Influence of Milling Parameters on Sound Pressure Level during the Milling of Wood-plastic Composites

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The high-intensity noise generated during high-speed milling of wood-plastic composites, due to the material properties of anisotropy and non-uniformity, seriously affects the working environment and operator comfort. The influence of axial depth of cut, radial depth of cut, cutting speed, and feed per revolution on the sound pressure level of milling noise in wood-plastic composites was analyzed through single-factor milling experiments. Furthermore, a principal component variance analysis was conducted using multi-level factorial milling experiments to investigate the interaction effects of milling parameters on milling noise variation. The results showed that, for a fixed milling length, the significance of milling parameters on milling noise sound pressure level decreased in the order of cutting speed, axial depth of cut, radial depth of cut, and feed per revolution. A smaller axial depth of cut was suggested to control noise emission while ensuring machining efficiency. With a constant axial depth of cut, lower feed per revolution and radial depth of cut helped achieve reduced noise levels. This study provides a theoretical basis for addressing the challenge of high-intensity noise generated during high-speed milling of wood-plastic composites.

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Keywords: Wood-plastic composites; Milling; Milling parameters; Sound pressure level

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INTRODUCTION

Wood-plastic composites (WPCs), which are made by blending wood particles or flour with polymers, are a novel type of wood material that has emerged worldwide in recent years (Bhaskar *et al*. 2021). The machining noise during milling of WPCs can impact machining quality, contaminate the working environment, and pose health risks to workers. This noise is quantified by sound pressure, a measure of loudness based on acoustic intensity, typically expressed in decibels (dB). Therefore, research on the noise generated during the high-speed machining of WPCs is an issue that needs attention in the field of mechanical machining.

Presently, noise issues in wood processing are receiving increasing attention. Scholars have carried out a series of studies on the effect of circular saw blade tooth spacing on log cross-cutting noise (Krilek *et al*. 2016), the influence of tool parameters on noise (Wellenreiter *et al*. 2022), and acoustic monitoring of tool condition (Górski *et al*. 2019). These studies on log processing noise have achieved considerable success, yet research on noise emission during high-speed milling of WPCs remains relatively scarce. Meanwhile, prediction models for WPCs milling noise have been developed to achieve accurate noise forecasting through data processing (Wei *et al*. 2022). However, research on how milling parameters and their interactions specifically affect noise levels and the underlying reasons during high-speed milling of WPCs remains limited. These mechanisms need to be investigated for effective noise reduction. The high-speed milling experiments on WPCs were carried out using cemented carbide tools in this study. The milling noise signals were acquired by a decibel meter and microphone. The influence of axial depth of cut a_p, radial depth of cut a_e, cutting speed v_c, and feed per revolution f on the sound pressure level of milling noise in WPCs was analyzed through single-factor experiments, and the variation patterns of milling noise were summarized. Furthermore, a principal component variance analysis of milling parameters was conducted using multi-level factorial experiments to investigate the interaction effects among milling parameters on milling noise, and methods for controlling milling noise were proposed. This study is expected to enhance the environmental friendliness of high-speed machining of wood-plastic products and offer guidance for mitigating high-intensity noise in the machining process of WPCs.

EXPERIMENTAL

Materials

The experimental workpiece was made of wood powder and polyethylene composite material, produced by Nanjing Dayuan WPC Material Co., Ltd. (Nanjing, China). The dimensions of the workpiece were 320 mm (*L*) × 80 mm (*W*) × 39 mm (*H*). The material compositions of the WPCs were as follows: wood powder 54.70%, calcium carbonate 13.70%, recycled polyethylene 27.35%, phase solvent 2.72%, lubricant 1.53%. The basic properties of the wood-plastic workpiece are as follows: density 1.19 g/cm^3, flexural modulus 28 MPa, and Shore hardness 58 HD. The high-speed milling experiments employed cemented carbide inserts. A BAP40r CNC milling cutter arbor (Suzhou, China) with a diameter of 25 mm was used. All experiments were performed on an XH714 vertical machining center (Tengzhou, China).

