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Research on Cutting Force and Cutting Vibration in Milling of PE WPC

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Abstract

This paper presents the impact of the change of cutting parameters on cutting force and cutting vibration by the milling experiment of PE WPC. In the text, 60% wood flour content and 70% wood flour content WPC are compared in up milling and down milling. The result shows that cutting force shows a progressive increasing trend as the feed speed increasing. The cutting force in up milling is totally smaller than in down milling with the change of cutting speed. Cutting force shows an increasing trend with the cutting width increasing. The impact of feed speed on cutting vibration is more obvious. The cutting vibration of 60% wood flour content is more susceptible than 70% wood flour content. In the cutting speed experiment, the cutting vibration in up milling is obviously bigger than in down milling. The cutting vibration of 60% and 70% wood flour content is almost the same in down milling. However, it is opposite in up milling. The cutting vibration shows a progressive increasing trend in down milling and steady in up milling as the cutting width increases.

Keywords*: PE WPC; milling; cutting force; cutting vibration*

1. Introduction

PE WPC is widely used in many kinds of industries, such as building materials, auto industry, packing and shipping of goods, warehousing, decoration materials, daily life tools and so on [1]. Cutting force and cutting vibration are two important physicals of cutting process [2-3]. They have close relationships with surface quality and power consumption. It is an important meaning for the milling of PE WPC [4-5].

In the cutting force aspect, the main factors are cutlery and cutting parameters. Engin [6] *et al*. did the MDF milling experiment. They tested the cutting component of X-axis and Y-axis in the milling process. They also set up formulas of the two components with deed speed, milling thickness and cutlery angle. Liu [7] designed the multiple regression analysis experiment. Spindle speed, feed speed and cutlery clearance angle are chosen as the factors. She researched WPC cutting performances such as cutting force, cutting temperature, Surface roughness and so on. Set up mathematical model of each cutting performance through the variation of each cutting performance. Through the experiment, Zhang [8] found that main cutting force and normal cutting force all decrease as the serrated rake angle increases and increase as the cutting thickness increases. Cutting speed has little impact on it. Zhang [9] then researched the impact of wood cutting direction on cutting force. The result shows that wood main cutting force has an anisotropy in different cutting directions. The main tend is the main cutting force is biggest in end direction and smallest in lateral. In the cutting vibration aspect, wood vibration cutting is pulse cutting. During the cutting process, cutlery leaves and contacts wood periodically. The size and direction of the speed are change constantly. Hessainia [10] studied the wood cutting

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vibration initially through the experiment. Eyma [11] studied the impact of cutting parameters on wood cutting vibration during the milling.

In summary, the research of PE WPC milling is relatively less. Thus, in this paper, we research the impact of cutting parameters on cutting force and cutting vibration to provide technical support for efficient and high-quality process.

2. Experiment Settings

2.1. Experiment Materials and Equipment

The experiment uses the PE WPC which is developed and made in State Key Laboratory for Materials of Northeast Forestry University. It is made up with PE, wood flour, coupling agent, lubricants and so on. The specific parameters are shown in Table 1.

Table 1. PE WPC Mechanical Properties

Material	Wood flour content	Size(length×width ×thickness) mm	MOE(MPa)	Poisson ratio
PE WPC	60%	500×120×20	2435	0.35
	70%		2875	0.49

Experiment uses CNC milling, experimental equipment is shown in Figure 1. The machine tool is MIKRON UCP 710. Cutter is indexable insert cutter made by Leitz. The diameter of shank cutter is 30mm and model is WL101-2-040854. The blade model is HW-05-005161. The testing equipment used in the experiment are dynamometer, whose model is Kistler 9257B, and acceleration transducer, whose model is Kistler 353A02.

