J Wood Sci (2011) 57:149–154
DOI 10.1007/s10086-010-1145-y

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Difference in mass concentration of airborne dust during circular sawing of five wood-based materials

Received: March 31, 2010 / Accepted: July 2, 2010 / Published online: October 18, 2010

Abstract The object of this study was to compare the mass concentration of airborne dust during circular sawing of five wood-based materials: solid sugi (*Cryptomeria japonica*) lumber, tropical hardwood plywood, softwood plywood, particleboard, and medium-density fiberboard. Specimens were sawn at a constant feed per tooth (0.05 mm) using two saw speeds. The mass concentration of airborne dust of diameter 7.07 μm or less (respirable dust) was measured with a light-scattering dust monitor. The mass concentration showed a log-normal distribution, and the geometric means of mass concentration at saw speeds of 2000 and 3000 rpm were 2.33 and 2.89 mg/m^3 for tropical hardwood plywood, 1.13 and 2.84 mg/m^3 for particleboard, 0.91 and 2.28 mg/m^3 for medium-density fiberboard, 1.09 and 1.38 mg/m^3 for softwood plywood, and 0.32 and 0.66 mg/m^3 for sugi lumber. The mass concentration for all five wood-based materials increased with the revolution speed of the circular saw.

Key words Respirable dust · Mass concentration · Circular saw · Wood-based material · Saw speed

Introduction

Airborne dust generated in the wood machining process is likely be inhaled by workers and can cause serious diseases such as cancer.[1] The International Agency for Research on Cancer classified wood dust as carcinogenic to humans based on epidemiological evidence.[2] The Japan Society for Occupational Health (JSOH) also classified wood dust as carcinogenic in 1998, and set the occupational exposure limit for wood dust at 1 mg/m^3 of respirable dust and 4 mg/m^3 of total dust.[3] Exposure to dust from certain species of wood, such as western red cedar (*Thuja plicata*) and oak (*Quercus robur*), may cause asthma.[4,5] In Japan, asthma caused by the dust of western red cedar is well known.[6]

The development of a technique to reduce airborne dust in the wood machining process is essential, and it is necessary to investigate the mass and size of dust generated from woodworking machinery and to clarify the effect of machining conditions on the properties of dust. Palmqvist and Gustafsson[7] reported that the mass concentration of dust generated from milling medium-density fiberboard (MDF) was six times that generated from milling solid pine or beech. Hemmilä and Usenius[8] measured the amount of dust (particle size < 100 μm) during milling and reported that the amount of dust generated was 27 times larger for MDF than for solid pine. Rautio et al.[9] reported that the milling of MDF generated 30 times and 8 times more airborne dust than that of solid pine and particleboard, respectively. These studies suggest that the properties of dust differ among solid wood, particleboard, and MDF. In the experiments of Rautio et al., the milling knives were enclosed in a dust collector and the generated dust was collected for measurement. However, dust collectors cannot remove all the dust, and the remaining dust is hazardous to human health.

Circular sawing machines are some of the most common woodworking machines, and workers near the machines are exposed to dust not removed by the dust collector. Thus, it is necessary to investigate the dispersal of this dust. However, only a few researchers[10–12] have investigated the dust generated from circular sawing. Kos et al.[12] measured the dust around several kinds of woodworking machines, including circular saws, and reported that the limit values for respirable dust were exceeded around the circular saw when machining particleboard or beech wood. Ikegiwa and Matsueda[11] reported a higher mass concentration of

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Part of this article was presented at the 54th Annual Meeting of the Japan Wood Research Society in Sapporo, August 2004

Table 1. Wood-based materials used in this experiment

Wood-based material	Density (g/cm^3)	Moisture content (%)
Sugi lumber (SL)	0.37	13.2
Tropical hardwood plywood (TPW)	0.66	8.2
Softwood plywood (SPW)	0.48	9.8
Particleboard (PB)	0.67	10.0
Medium-density fiberboard (MDF)	0.63	8.1

airborne dust when circular sawing particleboard or plywood compared to western hemlock lumber.