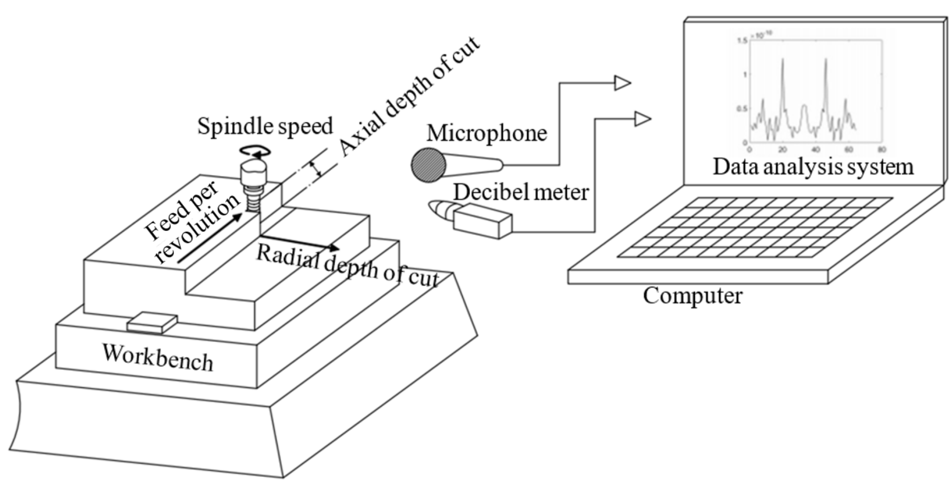


Fig. 1. Experimental platform layout

The milling noise and background noise were collected using a condenser microphone with a frequency response range of 80 to 14000 Hz. The milling noise sound pressure level was measured by the Ar844 SMART Sound Level Meter (Hongkong, China) with a frequency response range of 31.4 Hz to 8.5 kHz and a measurement accuracy of ± 1.5 dB. Following GB/T 16769-2008 standard, the microphone and sound level meter were positioned at a height of 1.5 m above the ground, 1 m away from the workpiece and a 10 m (*L*) × 10 m (*W*) × 4.5 m (*H*) laboratory with epoxy resin flooring. Background noise was controlled in accordance with the standard requirements. The spindle noise, noise emitted from other areas of the milling machine, and environmental noise were considered as background noise. The milling noise signals collection system is shown in Fig. 1.

Methods

Single-factor experiments were conducted to investigate the effects of a_p, a_e, v_c and f on milling noise. The milling sound pressure level was calculated and post-processed using MATLAB software (MathWorks Inc., R2019a, Natick, MA, USA). Subsequently, a multi-level factorial experiment was conducted, and the obtained data were imported into Design-Expert software (Stat-Ease Inc., Version 13, Minneapolis, MN, USA) for processing and analysis.

Sound pressure level (SPL) is defined as the logarithm to the base 10 of the ratio of the effective root-mean-square sound pressure *P*(e) to the reference sound pressure *P*(ref), multiplied by a constant of 20. The unit is decibels (dB). The mathematical equation for SPL is expressed as follows (Hu *et al*. 2022).

$$SPL = 20 \log \left(\frac{P(\mathrm{e})}{P(\mathrm{ref})}\right) \quad (1)$$

The reference sound pressure (*P*(ref)) is typically set at 2×10^{-5} Pa, a value corresponding to the SPL perceptible to the human ear (Lin *et al*. 2022). The noise signals collected during milling experiments were mixed with background noise. Due to the presence of background noise, the sound level meter readings are higher than the actual values in milling experiments. Therefore, the recorded background noise was subtracted from the noise measured during testing to determine the SPL. The actual SPL of the measured target signal is expressed by the following Eq. 2 (Mansor *et al*. 2020),

$$L_{\mathrm{ps}} = 10 \log \left(10^{\frac{1}{10}L_{\mathrm{p}}} - 10^{\frac{1}{10}L_{\mathrm{pB}}}\right) \quad (2)$$

where L_{ps} is the actual sound pressure level of the measured target signal, L_p is the sound pressure level of the mixed noise, L_{pB} is the sound pressure level of the background noise, with all units measured in decibels.

RESULTS AND DISCUSSION

Impact of Milling Parameters on the Milling SPL of WPCs

The influence of milling parameters on milling SPL was investigated through single-factor experiments under up-milling conditions, and SPL was calculated in MATLAB using Eq. 1. The background noise, spindle idle noise and other ambient noise under the corresponding experimental conditions were measured before each milling operation. Subsequently, the overlapping portions of SPL between background noise and milling noise were eliminated using the decibel subtraction Eq. 2.

Impact of radial depth of cut on milling noise

The variable a_p was maintained at 4 mm, f at 0.3 mm/rev, and v_c at 250 m/min, while a_e was set to 2, 4, 6, 8, and 10 mm. The SPL (a_e) of milling was measured with a_e as the variable and the maximum value of the SPL was taken as the numerical result; a_e, the SPL variation curve under single-factor variations is shown in Fig. 2. In the test, the background noise initially decreased and then increased with a changing rate that started slow and then accelerated. In comparison to the initial background noise, the final background noise slightly increased. Overall, the background noise approximated a constant value under constant spindle speed conditions. After eliminating background noise interference, the average milling noise decreased 2 dB. When a_e increased from 2 mm to 4 mm, the milling noise SPL rose from 80.5 to 83.4 dB. Subsequently, when a_e increased from 6 mm to 8 mm, the milling noise SPL rose from 83.6 to 86.6 dB. In both stages, there were relatively rapid increases in the milling noise SPL. However, when a_e increased from 4 mm to 6 mm and from 8 mm to 10 mm, the milling noise SPL showed gradual slowdowns in the rate of increase.

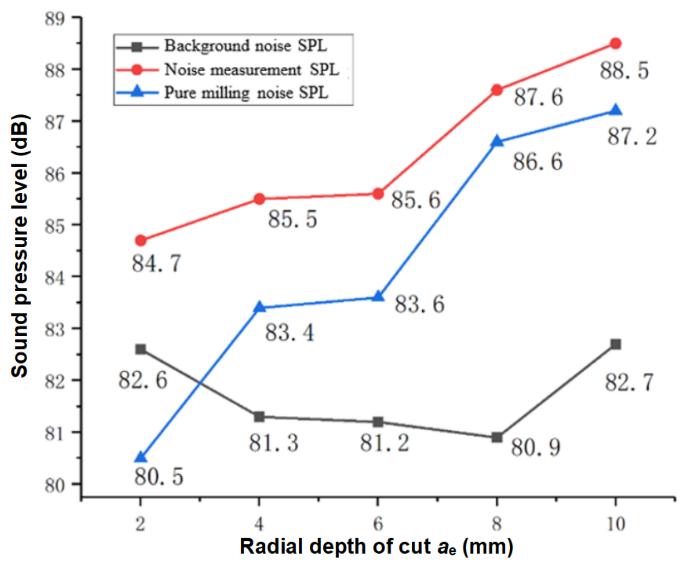


Fig. 2. Radial depth of cut – Sound pressure level variation curve

When a_e increased, the overall milling noise SPL showed a stepwise upward trend. Although the chip morphology of WPCs workpiece after milling showed little variation with the progressive increase in a_e (Wei *et al*. 2021), the increase in a_e led to a significant increase in the effective contact length between the tool and workpiece, thereby enhancing the cutting interaction. Comparable observations were documented by European scholars (Kminiak *et al*. 2023).

