

Optimizing Milling Process Parameters of Bovine Horns for Maximizing Surface Quality and Minimizing Power Consumption

Audrey Rahmanti Unadi^{1, a}, Teddy Sjafrizal^{1, b}, Rino Andias Anugraha^{1, c} and Muhammad Iqbal^{1, d}

¹Industrial Engineering Department, School of Industrial Engineering, Telkom University, Bandung 40257, Indonesia

[a](mailto:audrey.rahmanti@gmail.com)audrey.rahmanti@gmail.com, [b](mailto:teddysjafrizal@telkomuniversity.ac.id)teddysjafrizal@telkomuniversity.ac.id,
[c](mailto:rinoandias@telkomuniversity.ac.id)rinoandias@telkomuniversity.ac.id, [d](mailto:muhiqbal@telkomuniversity.ac.id)muhiqbal@telkomuniversity.ac.id

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Abstract. Bovine Horn is an abundant natural resource, yet its industrial application is limited. Introducing this natural material to the machining process is expected to improve the adoption of this material in producing industrial products. This study aims to describe the optimization of bovine horns milling process parameters, depth of cut (d), feed-rate (f), and spindle speed (s), in obtaining a maximum surface quality as well as minimizing power consumption. The results showed that at $d = 1$ mm, $f = 72$ mm/min, and $s = 860$ rpm, the work-piece exhibited low surface roughness ($R_a = 0.614 \mu\text{m}$), whereas at the setting of $d = 1$ mm, $f = 155$ mm/min, and $s = 360$ rpm, the process consumed the least power ($P = 0.858$ kW). Grey rational analysis (GRA) was applied to obtain the optimal point from these two conditions. This analysis proposed $d = 1$ mm, $f = 72$ mm/min, and $s = 860$ rpm as the milling parameters to produce good surface quality ($R_a = 0.614 \mu\text{m}$) with less power consumption ($P = 0.991$ kW). Finally, decreasing feed-rate and depth of cut of the milling process is the reasonable approach to produce the machined products made of bovine horns with good surface quality and minimum power consumption.

Introduction

Bovine horn is a natural resource with a unique material characteristic. Its structure is mainly built up by keratin in fiber morphology [1–3]. Thus, the mechanical properties of bovine horns behave anisotropically, and it is subjected to the microstructure [4]. Another uniqueness of this material is that the hardness is controlled by its water content [5, 6]. A horn with lower water content has higher hardness, thus the maximum hardness could be obtained at 0 % water content [6].

Typically, bovine horns are utilized as the raw material for creative industrial product. Conventionally, the bovine horn is widely found as knife grips and as the raw material for fashion accessories. Recently, the extracted keratin from the horns is used as a mixture of dental filling [7]. It is argued that the utilization of bovine horn as raw materials for industrial products can be improved by conducting a study towards the use of this material on the manufacturing processes. Introducing this material to the machining process is one of the reasonable ways to improve its utilization in the industrial field.

As a modern manufacturing process, machining possesses a high level of flexibility and adoption in the industry. However, it is worth to understand the power consumption behaviour of the system and to reflect it to the surface quality of the machined components. In general, power consumption is inversely related to the surface quality [8]. Hence, study to understand the optimum machining parameter to obtain minimum power consumption and good surface quality in any workpiece material is very reasonable.

A numerous number of previous studies have been conducted in understanding the optimum machining parameters [9–11]. For example, the study by [9, 12] utilize the Taguchi method in selecting the machining parameters to optimize the surface roughness and the micro-hardness of a milling process. A similar method was also used by other work in optimizing the machining performance of scots pine [11]. Throughout those studies, it summarizes that the most influential parameters of milling are the depth of cut, feed rate, and spindle speed [13–16].

To the author’s best understanding, there is no previous study on understanding the machining process on bovine horns as the work-piece. Therefore, this study aims to optimize power consumption and surface roughness by selecting the machining process parameters. The result of the study could be used as a reference to improve the utilization of this material in the future industry.

Experimental Procedure

Bovine horns samples were obtained from the local sources in West Java, Indonesia. There was no special treatment on the as-received material. The dimension of the work-piece was 30mm x40mm x 20mm. The work-pieces were machined by a conventional milling machining (Hauw Gan ZX7550Z). The 12mm end-mill carbide with four blades of flute was used as the cutting tool. The investigated machining parameters for this experiment were the depth of cut (d), feed-rate (f), and spindle speed(s), with three levelling on each parameter (Table 1). The experiment runs were generated from L₂₇ (3³) orthogonal array with the total combinations of 27 samples (Table 2).

