Preliminary Study of Effects of Tip Geometry and Material Type of Circular Saws on Cutting Surface Quality of Medium-Density Fiberboard

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Abstract

Effects of tip height and material type, radial clearance angle, and blade lateral runout of circular saws on the machined surface quality of medium-density fiberboards (MDF) cut by circular saws in terms of roughness height were investigated. Experimental results indicated that the tip material type and magnitude of tip radial clearance angle affected the surface roughness height of MDF the most. Using circular saws brazed with polycrystalline diamond (PCD) tips can significantly reduce the surface roughness height compared with using tungsten carbide tips. Circular saws brazed with PCD tips of a radial clearance angle of 0.5° reduced the surface roughness height by as much as half compared with the one with a radial clearance angle of 1.0°. Analytical analysis results indicated that a circular saw with longer tips of a smaller radial clearance angle should be preferred.

Circular saws brazed with tips of hard alloy materials such as tungsten carbide (TC) or polycrystalline diamond (PCD) are used for cutting solid wood and wood-based composites because of their good tool wear resistance. Recent trends in the development of PCD circular saws from shorter cutting tips to sharpen-free tips are gaining popularity because these tools do not require maintenance. This is because recent acceleration in the use of wood-based composites by the furniture industry and fast production speeds demand cutting tools requiring less maintenance time. Quantifying the surface quality of a wood-based composite part cut by saws brazed with TC or PCD tips becomes important because the machined surface quality will affect the quality of subsequent operations such as adhesion properties of panel edge banding. The surface roughness height is commonly used to quantify the surface quality of a machined wood-based composite part. The surface roughness height of a machined piece is influenced by various factors, such as radial clearance angle, tip lateral runout, tip height, and tip material type.

The major concern about circular saws with PCD tips is that the flange of a main shaft, which is attached to the saw blade, has a relatively larger lateral runout. This flange lateral runout can cause the lateral runout of saw tips to become gradually larger after each set of revolutions is completed. Even though in some cases the lateral runout of the flange is smaller, the wear and damage of cutting tips can also cause a larger lateral runout of a saw blade, which will lead to a larger tip lateral runout. As the result of these larger lateral runouts, the waved cut marks on the surface of machined wooden parts can get deeper, i.e., the surface roughness height will be larger, which will result in poor surface quality. Therefore, there is a need for understanding the cause of this larger roughness height on wood-based composites cut by circular saws and a need to design a new type of circular saw system that can reduce the roughness height and improve the surface cutting quality.

Much research has focused on machining wood-based composites using circular saws (Bai et al. 2002, Gittel

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2003). Many studies (Mckenzie 1960, Lemaster and Beall 1993, Mitchell and Lemaster 2002) showed that the increase of cutting speed improves the surface quality of a machined wood product. Bai et al. (2004) found that PCD tool wear was due to intergranular wear and partial cleavage fracture, and microcracking was a key factor influencing PCD tool wear. Miklaszewski et al. (2000) found a new peeling mechanism after the investigation of machining sandwich boards using PCD tools. In addition, increasing the height of the sawing profile on a wood piece can heat up the edge of a saw blade and cause thermal buckling (Ershov 1992, Schajer and Kishimoto 1996). The thermal deflection along the edge of a saw blade can be reduced when the saw blade is tensioned or has different slots prepared along the edge (Li et al. 2007).

The objective of this study was to investigate the effects of tip height, radial clearance angle, blade lateral runout, and tip materials of circular saws on the surface quality of machined wood-based composites in terms of the surface roughness height.

Methods

Theoretical relations between roughness height and lateral runout

Longer tips ($L_r \geq 6$ mm).—Figure 1 illustrates the geometrical relationship between the surface roughness height of a machined piece, δ, the radial clearance angle, γ, the lateral runout of a saw blade, α, and the feeding length per revolution of a circular saw, S_R. The S_R (mm/r) can be calculated using the following formula (Meng et al. 2003):

$$S_R = 1{,}000F/N \tag{1}$$

where F is the feeding speed of cutting materials (m/min), and N is the spindle speed in revolutions per minute (rpm).

In the case of a radial clearance angle (rad.), $\gamma \leq 2\alpha/S_R$ (Figs. 1b and 1c), the surface roughness height (mm) of a machined piece is (Meng et al. 2003)

$$\delta = 2\alpha\gamma/(\gamma + 2\alpha/S_R) \tag{2}$$

where α is the lateral runout of a saw blade (mm).