Impact of feed per revolution on milling noise

The a_p was maintained at 4 mm, a_e at 6 mm, and v_c at 250 m/min, while f was set to 0.1, 0.2, 0.3, 0.4, and 0.5 mm/rev; f, the SPL variation curve under single-factor variations is shown in Fig. 3. It could be observed that the SPL of background noise remained approximately constant and was notably distant from both the noise measurement SPL curve and the pure milling noise SPL curve, there was a substantial disparity in these SPLs. The pure milling noise SPL curve closely followed the trend of the noise measurement SPL curve. After subtracting the background noise interference using the decibel subtraction equation, the average SPL was reduced 1.7 dB. The change in *f* significantly affected the milling noise SPL. As *f* increased from 0.1 mm/rev to 0.2 mm/rev, the milling noise SPL rapidly rose from 78.3 to 84.1 dB, an increase of 5.8 dB. However, as *f* further increased from 0.2 mm/rev to 0.5 mm/rev, the rate of increase in the milling noise SPL markedly slowed down. When *f* increased, the overall milling noise SPL showed a stepwise upward trend. In the stage of *f* increasing from 0.2 mm/rev to 0.3 mm/rev, the milling noise SPL was slightly affected by the changing *f*. When *f* reached 0.5 mm/rev, the milling noise SPL increased to 89.5 dB, representing an increase of 11.2 dB compared to the SPL at *f* of 0.1 mm/rev. This phenomenon resulted from the positive correlation between feed per revolution and cutting force. When cutting edges and spindle speed remained constant, increased feed per revolution elevated the feed rate, intensifying cutting force via chip compression (Durkovic *et al*. 2018) and friction. Log planing studies reported similar trends, noise increased with increasing feed rate (Ajdinaj *et al*. 2023).

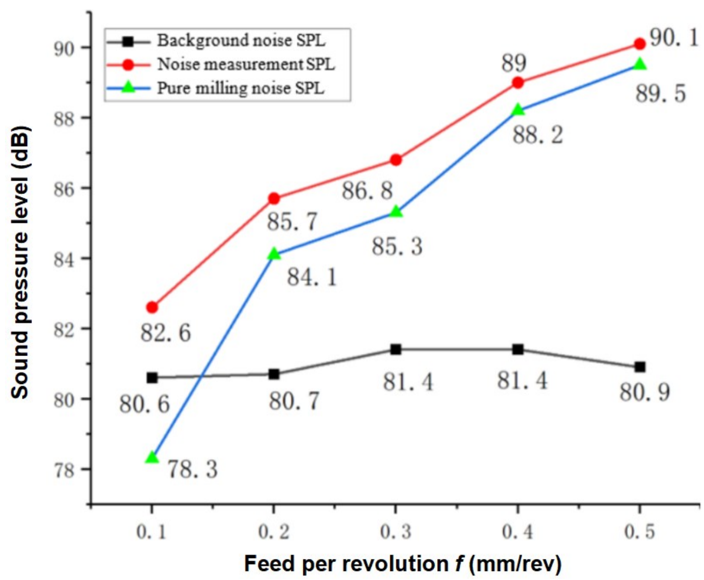


Fig. 3. Feed per revolution – Sound pressure level variation curve

Impact of cutting speed on milling noise

The a_p was maintained at 4 mm, a_e at 6 mm, and feed *f* at 0.3 mm/rev, while v_c was set to 150, 200, 250, 300, and 350 m/min; v_c, the SPL variation curve under single-factor variations is shown in Fig. 4.