Table 1 Machining Process level and parameters

Parameter process	Unit	Level		
		1	2	3
Depth of cut (d)	[mm]	1	2	3
Feedrate (f)	[mm/min]	72	155	240
Spindle Speed (s)	[rpm]	360	600	860

Table 2 L₂₇ (3³) Orthogonal Array

Sample	d [mm]	f [mm/min]	s[rpm]	Sample	d[mm]	f[mm/min]	s[rpm]
1	1	72	360	15	2	155	860
2	1	72	600	16	2	240	360
3	1	72	860	17	2	240	600
4	1	155	360	18	2	240	860
5	1	155	600	19	3	72	360
6	1	155	860	20	3	72	600
7	1	240	360	21	3	72	860
8	1	240	600	22	3	155	360
9	1	240	860	23	3	155	600
10	2	72	360	24	3	155	860
11	2	72	600	25	3	240	360
12	2	72	860	26	3	240	600
13	2	155	360	27	3	240	860
14	2	155	600				

Both surface roughness and power consumption were measured on each sample. Surface roughness (Ra) was measured by the Surftest SJ-410 (Mitutoyo), and the power consumption measurement (P) was carried out using the PM2205 Digital clamp meter (manufactured by Shenzhen Huayi Peakmeter Technology Co., Ltd.). The schematic diagram of the power consumption measurement is depicted by Fig.1. The gathered responses from the samples were analyzed accordingly. The optimum milling parameters were determined by applying the grey relational analysis.

The Grey Relational Analysis (GRA) procedure was started by the normalizing the responses by applying the Eq.1. Subsequently, the Grey Relational Coefficient (GRC) of each response was calculated by Eq.2. Finally, the Grey Relational Coefficient (GRC) value was derived from Eq.3. The optimum milling parameter was determined by the highest value of GRC [12].

Grey Relational Generation (Smaller is better)

Based on the optimal surface roughness and power consumption, the goal of smaller-is-better is reasonable.

$$y_i^*(j) = \frac{\max y_i(j) - y_i(j)}{\max y_i(j) - \min y_i(j)} \tag{1}$$

Grey Relational Coefficient (GRC)

$$\gamma_{ij} = \frac{\Delta_{\min} + \xi \Delta_{\max}}{\Delta_{oj}(k) + \xi \Delta_{\max}} \tag{2}$$

Grey Relational Grade (GRG)

$$\bar{\gamma}_j = \frac{1}{k} \sum_{i=1}^m \gamma_{ij} \tag{3}$$

Where,

- a. $y_i(j)$ value of each experimental run
- b. $y_o(k)$ is the highest value of normalized value
- c. $y_j(k)$ is the normalized value ($y_j(k) \ k=1,2\dots m$).
- d. $\Delta_{oj} = || y_o(k) - y_j(k) ||$ = The absolute difference between normalized value and the highest of normalized value
- e. Δ_{\min} = the smallest value of $y_j(k)$
- f. Δ_{\max} = the highest value of $y_j(k)$
- g. ξ coefficient between 0 and 1 ($0 \leq \xi \leq 1$)
- h. $\bar{\gamma}_j$ Grey relational grade for each experiment
- i. $y_i^*(j)$ the normalized value of each experiment
- j. $\max y_i(j)$ the highest value of the experimental run
- k. $\min y_i(j)$ the smallest value of the experimental run