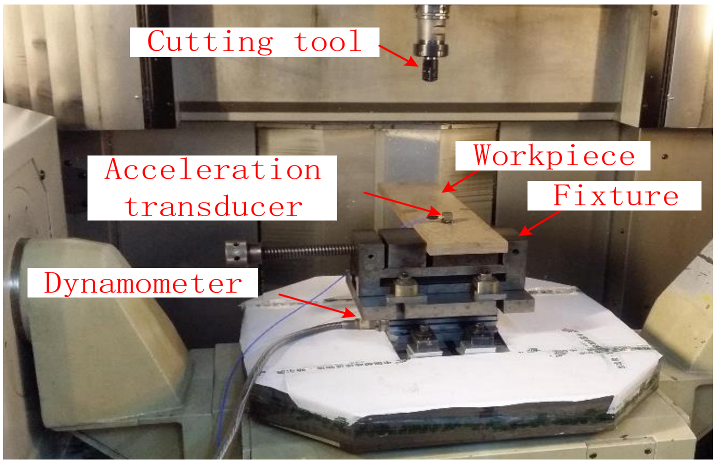

Figure 1. Experimental Equipment

2.2. Experimental Methods

Down milling and up milling are compared in the experiment. The test researches the impact of feed speed, cutting speed and cutting width on cutting force and cutting vibration (Concerning the material is sheet, cutting depth is without consideration). Table 2 shows the milling parameters of PE WPC. It concludes single factor experiment of feed speed, cutting speed and cutting width.

Table 2. PE WPC Experiment Parameters

Group	Feed speed f (m/min)	Cutting speed v (m/min)	Cutting width a_e (mm)	Cutting depth a_p (mm)
1	2, 4, 6, 8, 10, 12, 14	800	1	20
2	6	400, 600, 800, 1000, 1200, 1400, 1600, 1800	1	20
3	6	800	1, 2, 3, 4, 5, 6	20

3. Cutting Force Testing Result and Discussion

3.1. Impact of Feed Speed on Cutting Force

Figure 2 shows the impact of feed speed on cutting force of WPC whose wood flour content is 60% and 70% in XYZ directions during down and up milling. From the figure we can see that when the content is 60% in down milling, the force of X-axis increases from 13.9N to 23.5N as the feed speed increases. When f is 2-8m/min, the force of Z-axis is very steady and small (5.5-6.3N). When f is 10-142-8m/min, the force of Z-axis increases gradually. The cutting force of Y-axis is biggest and almost linearly increases around 26-52.8N. And the increasing trend is bigger than X-axis and Z-axis. The cutting force of up milling is obviously bigger than down milling. Cutting force increases as the feed speed increases. The force of Y-axis is biggest then is X and Z-axis. The change tend of X-axis cutting force, is similar with down milling, showing a slowly increasing trend (23.6-53.5N). Z-axis cutting force (6.9-36.2N) of each feed speed is smaller than X-axis and the curve is parallel with X-axis. Y-axis force is larger and shows an obvious fluctuation.

For the impact of WPC whose content is 70% in three directions, X-axis force is steady in Down milling and shows slight fluctuations in 7N (23.3-30.3N). Z-axis force is very small. When f is 2-6m/min, Z-axis force decreases from 10.9N to 7.7N. When f is over 8m/min, the force is around 6.7N. Y-axis force increases linearly from 36.3N-62.6N. X-axis force waves between 43.3N and 74.3N. When f is 2-12m/min, Z-axis force waves slightly between 17.9N and 33.2N. When f is 14m/min, Z-axis force suddenly increases to 109.2N. The impact is larger. The stability of Y-axis force is bad and the cutting force waves obviously.