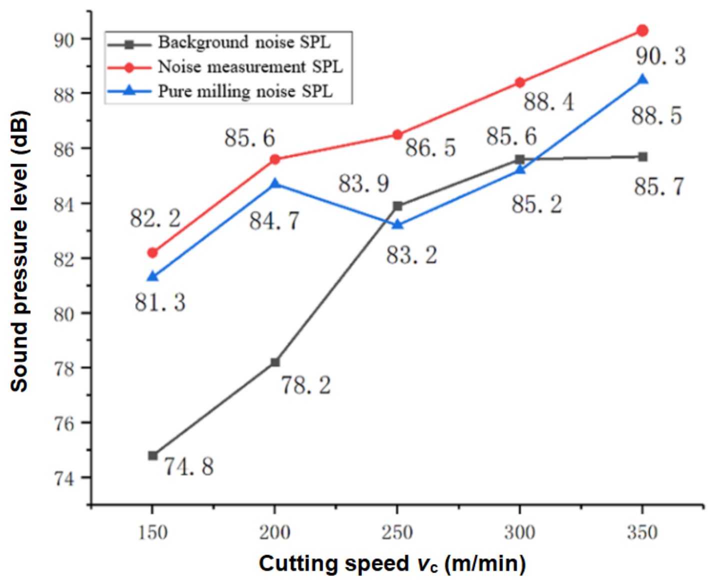


Fig. 4. Cutting speed – Sound pressure level variation curve

The background noise increased with the elevation of v_c. In v_c range of 150 m/min to 250 m/min, v_c had a pronounced impact on background noise, rising from the initial 74.8 dB to 83.9 dB. As v_c continued to rise in the range of 250 to 350 m/min, the SPL gradually tended to stabilize, reaching 85.7 dB at 350 m/min. Overall, the SPL of background noise increased with the growing v_c. Specifically, it had a significant rise of 10.9 dB compared to the initial level at v_c of 350 m/min. It was indicated according to the equation in references (Hu *et al*. 2021) that as the spindle speed gradually increased, v_c also increased. The increase in v_c led to two effects. On one hand, it amplified the aerodynamic noise generated by moving fluid (Sampath *et al*. 2007). On the other hand, it enhanced the impact energy generated by the spindle (Rech *et al*. 2017). Therefore, the milling noise showed a corresponding increase in SPL.

The milling noise steadily increased in the speed ranges of 150 to 200 m/min, 250 to 300 m/min, and 300 to 350 m/min. However, the milling noise showed a declining trend in the speed range of 200 to 250 m/min. This was attributed to the rise in temperature within a certain range as v_c increased, consequently reducing cutting forces and vibrations (Xu *et al*. 2018). The raw materials of WPCs incorporated thermoplastic plastics, when the friction heat between the milling tool and the workpiece increased, the surface of the workpiece softened. This led to a reduction in the frictional force between the milling tool and the workpiece, thereby decreasing the milling noise SPL. The milling noise showed another increase when v_c reached 250 m/min, and at v_c of 350 m/min, the milling noise pressure level reached 88.5 dB, representing a subsequent growth of 7.2 dB compared to the initial level. Based on the considerable variation in background noise pressure level with changing v_c, it was evident that alterations in v_c had a substantial impact on milling noise.

Impact of axial depth of cut on milling noise

The a_e was maintained at 6 mm, f at 0.3 mm/rev, and v_c at 250 m/min, while a_p was set to 2, 3, 4, 5, and 6 mm; a_p, the SPL variation curve under single-factor variations is shown in Fig. 5.

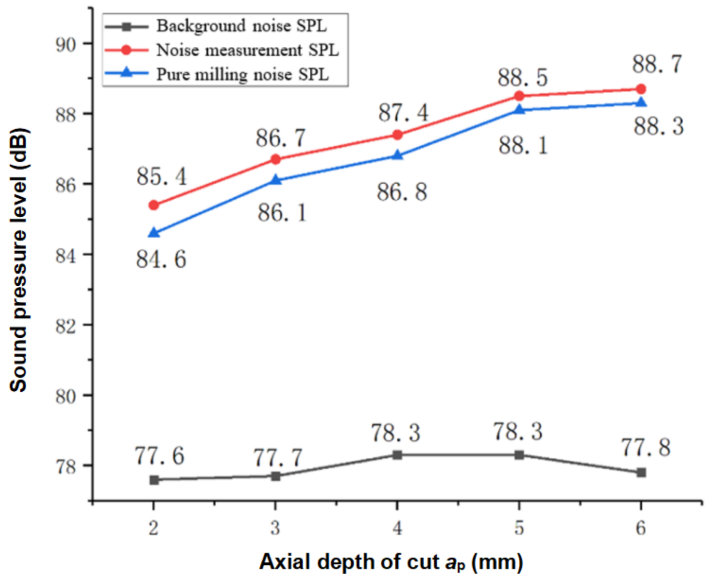


Fig. 5. Axial depth of cut – Sound pressure level variation curve

The background noise level remained relatively constant and its SPL curve was notably distant from both the noise measurement SPL curve and the pure milling noise SPL curve, and there was a substantial disparity in the SPL. After removing the interference of background noise, the average milling noise SPL decreased 0.56 dB. When a_p increased from 2 to 3 mm, the milling noise SPL increased from 84.6 to 86.1 dB. Similarly, as a_p increased from 4 to 5 mm, the milling noise SPL increased from 86.8 to 88.1 dB. There was a rapid increase in the milling noise SPL during these two stages. However, when a_p increased from 3 to 4 mm and from 5 to 6 mm, the milling noise SPL showed a gradual upward trend. When a_p increased, the overall milling noise SPL showed a stepwise upward trend. Through observation of the phenomena occurring during the milling process, it was evident that as a_p increased, the morphology of the WPCs chips changed with an increase in chip thickness, resulting in an increase in the reactionary force exerted on the mechanical system and ultimately manifested in an increase in milling noise.

Multi-factor Analysis of Milling Noise SPL

To comprehensively understand the interactions among various factors and their combined effects on the milling noise SPL, a multi-level factorial experiment with 4 factors at 3 levels (the level table is shown in Table 1) was designed in this study.