Sawdust that is not removed by a dust collector is mainly airborne dust. Therefore, it is necessary to investigate the relationship between the mass concentration of airborne dust and the mass and size of sawdust not removed by the dust collector.

In this research, we investigated the mass concentration of airborne dust generated from circular sawing solid lumber, plywood, particleboard, and medium-density fiberboard. In addition, sawdust not removed by the dust collector was collected from the table of a circular sawing machine and from the floor near the worker, and the particle size distribution and the mass of sawdust were investigated.

Experiments

Materials and sawing conditions

We used five wood-based materials of 1800 mm (sawing direction) × 15 mm (thickness): solid sugi (*Cryptomeria japonica*) lumber (SL), tropical hardwood plywood (TPW), softwood plywood (SPW), particleboard (PB), and medium-density fiberboard (MDF). The densities and moisture contents are listed in Table 1. Twenty-five specimens of each material were continuously sawed during one experiment at a position 5 mm from one edge. We carried out the experiments two or three times under one condition (one material and one saw revolution speed).

Figure 1 shows the circular sawing machine used in this experiment. The saw blade was 355 mm in diameter, 3.0 mm in kerf width, and 2.0 mm in thickness; it had 60 teeth, a rake angle of 20°, a clearance angle of 15°, and a top bevel angle of 5°. The height of the circular saw blade above the surface of the table was set at 20 mm (Fig. 1). The machine was equipped with feed rollers, and the main motor of the machine was equipped with an inverter. Various combinations of feed speed and revolution speed were available.

The amount of dust generated is strongly influenced by the average chip thickness.[7,9,12] In this experiment, the feed per tooth was fixed at 0.050 mm, which gave approximately 0.017 mm as the average chip thickness[13] for all materials. Since our previous research[10] showed that the mass concentration of airborne dust in the worker's breathing zone increased with the revolution speed of the saw blade, the experiment was carried out using two combinations of saw revolutions and feed speeds: 2000 rpm and 6.0 m/min, and 3000 rpm and 9.0 m/min.

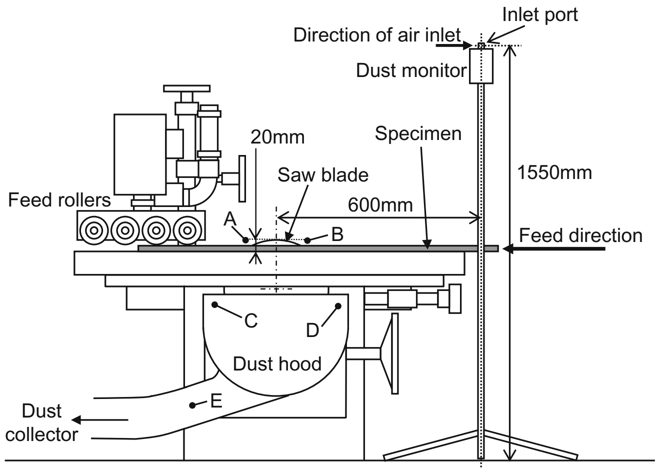

Fig. 1. Circular sawing machine setup for collection of sawdust. *A, B, C, D*, and *E* are the locations where the airflow velocity was measured

Table 2. Airflow velocity around the circular saw while operating the dust collector

Measurement location	Revolution speed of circular saw (rpm)	Airflow velocity (m/s)			State
		Max	Avg	Min	
A	2000	0.58	0.51	0.46	Idle running
B	2000	0.68	0.62	0.55	Idle running
C	2000	7.61	7.32	6.68	Idle running
D	2000	10.10	9.72	9.42	Idle running
E	2000	12.20	11.90	11.80	Idle running
A	3000	1.07	0.98	0.93	Idle running
B	3000	1.06	1.00	0.92	Idle running
C	3000	10.80	10.40	9.93	Idle running
D	3000	16.80	15.60	15.20	Idle running
E	3000	11.90	11.70	11.50	Idle running
A	2000	1.26	0.87	0.48	Sawing
B	2000	1.35	0.92	0.65	Sawing
A	3000	3.86	2.93	0.96	Sawing
B	3000	2.62	1.79	1.39	Sawing

Measurement locations A, B, C, D, and E refer to Fig. 1
Max, maximum value; Avg, average value; Min, minimum value

The experiment was performed in an experimental room in which the windows and the doors were closed to prevent any airflow other than that generated by the circular saw. The airflow velocity was less than 0.01 m/s and the relative humidity was 47%–63% near the machine before the start of sawing.