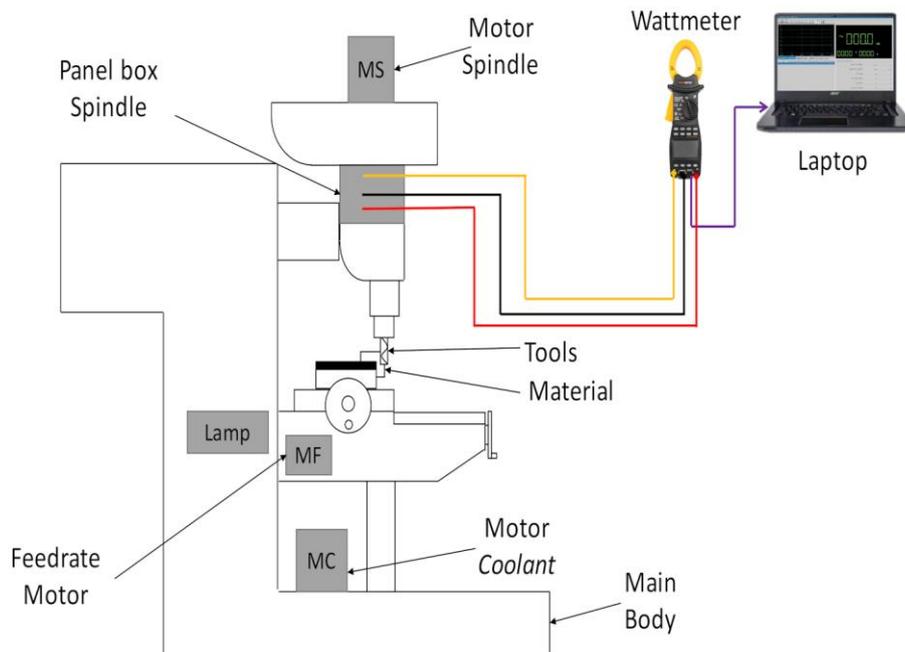


Fig. 1 Experimental Setup (schematically)

Result and Discussion

Fig. 2 represents the morphology of a bovine horn surface after the milling process. Similar to the general condition of any engineering material surface, the surface roughness of the bovine horn is characterized by the wavy patterns made by the interaction between the cutting tool and the workpiece. In addition to the machining parameter effect, the anisotropic characteristic of the horn was observed to contribute to the surface contour (highlighted area in Fig.2).

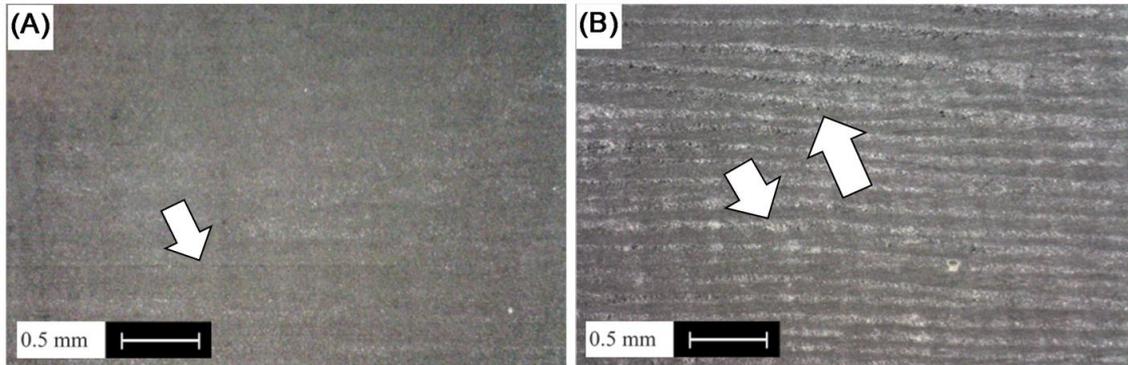


Fig. 2 Morphology of bovine horn surface after machining milling process, A). Sample 3, $R_a=0.614 \mu\text{m}$, $d = 1 \text{ mm}$, $f = 72 \text{ mm/min}$, $s = 860 \text{ rpm}$, B). Sample 16, $R_a= 1.843 \mu\text{m}$, $d = 2\text{mm}$, $f = 240 \text{ mm/min}$, $s = 360 \text{ rpm}$. The arrow represent bovine horn structure that affects the surface roughness value.

Table 3 Power consumption and roughness of the samples

Sample	R_a [μm]	Power Consumption [kw]	Sample	R_a [μm]	Power Consumption [kw]
1	0.646	0.976	15	0.797	0.925
2	0.622	0.986	16	1.843	0.984
3	0.614	0.991	17	1.030	1.014
4	1.545	0.858	18	0.850	0.943
5	0.820	0.926	19	0.898	0.982
6	0.741	0.927	20	0.645	1.044
7	1.616	0.934	21	0.877	0.956
8	0.953	0.946	22	1.210	0.884
9	0.832	0.991	23	1.032	0.919
10	0.868	0.964	24	0.674	1.205
11	0.680	1.048	25	1.608	0.959
12	0.740	0.973	26	1.341	0.992
13	1.186	0.925	27	1.168	1.002
14	0.952	0.955			