Table 1. Multi-Level Factorial Experiment Parameter Levels

Parameter	Unit	Low Level	Medium Level	High Level
a_p	mm	3	4	5
a_e	mm	6	8	10
v_c	m/min	250	300	350
f	mm/rev	0.1	0.3	0.5

Table 2. Multi-Level Factorial Experimental Data

Shuffle Sorting	Number	a_p	a_e	v_c	f	Pure Milling Noise SPL
		mm	mm	m/min	mm/rev	dB
8	1	5	10	350	0.1	77.7
4	2	5	10	250	0.1	74.1
13	3	3	6	350	0.5	80.2
12	4	5	10	250	0.5	90.2
16	5	5	10	350	0.5	72.8
9	6	3	6	250	0.5	82.2
15	7	3	10	350	0.3	80.8
10	8	5	6	250	0.3	83.3
5	9	3	6	350	0.1	81.9
17	10	4	8	300	0.1	83.5
19	11	4	8	300	0.5	82.3
3	12	3	10	250	0.5	93.6
1	13	3	6	250	0.1	77.1
6	14	5	6	350	0.1	68.3
14	15	5	6	350	0.3	82.5
7	16	3	10	350	0.5	85.5
11	17	3	10	250	0.1	89.1
18	18	4	8	300	0.5	79.4
2	19	5	6	250	0.1	68.5

The interference of background noise on milling noise was mitigated by the decibel subtraction equation, and the processed multi-level factorial experimental data and the pure milling noise SPLs are listed in Table 2.

Parameters a_p, a_e, f, and v_c were used as input variables in the experiment, while the milling noise signal SPL was the output variable. The noise collection time for each group corresponded to the duration required for milling a length of 320 mm. Before each experiment, the spindle idle noise for the duration required to mill a length of 320 mm was collected. The maximum milling SPL and maximum spindle rotation noise pressure level of each group were recorded as the experimental data (Sio-Sever *et al*. 2022).

Principal component analysis of milling parameters

The parameters of the multi-level factorial experiment were input into the Design-Expert software to conduct a variance analysis on the four milling parameters affecting the milling noise SPL. The significance of the effects of a_p, a_e, v_c, f, and their interactions on the milling noise SPL was analyzed, and the results are shown in Table 3. The significance levels of each parameter are indicated in Fig. 6.

Table 3. Milling Parameters Variance Analysis Results

Sources of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F-value	P-value
Fitted Model	465.76	9	51.75	34.07	< 0.0001
A–a_p	110.78	1	110.78	72.94	< 0.0001
B–a_e	35.11	1	35.11	23.11	0.0013
C–v_c	255.20	1	255.20	168.03	< 0.0001
D–f	30.53	1	30.53	20.10	0.0020
AB	12.08	1	12.08	7.95	0.0225
AC	5.64	1	5.64	3.71	0.0901
AD	1.89	1	1.89	1.24	0.2969

BC	3.15	1	3.15	2.07	0.1878
BD	11.39	1	11.39	7.50	0.0255
Residual Error	12.15	8	1.52		
Lack of Fit	11.40	6	1.90	5.09	0.1733
Pure Error	0.7467	2	0.3733		
Sum	478.36	18			

Here, the null hypothesis H_0 was set as follows: The factors (a_p, a_e, v_c, f) have no effect on the SPL, with a significance level set at 0.05. In analysis of variance, the F-value represents the ratio of between-group variance to within-group variance. The larger the F-value, the greater the between-group variance, indicating that the factor has a more significant impact on the experimental results. The P-value represents the probability of observing results as extreme or more extreme than the actual results under the assumption that the null hypothesis is true. When the P-value is less than the predetermined significance level, the experimental results are considered significant. Furthermore, a smaller *P*-value indicates that the factor has a more significant impact on the experimental results.

According to Table 3, the fitted model showed a relatively high level of fit with an *F*-value of 34.07 and a P-value less than 0.0001. The F-value for v_c was 168.03, with a P-value less than 0.0001. Furthermore, it was evident that v_c had the most significant impact on milling noise, as shown in Fig. 6. This observation aligned with the analysis of the impact of v_c on milling noise. The *F*-value for a_p was 72.94, with a P-value less than 0.0001. Similarly, it could also be seen from Fig. 6 that a_p significantly influenced the milling noise SPL. The F-values for a_e and f were 23.11 and 20.10 respectively, with corresponding P-values of 0.0013 and 0.002. Both factors had a relatively significant impact on the milling noise SPL. From Fig. 6, the significance of the impact on the milling noise SPL could be ranked as follows: v_c had the greatest effect, followed by a_p, a_e, and finally f.