The circular sawing machine used was connected to a mobile dust collector (Suzuki Kogyo, DT-30M). The dust collector was operated only during sawing. The maximum, average, and minimum values of airflow velocity around the circular saw at measurement locations A, B, C, D, and E with the dust collector in operation (Fig. 1) are shown in Table 2. The performance of the dust collector was equivalent to the dust collectors normally used in wood processing factories.

Measurement of respirable dust

The mass concentration of respirable dust (of aerodynamic diameter 7.07 μm or less) was measured with a light-scattering dust monitor (Shibata Scientific, LD-3K). This meets the Working Environment Measurement Standards from the Ministry of Health, Labour and Welfare.[14] The dust monitor was set at a point 1550 mm above the floor and 600 mm from the axis of the circular saw toward the work station of an operator (Fig. 1). This point corresponded to the worker's breathing zone. Dusty air was collecting at 3.4 l/min from an inlet port and sampled at intervals of 1 s for approximately 1 h during one experiment.

Analytical procedure for dust mass concentration

The measurement value of the light-scattering dust monitor is the relative concentration (count per minute: CPM). The relative concentration is converted to a mass concentration (mg/m^3) using the calibration factor of the dust monitor (*K*-factor). The *K*-factors were estimated by comparing the weight of the dust collected using a low-volume air sampler (Shibata Scientific, SL-20) with the relative concentration when sawing wood-based materials (Table 3).

In order to accurately evaluate the mass concentration, we calculated the mean, standard deviation, and maximum, because a worker is exposed to a high dust mass concentration when the standard deviation and the maximum are high even if the mean is low.

Since the distribution of measured values of mass concentration shows a log-normal distribution, the Working Environment Measurement Standards[14] require the geometric mean (M_g) and the geometric standard deviation (σ_g) to assess dust mass concentration. In this experiment, therefore, we calculated M_g and σ_g as follows:

$$\log M_g = \frac{\sum \log x_i}{n} \quad (1)$$

$$\log \sigma_g = \sqrt{\frac{\sum \log^2 x_i - n \log^2 M_g}{n-1}} \quad (2)$$

where x_i is the mass concentration for the *i*th measurement and *n* is the number of measurements. The maximum mass concentration (C_{max}) was obtained from the data on mass concentration.

Measurement of particle size distribution and mass of sawdust

After the sawing test at a revolution speed of 3000 rpm and a feed speed of 9.0 m/min, the sawdust that was not removed by the dust collector was collected from the table of the circular sawing machine and from the floor in the experimental room. The mass of sawdust from both places and the particle size distribution of sawdust from the floor were measured. The theoretical mass of sawdust was calculated from the density, height, and length of the specimen and the kerf width of the circular saw; this value was compared with the mass of sawdust that was not removed in order to obtain the percentage of sawdust not removed. The particle size distribution of the sawdust was measured by classifying it with a sieving machine for 20 min at the following size intervals: <0.063, 0.063–0.125, 0.125–0.25, 0.25–0.5, 0.5–1.0, 1.0–2.0, 2.0–4.0, and >4.0 mm.