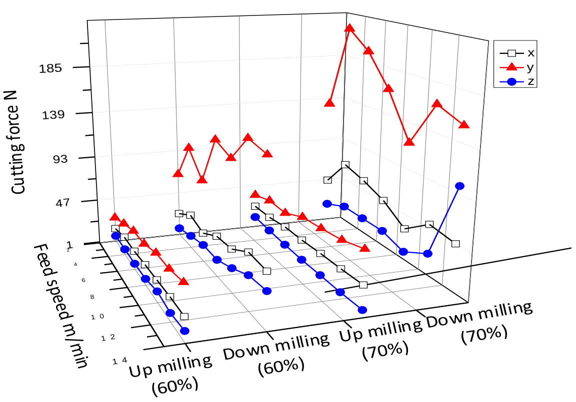

Figure 2. Impact of Feed Speed on Cutting Force

3.2. Impact of Cutting Speed on Cutting Force

Figure 3 shows the impact of cutting speed on cutting force of WPC whose wood flour content is 60% and 70% in XYZ directions during down and up milling. From the figure we can see that when the content is 60% in down milling, the force of X-axis decreases from 24.8N to 6.5N as the cutting speed increases but the total change range is small. Z-axis force is generally between 15N and 3N, which shows a decreasing tend. But when v is 1200m/min, Z-axis force suddenly increases to 21.3N. Y-axis force gradually decreases from 73.6N to 18.3N. When v is 1200m/min, the force also suddenly increases to 83.2N. X and Z-axis force change similarly in up milling that shows a decreasing tend between 39.5N and 5.4N. When v is 1000m/min, X force increases to 39N and Z force increases to 49.9N. Y-axis force change is similar with X and Z-axis force. It also has a discontinuity when v is 1000m/min. The stability of Y-axis force is bad.

For WPC of 70% wood flour content, three forces all show a decreasing tend as the cutting speed increased in Down milling. The force of Y-axis is bigger than X-axis and X-axis is bigger than Z-axis. When v is 1000m/min, Y force increases to 95.1N suddenly. Three forces all show a decreasing tend as the cutting speed increased in up milling but the extent is smaller than down milling. X and Z-axis forces is stable and the change is small. Y force increases suddenly when v is 1600-1800m/min. Especially when v is 1600m/min, the force suddenly increases to 88. 7N.

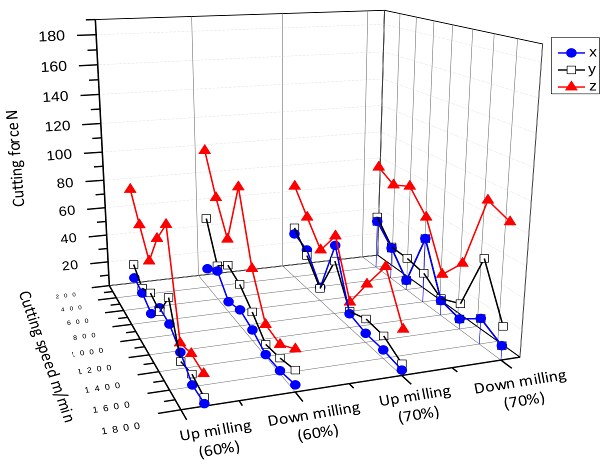

Figure 3. Impact of Cutting Speed on Cutting Force

3.3. Impact of Cutting Width on Cutting Force

Figure 4 shows the impact of cutting width on cutting force of WPC whose wood flour content is 60% and 70% in XYZ directions during down and up milling. When the content is 60%, three force all increases linearly as the cutting width increases. The cutting force is Y>X>Z. X-axis force (44.8N-63.6N) waves slightly in up milling. Z force shows a gradually increasing trend. Y force (123.4N-108.4N) decreases as the cutting width increases but the amount of change is small.

When the content is 70%, three force all increases linearly as the cutting width increases. X force is stable in up milling which is between 55.2N and 68.6N. When W is 4-5mm, Z-axis force increases to 99N suddenly. Y force decreases gradually. But when W is 3-5mm, it shows an obvious fluctuation.