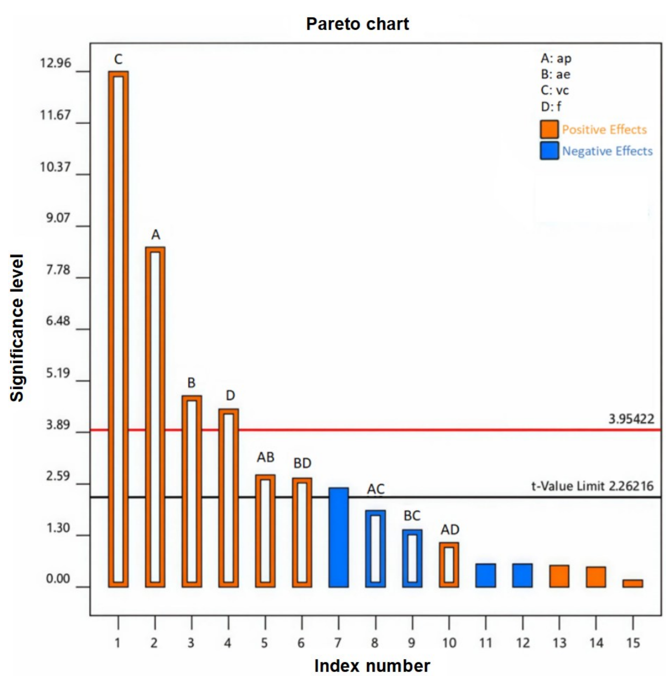
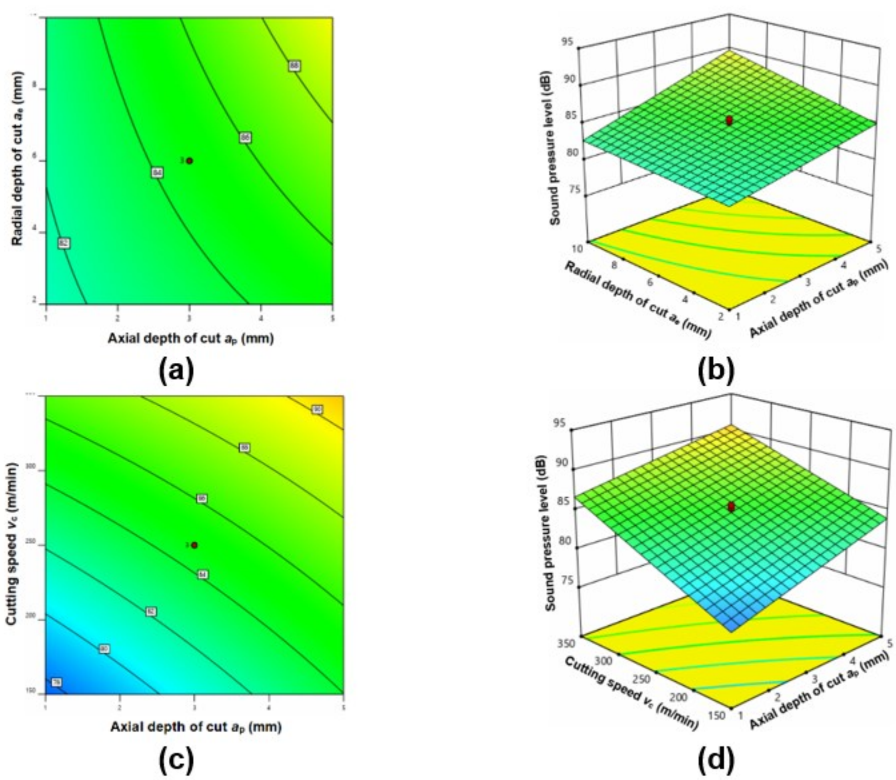


Fig. 6. Milling parameters significance level plot

Analysis of the interactive effects of milling parameters and strategies for milling noise control

To better analyze strategies for controlling milling noise, it was necessary to further analyze the interaction effects among these parameters on the milling noise SPL. The contour plots and 3D surface plots illustrating the correlation between the milling noise SPL and milling parameters were exported from the Design-Expert software and are shown in Fig. 7. From Fig. 7a and Fig. 7b, it is apparent that the contour plots and 3D surfaces exhibited varying undulations, and their interaction had a significant impact on the milling noise SPL. When a_p was kept below 4 mm, the slope of a_e curve changed gradually, indicating that an increase in a_e had relatively little impact on the milling noise SPL. When a_p ranged from 4 to 5 mm, the milling noise increased notably with the increase in a_e. Therefore, to control noise emission, a_p should be maintained within the range of 0 to 4 mm, and the magnitude of a_e can be further adjusted accordingly. From Fig. 7c and Fig. 7d, it is evident that both a_p and v_c have a significant impact on milling noise. Thus, a more intuitive confirmation could be obtained that milling noise SPL was more significantly influenced by v_c through comparison. However, as the contour slope approximated to a linear plane, the interaction between the two variables did not significantly affect the milling noise SPL, which was consistent with the previous analysis. As v_c gradually increased to high speed, the growth of milling noise was not as significant as it was at low speeds. This was because the milling force increased significantly and rapidly as the cutting depth grew in the low-speed phase.