Results and discussion

Mass concentration of respirable dust

Figure 2 shows an example of the change in mass concentration of respirable dust with time. The mass concentration rapidly increased soon after the start of sawing and then fluctuated widely. It rapidly decreased after the end of

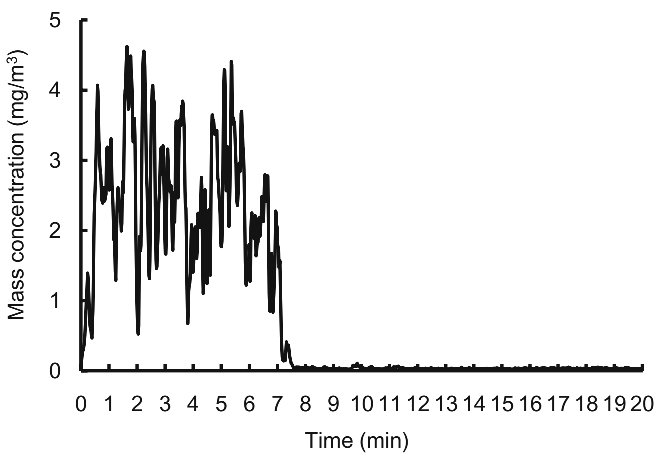

Fig. 2. Change in mass concentration of respirable dust with time while sawing particleboard at a saw revolution speed of 2000 rpm and a feed rate of 6.0 m/min. Sawing started at 0 min and ended at 7 min

Table 3. Calibration factor of the dust monitor, *K*-value

	SL	TPW	SPW	PB	MDF
Mass of dust (mg)	0.22	0.28	0.19	0.12	0.28
Mass concentration of airborne dust (mg/m^3)	1.10	1.40	0.95	0.60	1.40
Relative concentration of airborne dust (CPM)	1103	1101	758	797	1426
K-value ($mg/(m^3/CPM)$)	0.00100	0.00127	0.00125	0.00075	0.00098

Revolution speed, 2000 rpm; feed rate, 6.0 m/min; measurement time, 20 min
CPM, counts per min

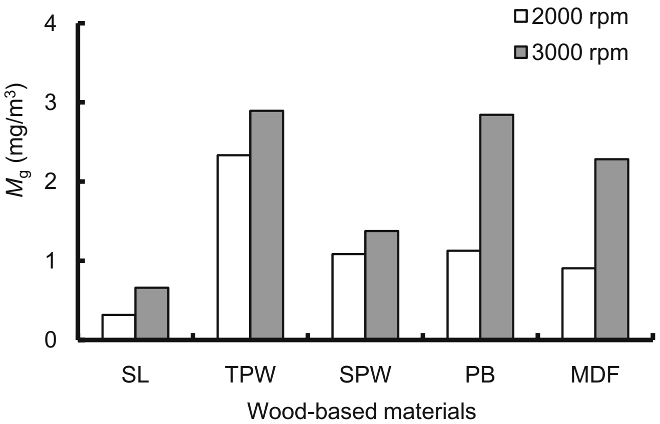

Fig. 3. Geometric means of mass concentration of respirable dust, M_g, for five wood-based materials at two revolution speeds of the circular saw. *SL*, solid sugi lumber; *TPW*, tropical hardwood plywood; *SPW*, softwood plywood; *PB*, particleboard; and *MDF*, medium-density fiberboard

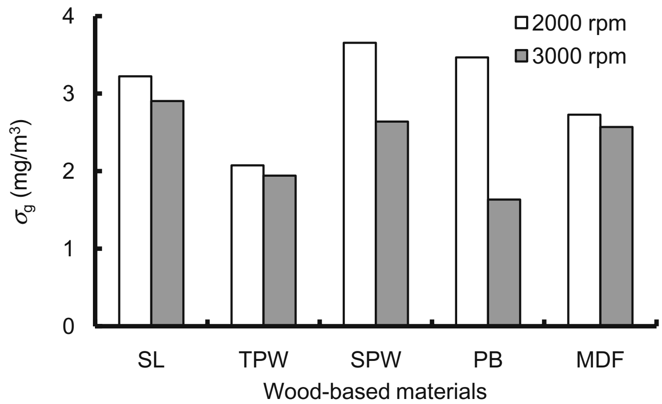

Fig. 4. Geometric standard deviations of mass concentration of respirable dust, σ_g, for five wood-based materials at two revolution speeds of the circular saw

sawing and had almost returned to the initial background value about 1 h after the end of sawing. The fluctuations were caused by the variation of airflow velocity. The difference between maximum and minimum value of airflow velocity during sawing was larger than the difference during idle running (Table 2), i.e., the variation of airflow velocity during sawing was larger than that during idle running. This variation was influenced by the properties of the specimen, such as annual rings and knots.