In the case of $\gamma \geq 2\alpha/S_R$ (Figs. 1a and 1b), the surface roughness height of a machined piece is

$$\delta = \alpha \tag{3}$$

In the case of an off-center cutting (Fig. 2), the S_R in above formulas is replaced with the S_r calculated using the following equation:

$$S_r = S_R \times \sin\left[\cos^{-1}\left(\frac{D/2 - H}{D/2}\right)\right] \tag{4}$$

where D is the blade outer diameter (mm), and H is the cutting depth (mm).

Shorter tips ($L_r \leq 6$ mm).—In the case of $\gamma \leq 2\alpha/S_R$ (Fig. 3), the smallest tip height L_0 (mm) and the minimum value of a surface roughness height δ_0 (mm) can be calculated using the following formulas, respectively:

$$L_0 = \frac{2\alpha}{\gamma + \frac{2a}{S_R}} \tag{5}$$

$$\delta_0 = \frac{2\alpha\gamma}{\gamma + \frac{2a}{S_R}} \tag{6}$$

But, if the shorter tip height is L_r not L_0, the surface roughness height is

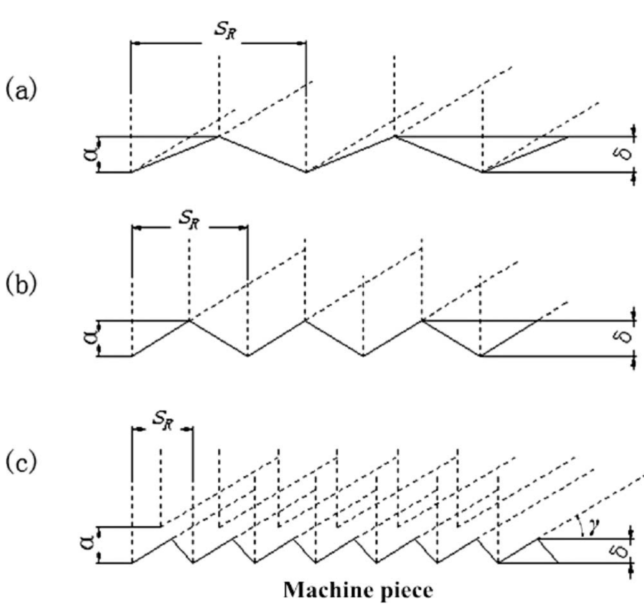


Figure 1.—Diagram showing geometrical relationships among the surface roughness height of a woodworking piece (δ), the radial clearance angle (γ), the lateral runout of a saw blade (α), and the feeding length per revolution of a circular saw (S_R).

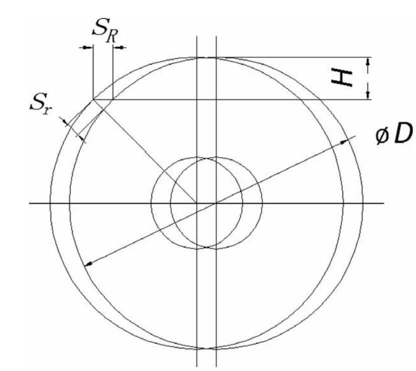


Figure 2.—Diagram shows saw blade cutting position in relation to feeding speed for off-center cutting.

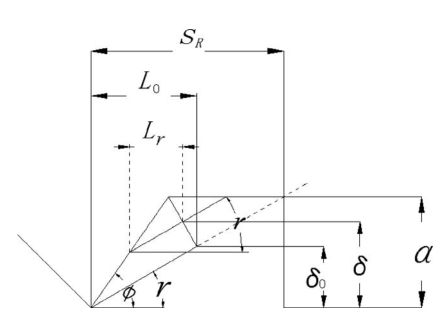
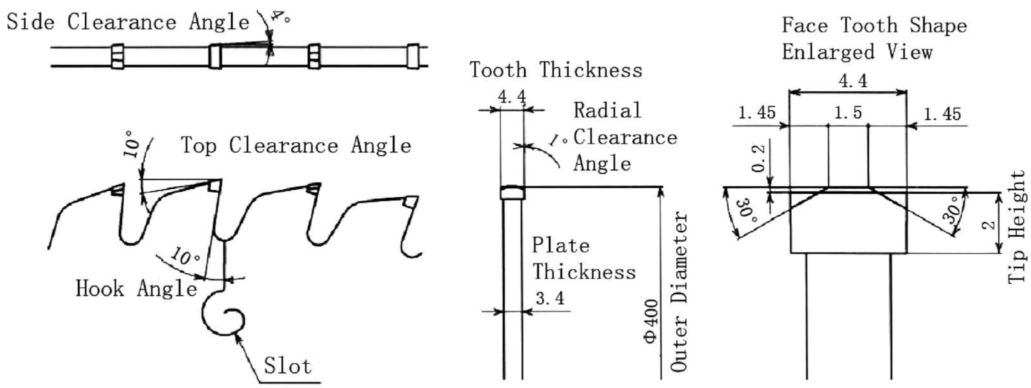


Figure 3.—Diagram showing geometrical relationships between the surface roughness height of a machined part and circular saw parameters.