Based on the responses (Table 3) the minimum surface roughness is sample 3 with the parameter combination $d = 1 \text{ mm}$, $f= 72 \text{ mm/min}$ and $s = 860 \text{ rpm}$ ($0.614 \mu\text{m}$). Feed-rate, depth of cut, and spindle speed parameters are the parameters that highly correlates to surface roughness. Minimum power consumption was obtained from $d = 1 \text{ mm}$, $f= 155 \text{ mm/min}$ and $s = 360 \text{ rpm}$ on sample 4 (0.858 kW). Relating to the common practice of the milling process, the parameters selection to obtain better power consumption is different from the parameter for minimizing the surface roughness. Typically, the smooth surface could be realized by lowering the depth of cut, slowing the feed-rate and increasing the spindle speed, whereas the power consumption is mainly determined by the power drawn out by the spindle [14, 16, 17].

Grey rational analysis was performed on the responses to obtain milling parameters with good surface roughness as well as minimum power consumption. Table 4 depicts the calculation result of the grey rational analysis.

Table 4 Calculation using grey rational analysis (GRA)

Sample	Surface Roughness		Power Consumption		GRG	Rank
	R _a (μm)	GRC	P (kW)	GRC		
1	0.646	0.951	0.976	0.596	0.773	3
2	0.622	0.987	0.986	0.576	0.781	2
3	0.614	1.000	0.991	0.566	0.783	1
4	1.545	0.398	0.858	1.000	0.699	9
5	0.820	0.748	0.926	0.720	0.734	6
6	0.741	0.828	0.927	0.717	0.773	4
7	1.616	0.380	0.934	0.696	0.538	23
8	0.953	0.644	0.946	0.663	0.654	16
9	0.832	0.738	0.991	0.567	0.653	17
10	0.868	0.708	0.964	0.622	0.665	15
11	0.680	0.903	1.048	0.478	0.691	11
12	0.740	0.829	0.973	0.602	0.716	8
13	1.186	0.518	0.925	0.722	0.620	21
14	0.952	0.645	0.955	0.642	0.643	18
15	0.797	0.771	0.925	0.722	0.746	5
16	1.843	0.333	0.984	0.579	0.456	27
17	1.030	0.596	1.014	0.526	0.561	22
18	0.850	0.722	0.943	0.672	0.697	10
19	0.898	0.684	0.982	0.584	0.634	19
20	0.645	0.952	1.044	0.482	0.717	7
21	0.877	0.700	0.956	0.640	0.670	13
22	1.210	0.508	0.884	0.871	0.689	12
23	1.032	0.595	0.919	0.740	0.668	14
24	0.674	0.911	1.205	0.333	0.622	20
25	1.608	0.382	0.959	0.633	0.508	26
26	1.341	0.458	0.992	0.564	0.511	25
27	1.168	0.526	1.002	0.548	0.537	24