Figure 3 shows M_g values for the five wood-based materials at two revolution speeds of the circular saw. The highest M_g values were measured while sawing TPW and PB; the lowest M_g was measured while sawing SL. These findings are discussed in detail in the following section. Four of the wood-based materials (all except SL) had a higher M_g than the occupational exposure limit (OEL) of 1 mg/m^3 in Japan.[3]

In a previous study,[11] the mass concentration of airborne dust from the circular sawing of particleboard or tropical hardwood plywood was found to be higher than that from the sawing of solid western hemlock. Palmqvist and Gustafsson[7] and Gottlöber and Hemmilä[15] reported that the dust concentration from the milling of MDF was more than that from the milling of solid wood. Also, Rautio et al.[9] reported that the dust concentration was, in descending order, MDF, particleboard, and solid wood. This result is inconsistent with the findings of this study; three reasons for this difference were considered. First, in this study the respirable dust was collected from the worker's breathing zone, not from around the saw blade. We measured only the respirable dust that reached the worker's breathing zone, not all respirable dust, whereas Rautio et al.,[9] Palmqvist and Gustafsson,[7] and Gottlöber and Hemmilä[15] measured all the airborne dust because they collected it close to the milling tool. Second, the dust size measured was different. We measured the mass concentration of respirable dust of diameter 7.07 μm or less, whereas the other authors measured the mass concentration of airborne dust of diameter 100 μm or less. Third, the machining process was different. The machining process and tools have an influence on the production of airborne dust.

Figure 3 also shows that the M_g value at 3000 rpm was greater than that at 2000 rpm for all materials, although the average chip thickness was the same for both revolution speeds. The revolution speed affected the mass concentration of respirable dust. This implies that the quantity of respirable dust that reaches the worker's breathing zone increases with peripheral speed and that a larger amount of sawdust is dispersed. The differences in M_g between the two revolution speeds for plywood (TPW and SPW) were smaller than those for the other materials (SL, PB, and MDF). The reason for this finding is unclear; therefore, further experiments are needed.

Figure 4 shows the σ_g values for the five wood-based materials at two revolution speeds of the circular saw. σ_g varied from 1.63 to 3.65 mg/m^3. The σ_g values at 2000 rpm were greater than those at 3000 rpm; however, the σ_g values were not strongly influenced by the kind of specimen.

C_{max} for the five wood-based materials at two revolution speeds of the circular saw is shown in Fig. 5. C_{max} was greatest for TPW, followed by PB, MDF, and SPW; it was least for SL. This is the same order as that for M_g. There was no consistent relationship between C_{max} and the revolution speed of the saw blade.

Particle size distribution and mass of dust

Table 4 shows the mass and the percentage of sawdust not removed by the dust collector relative to the theoretical mass of sawdust. The mass and the percentage of sawdust not removed were greatest for PB, followed by SL, SPW, TPW, and MDF. Figure 6 shows the particle size distribution of the sawdust collected from the table and the floor. The median size (the size at cumulative undersize of 50%) was greatest for SL, followed by PB, TPW, SPW, and MDF. For PB, the mass and percentage of sawdust were highest both on the table and on the floor. These findings were related