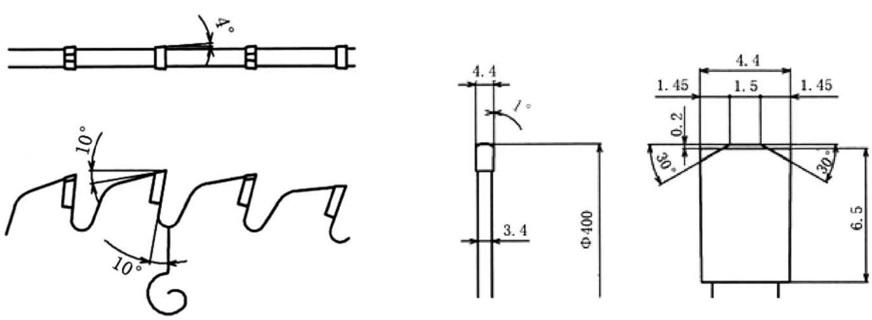
$$\delta = \alpha - \frac{(\alpha - \delta_0)L_r}{L_0} \qquad (7)$$

Experiment

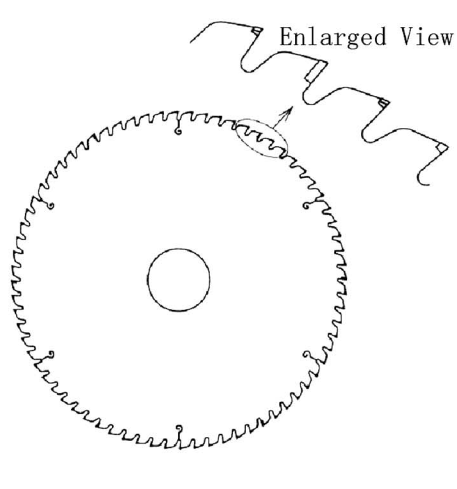
Circular saw.—Figure 4 shows configurations of three types of circular saws, A, B, and AB, used in this study. They all had an outer diameter of 400 mm, kerf thickness of 4.4 mm, saw blade thickness of 3.4 mm, and bore diameter of 75 mm. All saw blades had 72 square and trapezoidal-type teeth with a hook angle of 10°, top clearance angle of 10°, side rake and top flank angle of 0°, side clearance angle of 4°, and radial clearance angle of 1°. The different parameters among these three types of saws, such as tip height, L_r, top clearance angle, etc., are listed in Table 1 and also illustrated in Figures 4a, 4b, and 4c.



(a)



(b)



(c)

Figure 4.—Configurations of circular saws of type A (a), type B (b), and type AB (c).

Table I.—Specifications of circular saws evaluated in this study.

Type	No. of teeth	L_γ (mm)	γ (deg)	Tip material type[a]
A	72	2.0	1.0	PCD
B	72	6.5	1.0	TC
AB	66	6.5	1.0	PCD
	6	2.0	1.0	PCD
AB-0.5	66	6.5	0.5	PCD
	6	2.0	0.5	PCD

[a] PCD = polycrystalline diamond; TC = tungsten carbide.

Material.—The material used in this study was 15-mm-thick, two-sided melamine laminated medium-density fiberboard (MDF) with a density of 0.72 g/cm^3.

Laboratory cutting test.—Figure 5 shows the setup of a laboratory cutting test of two laminated MDF panels stacked together and fed through a circular saw. The flange of the test saw blade had an outer diameter of 120 mm and was fixed to the main shaft with an outer diameter of 25.4 mm through a bush with an outer diameter of 75 mm. The main shaft spindle speed was 3,600 rpm and material feeding speed was 39 m/min. The distance from the lowest point of the saw to the bottom of the cutting pieces was 5 mm (Fig. 5). The lateral runout of a test saw was produced through adding shims between the flange and the saw blade on the motor side. The lateral runout of tip sides was 0.04 mm when no shim was added, and it changed to 0.52 mm when shims were added. The surface roughness height of a machined part was measured using a stylus profile meter.