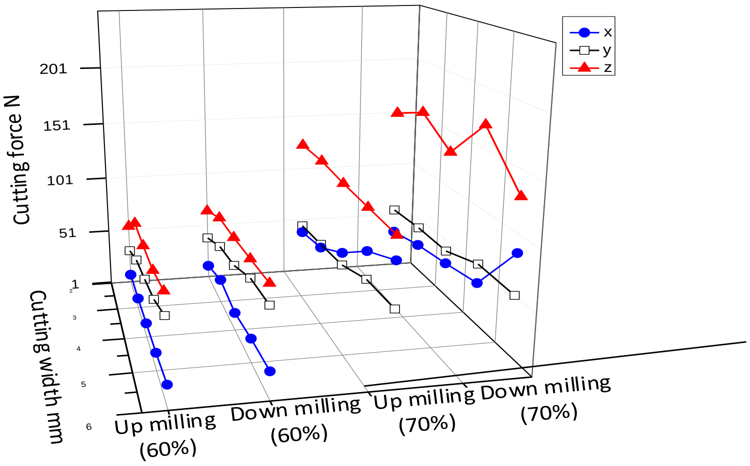

Figure 4. Impact of Cutting Width on Cutting Force

4. Cutting Vibration Testing Result

4.1. Impact of Feed Speed on Cutting Vibration

Figure 5 shows the impact of feed speed on WPC cutting vibration of two contents. When the content is 60% in down milling, Y-axis vibration increases gradually from 6.2m/s^2 to 33.8 m/s^2. X and Z directions also show increasing tend but the fluctuation is very big in each feed speed. The vibrations of all directions increase in up milling. Y-axis vibration is obviously bigger than X and Z-axis vibrations.

When the content is 70%, three directions vibrations show an obvious increasing tend when f is 2-12m/min in down milling. When the feed speed is 14m/min, Y-axis vibration decreases obviously, from 20.1 m/s^2 to 14.5 m/s^2. Cutting vibration changes slightly in up milling. The whole vibration is Y>X>Z.

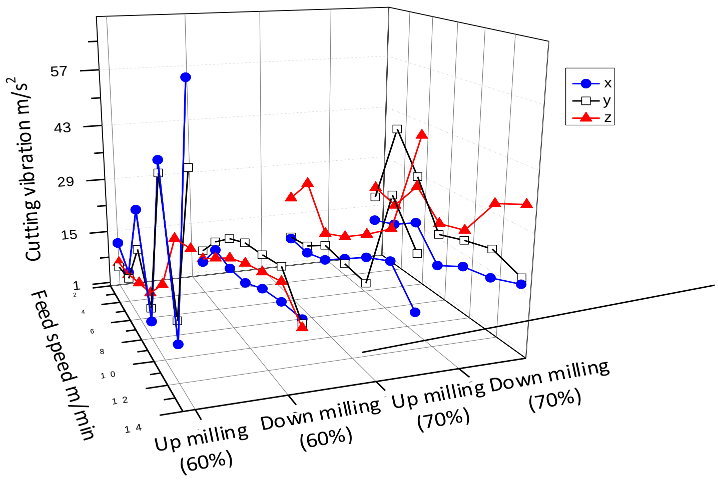

Figure 5. Impact of Feed Speed on Cutting Vibration

4.2. Impact of Cutting Speed on Cutting Vibration

Figure 6 shows the impact of cutting speed on WPC cutting vibration of two contents. When the content is 60% in down milling, X-axis vibration changes slightly between 4.1 and 19.2 m/s^2. Y-axis vibration changes between 7.8 and 17.8 m/s^2. Z-axis vibration changes between 5.8 and 25.4 m/s^2. X and Z-axis vibrations are stable in up milling. When v is 400-800m/min, the vibration is about $25m/s^2$. When v is more than 1200m/min, the vibration increases to $57.7\text{-}67.4m/s^2$.

When the content is 70%, the vibrations of three directions are all around $10m/s^2$ in down milling. When v is 1600m/min, Y-axis vibration increases to $34.8m/s^2$ suddenly. Cutting vibration shows an increasing trend in up milling. When v is 1400-1600m/min, Y-axis vibration increases to about $54m/s^2$ suddenly. When cutting speed is 1800m/min, the vibration is back to $17.8m/s^2$.