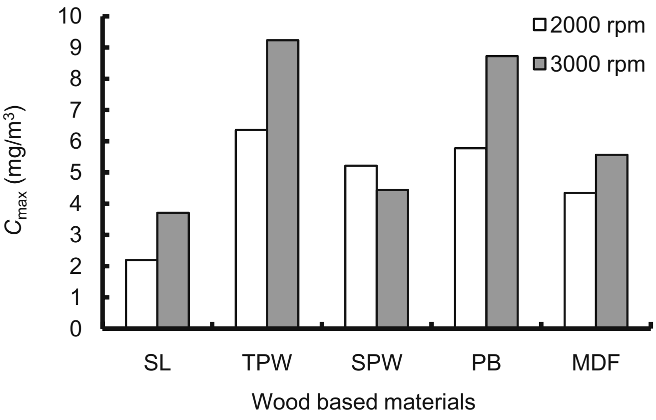

Fig. 5. Maximum of mass concentration of respirable dust, C_{max}, for five wood-based materials at two revolution speeds of the circular saw

Table 4. Mass and percentage of sawdust not removed by the dust collector

Wood-based material	Calculated total mass of sawdust (g)	Mass of sawdust not removed (g)		Percentage of sawdust not removed (%)	
		Floor	Table	Floor	Table
SL	749	3.28	2.43	0.44	0.32
TPW	972	1.74	2.43	0.18	0.25
SPW	1337	4.67	4.03	0.35	0.30
PB	1357	7.44	10.67	0.55	0.79
MDF	1276	0.71	2.28	0.06	0.18

Sawdust was collected after sawing tests at a saw revolution speed of 3000 rpm and a feed speed of 9.0 m/min
Floor, collected from the floor in the experimental room; Table, collected from the table of the circular sawing machine

to the high M_g for PB at 3000 rpm (Fig. 3). Although the second highest mass of sawdust not collected was for SL, the M_g for SL was lowest. This result depends on the largest size of sawdust (Fig. 6). For MDF, the mass and percentage of sawdust not removed were the least. These findings imply that the sawdust of MDF was well collected by the dust collector, even though the M_g value was relatively high. This was due to the small size of MDF sawdust. Since the median size for MDF was the smallest (Fig. 6), MDF sawdust clearly contains many fine particles.

Conclusions

We investigated the influence of the type of wood-based material on the mass concentration of respirable dust generated from circular sawing for two revolution speeds of the circular saw. From the experimental findings the following conclusions can be drawn:

1. The geometric mean (M_g) mass concentration of respirable dust from sawing tropical hardwood plywood and particleboard was higher than that for the other materials. The lowest M_g was observed while sawing sugi

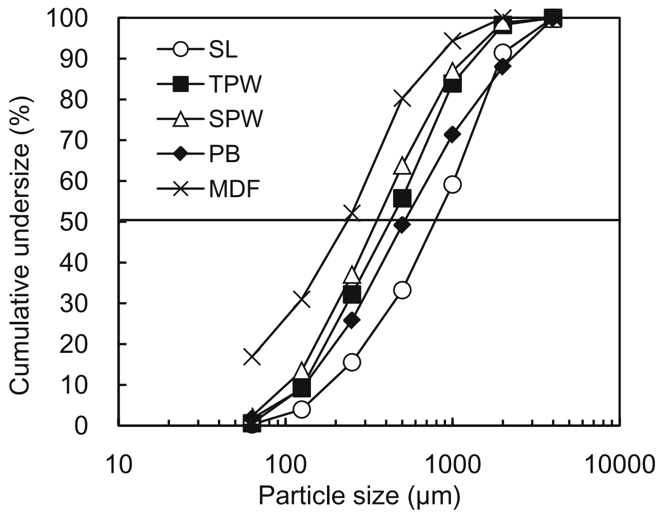

Fig. 6. Cumulative undersize distributions of sawdust collected from the floor in the experimental room

lumber. The geometric standard deviation (σ_g) and the maximum mass concentration were not greatly affected by the type of specimen. Four kinds of wood-based materials (all except sugi lumber) showed higher M_g values than the occupational exposure limit of 1 mg/m³ in Japan.[3]
2. The M_g value at 3000 rpm was greater than that at 2000 rpm for all materials, although the average chip thickness was constant. The σ_g value at 2000 rpm was greater than that at 3000 rpm.
3. The percentage of sawdust not removed by the dust collector was highest for sawing particleboard, and was lowest for medium-density fiberboard.

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