Field cutting test.—The field cutting test was performed at a local furniture manufacturing facility. Five laminated MDF panels were stacked together and fed through the test saw. These tested MDF panels were the same type as those used in the laboratory cutting tests. Test saws were type B, type A, and type AB-0.5, which were the same types used in the laboratory cutting tests. The flange of the saw blades had an outer diameter of 130 mm. Other cutting parameters and conditions were maintained to be the same as the laboratory cutting test condition. The initial lateral runout of tip sides was 0.05 mm, and later it reached 0.15 to 0.20 mm during the cutting process.

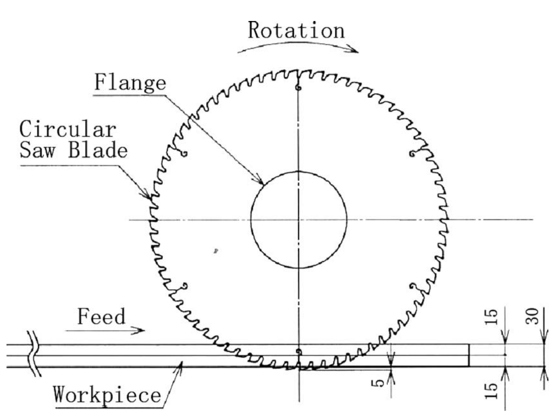


Figure 5.—Laboratory cutting test setup showing the direction of feeding two stacked 15-mm-thick medium-density fiberboard panels cut with a circular saw rotating as indicated.

Results and Discussion

Analytical

The plotted curves in Figures 6a and 6b show relationships between surface roughness height and material feeding speed for each of five tip lengths from 1 to 12 mm within each of two radial clearance angles of 1° and 0.5°, respectively. The results were calculated based on the equations discussed previously through setting the lateral runout of tip sides to 0.3 mm and varying the saw tip height from 1 to 12 mm.

These two plots indicate that if a circular saw has a larger tip height, the surface roughness height of a machined piece tends to increase proportionally to the material feeding speed and converge to the magnitude of the lateral runout of the tip sides for the first half turn of each revolution. As saw tip height decreases, the surface roughness height of a machined piece increases rapidly at a certain feeding speed and also converges to the magnitude of the lateral runout of the tip sides. The shorter the tip height is, the larger the surface roughness height will be.

At a lower material feeding speed, if a saw with, e.g., 1-mm-long tips is used, the surface roughness height can reach a higher value at a faster pace. In contrast, a saw with, e.g., 12-mm-long tips will yield a slower rate of increase for the

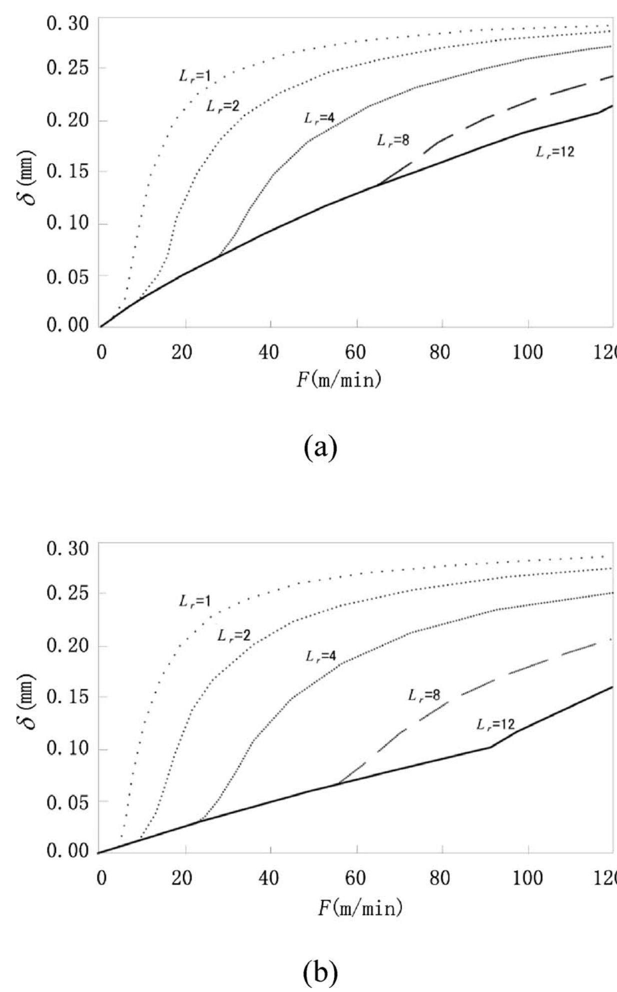


Figure 6.—Surface roughness height versus material feeding speed curves for each of five tip lengths within each of two radial clearance angles of 1° (a) and 0.5° (b).

surface roughness height of a machined part. In addition, the radial clearance angle seems to affect the slope of the surface roughness height–feeding speed curve at a larger tip height, i.e., the larger the radial clearance angle is, the higher the curve slope is, but this is not the case as the tip height decreases.