GRC = Grey rational coefficient

GRG = Grey rational grade

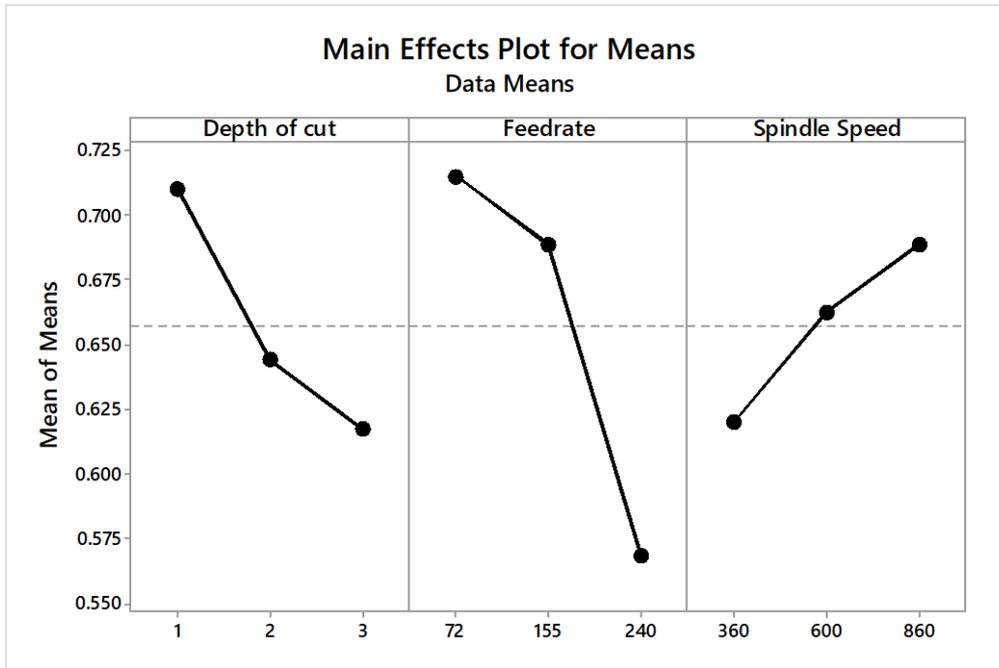


Fig. 3 Grey relational grade graph

Based on the Table 4 and Fig. 3 the optimum parameters selected highest GRG value. In this set of experiment, sample number 3 exhibited the highest GRG value ($d = 1$ mm, $f = 72$ mm/min, $s = 860$ rpm, $GRG = 0.783$). Whereas, the second highest GRG value was obtained from sample number 2 ($d = 1$ mm, $f = 72$ mm/min, $s = 600$ rpm, $GRG = 0.781$). Comparing the milling parameters of these two samples, the point of difference was only at the value of spindle speed. It indicates that by changing the value of spindle speed from 600 to 860 rpm, with $f = 72$ mm/min, $d = 1$ mm, the optimum responses (minimum surface roughness and minimum power consumption) could be still realised.

On the other extreme sites, two of the lowest GRG value was obtained from sample number 16 ($GRG = 0.456$) and sample number 25 ($GRG = 0.508$). These two samples had the value of spindle speed at the minimum point (360 rpm), feed-rate at the maximum (240 mm/min) with depth of cut value changed. This condition suggests that the contribution of the spindle speed and feed-rate to the responses overcomes the effect of changing the depth of cut. In addition, the low hardness of the bovine horns contributes to the minimum impact upon changing the depth of cut.

Finally, ANOVA was performed to understand the dominant milling parameters that contributed to the surface and power consumption (Table 5). With p-value < 0.05 as the cut off for determining the dominant factor, the feed-rate selection was the main parameter contributing to the value of surface hardness and power consumption. Therefore, this result suggests that the decision to determine the feed-rate value is very crucial at the setup process of milling process on bovine horns.

Table 5 Analysis of Variance

Variable Source	DF	SS	p-Value	Contribution
Depth of cut	2	0.041	0.001	20%
Feedrate	2	0.110	0.000	52%
Spindle speed	2	0.021	0.012	10%
Error	20	0.039		
Total	26	0.211		

DF = Degree of freedom
SS = Sum of square

Conclusions

In this study, selecting the milling process (depth of cut, federate, and spindle speed) of bovine horns to obtain minimum surface roughness and power consumption has been conducted. The findings are summarized below:

1. A minimum surface roughness could be achieved by lowering the depth of cut, slowing the feed-rate and increasing the spindle speed. In this current study, the selected milling parameters for minimum roughness were: the *depth of cut* = 1 mm, *feed-rate* = 72 mm/min, and *spindle speed* = 860 rpm. On the other hand, power consumption is mainly determined by the power drawn out by the spindle. Minimizing the depth of cut and the feed-rate have the least effect on power consumption. This study described the selected parameters for minimum power consumption as the *depth of cut* = 1 mm, *feed-rate* = 155 mm/min, and *spindle speed* = 360 rpm.
2. The preferred machining parameters in minimizing surface roughness as well as lowering power consumption, as suggested by the grey relational analysis, could be obtained by lowering the depth of cut and slowing the feed-rate. At this study, the approach was achieved at a *depth of cut* = 1 mm, *feed-rate* = 72 mm/min, and *spindle speed* 860 rpm. The setup exhibited surface roughness (R_a) = 0.614 μm and power consumption (P) = 0.991 kW.
3. Statistically, it suggests that feed-rate, depth of cut, and spindle speed are the dominant parameters contribute to the surface roughness and the power consumption of a milling process on bovine horns.

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