1482	0.05
10	4000	50	0.125	1208	0.08
11	4000	60	0.150	1368	0.13
12	4000	70	0.175	1882	0.23
13	5000	40	0.100	2111	0.16
14	5000	50	0.125	1062	0.73
15	5000	60	0.150	3592	0.32
16	5000	70	0.175	2063	0.35

Figure 3.1(a) shows the milling process in the direction of the positive x-axis and the negative x-axis, each experiment with a groove length for each experiment is 6 cm as shown in Figure 3.1(b). Figure 3.1(d) shows a picture of the milling process that occurs. $\mathbf{a_{p1}}$ to $\mathbf{a_{p8}}$ feed motion processes occur 8 times for each experiment with the parameters shown in Table 2.1 For each feed motion, the value of the surface roughness is recorded, then the results are averaged. The point where the surface roughness value is taken is shown in Figure 3.1(b). the results of the surface roughness values from each 3 points are then averaged.

Table 3.3. Table Anova 2

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	3	288.65	288.65	96.218	3.02	0.115
Feed	3	182.08	182.08	60.694	1.91	0.230
Depth of Cut	3	10.71	10.71	3.571	0.11	0.950
Residual Error	6	190.94	190.94	31.823		
Total	15	672.38				

Figure 3.2 Main effect graph for S/N Ratio Vs spindle speed, feed rate, depth of cut

Figure 3.2 shows the average value of the response value at each variable level of Speed, Feed and Depth of Cut. Speed shows the variable that most significantly affects the S/N Ratio compared to the Feed and Depth. of Cut variables.

Tabel 3.4 S/N Respon Table

Level	Speed	Feed	Depth of Cut
1	18.100	20.448	15.929
2	19.784	17.712	17.930
3	19.619	17.571	16.041
4	9.477	11.250	17.080
Delta	10.307	9.198	2.001
Rank	1	2	3

Table 3.4 shows the S/N Ratio rank values of the cutting parameters. The most influential factor in the machining process is Speed compared to the feed and Depth of Cut parameters [15]. By using the Response

Surface Methodology (RSM), the Regression Equation obtained can be displayed below [17]. From these results, mathematical and statistical modeling of the machining conditions during testing was obtained.

VB = 2.87 – 0.000368 **Speed -** 0.0480 **Feed** – 17.6 **Depth of Cut** + (0.000000 **Speed**^{2} – (0.000011 **Feed**^{2}) - (34.7 **Depth of Cut**^{2}) - (0.000002 **Speed*Feed**) + (0.00069 **Speed*Depth of Cut**) + (0.443 **Feed*Depth of Cut)**

From the results of micro photo observations, a clear image of chisel wear is obtained, as shown in Figure 3.3.

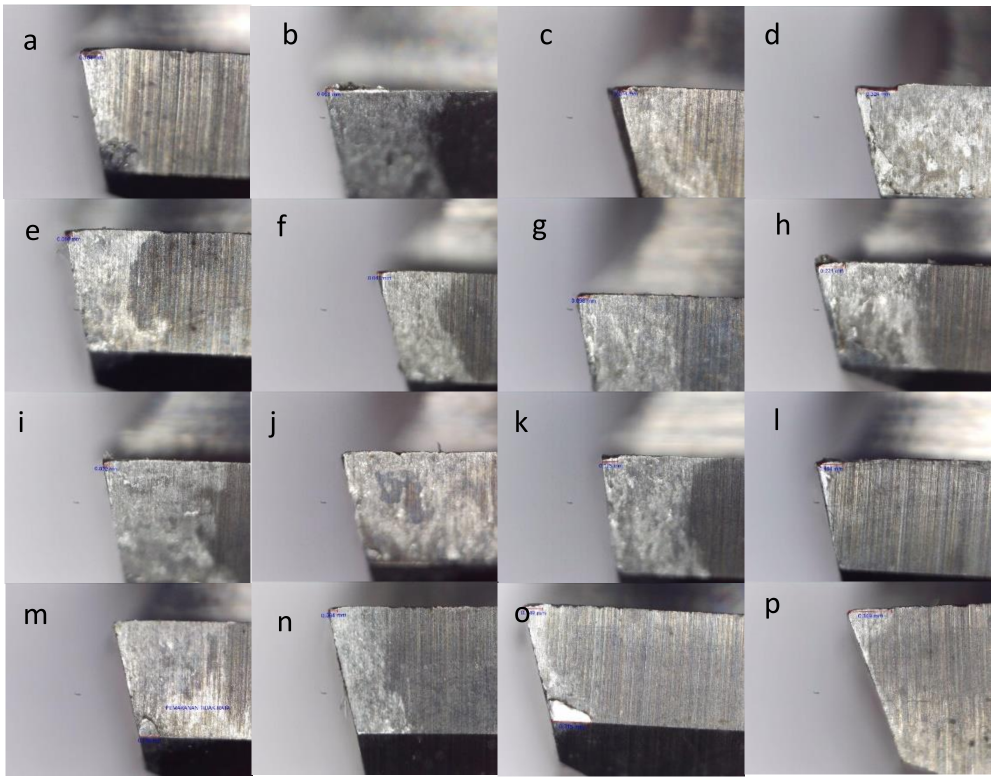

Figure 3.3. Image a top with measurement results Wear Digital chisel Zoom 300X 16 chisels

4. *Conclusion*

From the Taguchi analysis, it is known that the order of parameters that influence the tool life is the first variable, Cutting Speed, second, Feed motion, third, Depth of Cut. Where the cutting speed parameter gives a contribution of 3.02 The second is the feed motion parameter which gives a contribution of 1.91. And the last is the Depth of Cut parameter which gives a contribution of -0.950%. For further research, it can be considered the selection of materials to be cut with a higher level of hardness. This is necessary to see the extent of the capabilities of the mini CNC.

5. *Acknowledgements*

Thank you to Universitas HKBP Nommensen for providing funding to conduct this research. and to the research team who also provided input so that this research can be better.

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