Experimental

Laboratory testing.—The experimental and analytical results of the surface roughness height per revolution as a function of the lateral runout of tip sides are plotted in Figure 7. In general, the estimated lines fit the experimental data points well. In other words, the analytical formulas used to derive the prediction curves can be used to estimate the surface roughness height of a machined piece with given parameters of a cutting tool.

Experimental results indicated that the MDF piece machined by type A and type AB saws yielded the same surface roughness height when both saws had the same radial clearance angle even though the two saws had different tip heights. This might imply that under the condition of a radial clearance angle of 1.0°, the surface roughness height of a cut MDF part will not be affected by the increase of tip height from 2.0 to 6.5 mm. In the case of the type B saw, the surface roughness height of a machined MDF part increased proportionally to the lateral runout of tip sides, and the rate of increase was much higher than with the type AB saw. This difference between type B and type AB saws could be due to different tip materials used, i.e., type AB had the tip material of PCD, which had better cutting performance than the TC used in the type B saw tip material.

The surface roughness height of a machined piece cut using a type AB circular saw with a radial clearance angle of 0.5° was about half of that cut with the type AB saw with a radial clearance of 1°. This indicated that the roughness height of cutting surfaces of MDF materials can be reduced using a saw with a smaller radial clearance angle instead of a larger one for longer saw tips. All of these indicate that the surface roughness height of MDF material cut with a circular saw having longer tips and smaller radial clearance angles will yield a better surface quality.

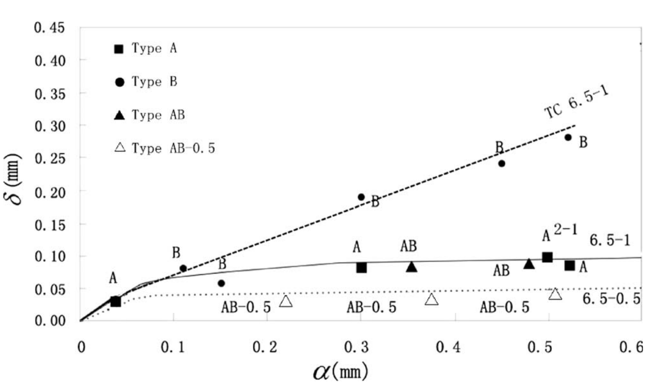


Figure 7.—Experimental results of measured surface roughness heights of medium-density fiberboards cut with four types of saws evaluated in this study were plotted against estimated curves.

Field testing.—The surface roughness height of MDF parts cut with type A saws was greater than 0.1 mm at the early cutting stage, which was considered by the company to be an unacceptable surface quality. The surface roughness height of parts cut with type B saws was less than 0.03 mm, but it was found that power consumption increased rapidly due to abrasion between the cutting tool and material. The MDF panel cut with type AB-0.5 saws had the surface roughness height of 0.03 mm measured at the early cutting stage. The roughness height can be controlled even though the abrasion wear of saw tips progressed and the lateral runout of the saw blade gradually increased during the cutting process performed. It was also observed that the longevity of saws with type AB-0.5 tips was more than 80 times the longevity of saws with type B tips.

Conclusions

Effects of tip height, material type, radial clearance angle, and blade lateral runout of circular saws on the surface roughness height of MDF materials cut with the saws were investigated. Preliminary experimental results indicated that the tip material type and magnitude of the tip radial clearance angle affected the surface cutting quality of a machined MDF part the most. Using PCD tips can significantly reduce the surface roughness height compared with using TC tips when MDF materials are cut. Using a circular saw brazed with PCD tips that have a radial clearance angle of 0.5° can reduce the surface roughness height by half compared with the one with a radial clearance angle of 1.0°. The circular saw brazed with PCD tips of a 0.5° radial clearance angle has a cutting life 80 times that of a saw with TC tips of 1.0° radial clearance angle. Analytical analysis results indicated that a circular saw with longer tips of a smaller radial clearance angle should be preferred. Therefore, among four types of circular saws evaluated in this study, the one brazed with 6.5-mm-long PCD tips with a 0.5° radial clearance angle is recommended for cutting MDF panel products.

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