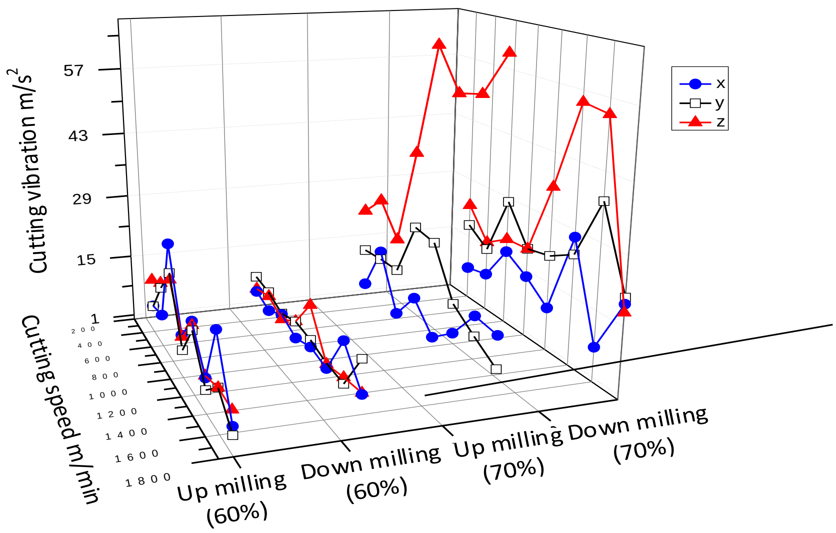

Figure 6. Impact of Cutting Speed on Cutting Vibration

4.3. Impact of Cutting Width on Cutting Vibration

Figure 7 shows the impact of cutting width on WPC cutting vibration of two contents. When the content is 60% in down milling, the cutting vibration increases first and then decreases. When the cutting width is 4mm, X-axis vibration increases to $52.7m/s^2$ suddenly. Cutting vibration is stable and the change is slight in up milling. The vibration is around $20m/s^2$.

When the content is 70%, three directions all show a slowly increasing trend. Y vibration is obviously bigger than the other two directions in down milling. Cutting vibration is stable in up milling. The sum of three directions vibrations changes slightly, around $33.7\text{-}45.7m/s^2$.

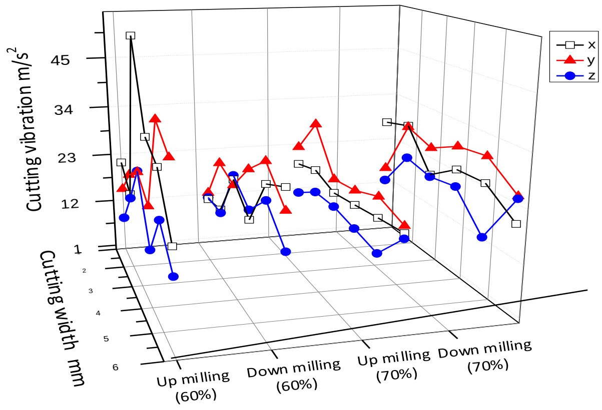

Figure 7. Impact of Cutting Width on Cutting Vibration

5. Conclusion

This paper studies the impact of cutting parameters on cutting force and cutting vibration through the milling experiment about PE WPC. We can get the conclusions through the experiment:

1) Cutting force shows a gradually increasing tend as the feed speed increases. In general, cutting force in up milling is bigger than down milling. Cutting force of 70% content is bigger than 60% content. Cutting force in up milling is smaller than Down milling as the cutting speed changes. Cutting force of 70% content is higher than 60% content. Cutting force shows an increasing tend as the cutting width increases. Cutting force in up milling is bigger than down milling. The force of 70% content is bigger than 60% content.

2) Compared with up milling, feed speed has an obvious impact on cutting vibration in down milling. 60% wood flour content is more easily influenced by feed speed than 70% content. In the cutting speed experiment, the cutting vibration in up milling is obviously bigger than down milling. The cutting vibration of 70% content is almost the same with 60% content in down milling. However, it is opposite in up milling. As the cutting width changes, cutting vibration shows a gradually increasing trend in Down milling, however, it is stable in up milling. Cutting vibration of 60% wood flour content is bigger than 70% in down milling. It is opposite in up milling.

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