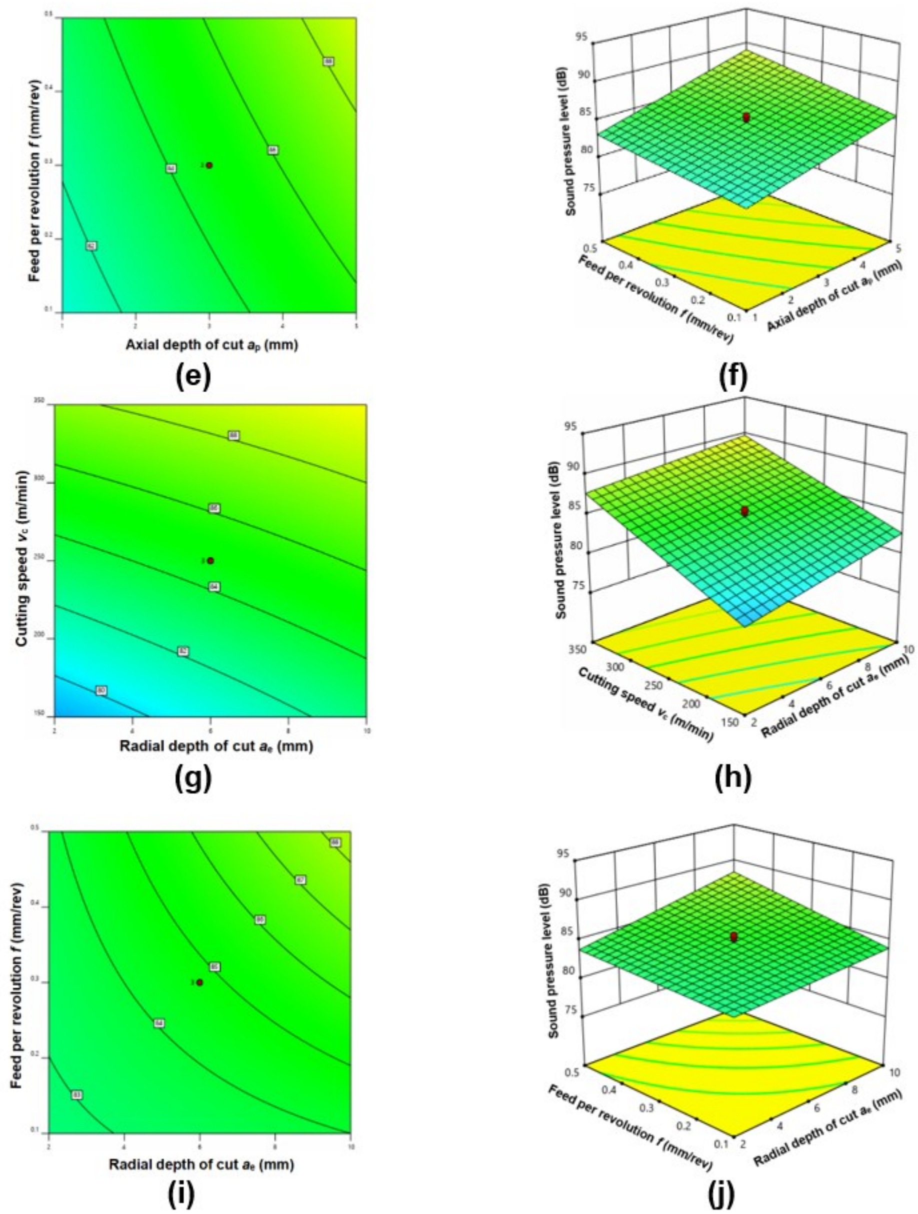


Fig. 7. Contour plots and 3D surface plots

However, when v_c reached a certain level, the influence of a_p on the increase in cutting forces became less significant and consequently resulted in a corresponding slowdown in the increase rate of milling noise SPL. In addition, when both a_p and v_c increased simultaneously, the milling noise SPL could reach a maximum of 91 dB. Therefore, under the premise of prioritizing machining efficiency, a smaller a_p should be selected after determining the appropriate v_c to control noise emission.

From Fig. 7e and Fig. 7f, it can be observed that the varying a_p significantly influenced the milling noise SPL when f was in the range of 0.1 to 0.5 mm/rev. The slope of the 3D surface plot was steeper in the direction of increasing a_p and the milling noise SPL increased obviously. However, when a_p was below 3.5 mm, the slope of the 3D surface plot was gentler in the direction of increasing f, which meant that the varying f had an insignificant effect on the milling noise pressure level. This was because when a_p was small, the varying f had an insignificant effect on the variation of cutting forces, which led to lower noise generation. Similarly, when a_p fell within the range of 3.5 to 5 mm, an increase in f led to a greater rise in the milling noise SPL. Therefore, it is advisable to limit a_p to the range of 0 to 3.5 mm when larger f is required for better control of noise emission. From Figs. 7g and 7h, it can be observed that the interaction between a_e and v_c was similar to the interaction between a_p and v_c. The variation in milling noise SPL was not significant under their interaction. The milling noise SPL increased with the growing a_e and could be controlled below 85 dB during low-speed milling. Therefore, when a_e is relatively high, v_c should be set within the range of 200 to 250 m/min to control noise emission while ensuring machining efficiency. From Fig. 7i and Fig. 7j, it can be observed that the contour lines of f and a_e interaction became denser as both factors increased, and the contour surface of the 3D plot fluctuated. Hence, the interaction between these two factors significantly affected the milling noise SPL. When a_e ranged from 2 to 6 mm and f ranged from 0.1 to 0.3 mm/rev, the rate of change in the milling noise SPL was relatively slow. This can help to maintain a steady level of noise in the machining environment.

CONCLUSIONS

1. The single-factor experimental results indicated that when the radial depth of cut, feed per revolution, and axial depth of cut were gradually increased, the corresponding noise measurement SPL and pure milling noise SPL exhibited similar variation trends, while changes in cutting speed had a significant effect on background noise. The variations in radial depth of cut and feed per revolution both resulted in noticeable changes in milling noise, with the former corresponding to a lower overall noise level and the latter to a higher overall noise level. Additionally, to maintain machining efficiency while minimizing noise, it is recommended to set the cutting speed within the range of 200 to 250 m/min.
2. Analysis of variance indicated that cutting speed v_c had the most significant effect on milling noise SPL under constant milling length conditions, followed by axial depth a_p, radial depth a_e, and feed per revolution f in descending order. Nevertheless, in terms of actual SPL variations, radial depth a_e and feed per revolution f also demonstrated considerable noise increases within certain parameter intervals.
3. The interaction analysis of milling parameters indicated that variations in cutting speed and radial depth of cut had a relatively minor effect on milling noise SPL, while under low-speed milling conditions, the SPL increased significantly with the increase of axial depth of cut. A smaller axial depth of cut should be adopted to control noise emission without sacrificing machining efficiency. Furthermore, when a_p is fixed, lower feed per revolution and radial depth of cut are beneficial for achieving reduced noise levels and maintaining a stable acoustic environment.

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REFERENCES CITED

Ajdinaj, D., Çota, H., Zejnullahu, F., Sejdiu, R., Bajraktari, A., and Mustafaraj, K. (2023). "Noise emission and quality of surface of thermally modified silver fir wood planed by horizontal milling machine," *Wood Research* 68(4), pp. 718-731. https://doi.org/10.37763/wr.1336-4561/68.4.718731

Bhaskar, K., Jayabalakrishnan, D., Vinoth Kumar, M., Sendilvelan, S., and Prabhahar, M. (2021). "Analysis on mechanical properties of wood plastic composite," *Materials Today: Proceedings* 45(Part 7), 5886-5891. https://doi.org/10.1016/j.matpr.2020.08.570

Durkovic, M., Mladenovic, G., Tanovic, L., and Danon, G. (2018). "Impact of feed rate, milling depth and tool rake angle in peripheral milling of oak wood on the cutting force," *Maderas-Ciencia y Tecnologia* 20(1), 25-34. https://doi.org/10.4067/S0718-221X2018005001301

Górski, J., Szymanowski, K., Podziewski, P., Smietanska, K., Czarniak, P., and Cyrankowski, M. (2019). "Use of cutting force and vibro-acoustic signals in tool wear monitoring based on multiple regression technique for compreg milling," *BioResources* 14(2), 3379-3388. https://doi.org/10.15376/biores.14.2.3379-3388

Hu, Y. T., Li, S. C., Deng, X., and Vadim, S. (2022). "Correlation analysis of noise sound pressure and vibration in aluminum alloy milling," *Journal of Vibration and Control* 28(3-4), 276-289. https://doi.org/10.1177/1077546320975977

Hu, Y. T., Li, S. C., Li, S. Y., and Popov, E. (2021). "Research on the combined prediction model of milling sound pressure level based on force-thermal-vibration multi-feature fusion," *International Journal of Advanced Manufacturing Technology* 115(1-2), 233-245. https://doi.org/10.1007/s00170-021-07071-w

Kminiak, R., Nemec, M., Igaz, R., and Gejdos, M. (2023). "Advisability-selected parameters of woodworking with a CNC machine as a tool for adaptive control of the cutting process," *Forests* 14(2), article 173. https://doi.org/10.3390/f14020173

Krilek, J., Kovác, J., Barcík, S., Svoren, J., Stefánek, M., and Kuvik, T. (2016). "The influence of chosen factors of a circular saw blade on the noise level in the process of cross cutting wood," *Wood Research* 61(3), 475-486.

Lin, H. J., Bengisu, T., and Mourelatos, Z. P. (2022). "Sound pressure levels and octave bands," in: *Lecture Notes on Acoustics and Noise Control*, Springer Nature, Cham, Switzerland, pp. 227-249.

Mansor, A. A., Abdullah, S., Ahmad Nawawi, M. A., Ahmed, A. N., Mohd Napi, N. N. L., and Ismail, M. (2020). "Temporal and spatial analysis of the occupational noise at rice mill in Kedah," *IOP Conference Series: Earth and Environmental Science* 498(1), article 012094.

Rech, J., Dumont, F., Le Bot, A., and Arrazola, P. J. (2017). "Reduction of noise during milling operations," *CIRP Journal of Manufacturing Science and Technology* 18, 39-44. https://doi.org/10.1016/j.cirpj.2016.09.001

Sampath, K., Kapoor, S. G., and DeVor, R. E. (2007). "Modeling and analysis of aerodynamic noise in milling cutters," *Journal of Manufacturing Science and Engineering* 129(1), 5-11.

Sio-Sever, A., Lopez, J. M., Asensio-Rivera, C., Vizan-Idoipe, A., and de Arcas, G. (2022). "Improved estimation of end-milling parameters from acoustic emission signals using a microphone array assisted by AI modelling," *Sensors* 22(10), article 3807. https://doi.org/10.3390/s22103807

Wei, W. H., Cong, R., Xue, T. M., Abraham, A. D., and Yang, C. Y. (2021). "Surface roughness and chip morphology of wood-plastic composites manufactured *via* high-speed milling," *BioResources* 16(3), 5733-5745. https://doi.org/10.15376/biores.16.3.5733-5745

Wei, W. H., Shang, Y. Y., Peng, Y., and Cong, R. (2022). "Prediction model of sound signal in high-speed milling of wood-plastic composites," *Materials* 15(11), article 3838. https://doi.org/10.3390/ma15113838

Wellenreiter, P., Hernández, R. E., Cáceres, C. B., and Blais, C. (2022). "Cutting forces and noise in helical planing black spruce wood as affected by the helix angle and feed per knife," *Wood Material Science & Engineering* 17(4), 549-558. https://doi.org/10.1080/17480272.2022.2056079

Xu, C. W., Dou, J. M., Chai, Y. Z., Li, H. Y., Shi, Z. C., and Xu, J. (2018). "The relationships between cutting parameters, tool wear, cutting force and vibration," *Advances in Mechanical Engineering* 10(1), article 1687814017750434. https://doi.org/10.1177/1687814017750434

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