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Fire-retardant-treated low-formaldehyde-emission particleboard made from recycled wood-waste

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Introduction

- According to the end uses of wood wastes and their possible reuse products, **particleboard** has found typical applications
- During the process of using recycled wood wastes for further reutilization, **formaldehyde** can be released from particleboards used as interior building products due to incompletely reacted UF, UMF, MF, or PF resins used in their manufacturing
- Among the properties of wood-based materials, fire retardancy is important for **fire safety**. The combustibility of wood-based materials can be decreased by fire-retardant (FR) treatment





Aim of work

- To evaluate the effects of FR treatment on the quantity of **formaldehyde emissions**
- To investigate the density, bending properties, ultrasonic properties, internal bond strength, thickness swelling, screw holding strength, and **surface FR performance** of particleboards made from recycled wood-waste particles using PMDI and PF resins





Materials

- **Particles** from mixed hardwood species including oak (*Quercus* spp.) and lauan (*Shorea* spp.) (with a mixture ratio of 50:50, w/w) were prepared from recycled construction and demolition wastes
- **PF resin** (76–78% solid content and pH 8–9) and **PMDI resin** (100% solid content)
- **FR1**: ammonium phosphate, diammonium phosphate, ammonium sulfate, borax, boric acid, and ammonium bromide, in the ratio of 20: 23: 40: 1: 1: 15 ; **FR2**: chloride, inflammable emulsion resin, phosphide, titan white, and other volatile components, with a 65% solids content





Materials

- The particles were first sprayed with FR1. The particles were then dried to a 2–4% moisture content (MC) at a temperature of 65 ± 2 °C in an oven. They were then sprayed with a water-soluble PMDI or PF resin according to the various PMDI/PF ratios
- Three-layer particle-mat was formed using coarse particles for the core layer and fine particles for the face and back layers.
- Painting with FR2 followed fabrication of the particleboards described above and was only used for comparing the surface FR performance with FR1-treated particleboards.





Methods

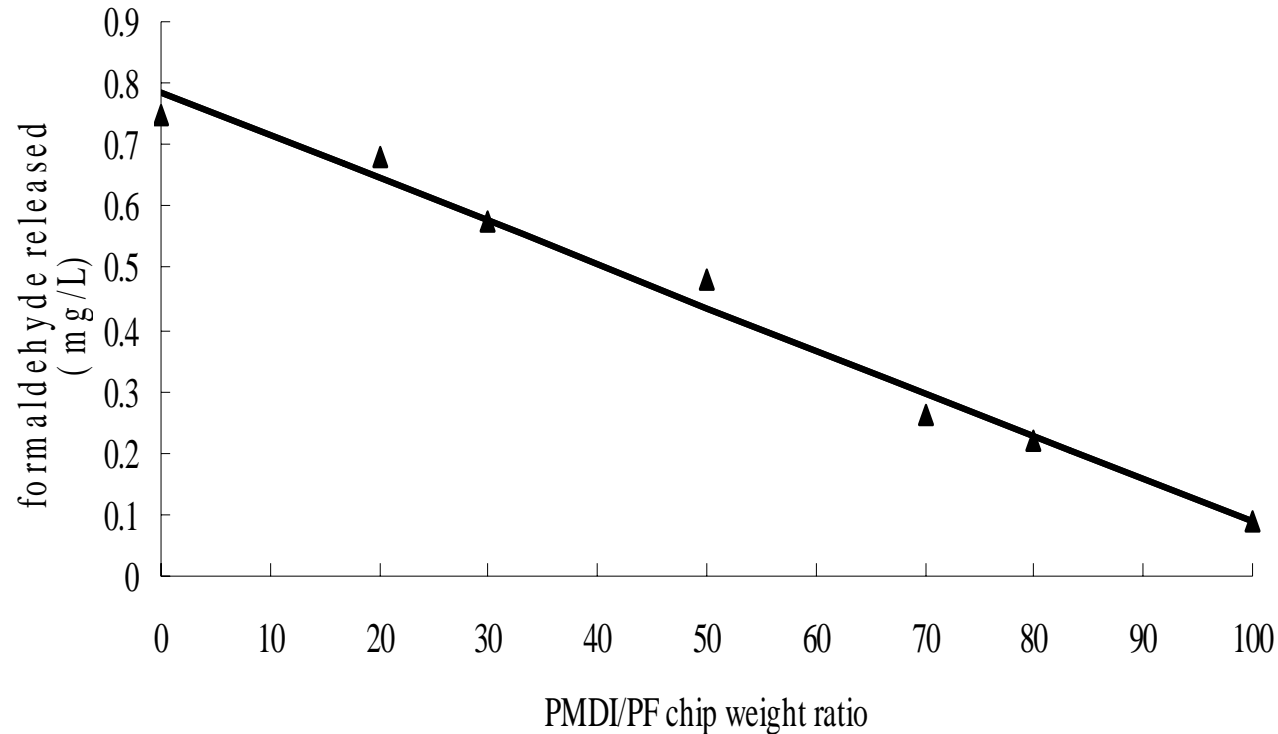
- The particleboards produced for this study were mainly tested in accordance with the Chinese National Standards CNS 2215 (2006) and CNS 6532 (2006), which involve various tests
- An ultrasonic wave instrument (Pundit, 54 kHz; CNS Electronics) was used to measure the time required for the transmission of an ultrasonic pulse through the specimen. The ultrasonic velocity was then calculated from the length of the specimen divided by the propagation time





Results

Quantity of formaldehyde emissions



Relationship between the quantity of formaldehyde released and PMDI/PF ratio of the fire-retardant-treated particleboard





Results

Quantity of formaldehyde emissions

- For FR1-treated specimens, with various PMDI/PF ratios, the quantity of formaldehyde emissions was less than 0.80 mg/L, which met the F3 standard (< 1.50 mg/L) of CNS 2215
- For FR1-treated specimens, with a **PMDI/PF ratio of 50/50**, the quantity of formaldehyde emissions was 0.48 mg/L, which met the F2 standard (< 0.50 mg/L) of CNS 2215
- Moreover, the quantity of formaldehyde emissions was 0.26 mg/L (< 0.30 mg/L; F**** of JIS A 5908) from FR1-treated samples with a **PMDI/PF ratio of 70/30**





Results

Bending properties and ultrasonic velocity

Property	Fire-retardant-treated low-formaldehyde-emission particleboard		
	PMDI/PF ratio		
	50:50 (FD group)	70:30 (FC group)	100:0 (FA group)
Air-dried density (g/cm ³)	0.83 ± 0.05 ^a	0.81 ± 0.06 ^a	0.80 ± 0.05 ^a
MOR (MPa)	14.5 ± 1.4 ^a	16.9 ± 2.2 ^b	18.4 ± 3.1 ^c
MOE (× 10 ² MPa)	22.1 ± 2.6 ^a	22.9 ± 3.6 ^b	26.5 ± 3.3 ^c
VI (m/s)	1583 ± 165 ^a	1682 ± 204 ^b	1868 ± 193 ^c
IB (MPa)	0.24 ± 0.07 ^a	0.31 ± 0.06 ^{ab}	0.34 ± 0.12 ^b
SH (N)	403.8 ± 67.1 ^a	577.2 ± 42.9 ^b	746.8 ± 80.5 ^c
TS (%)	11.9 ± 1.2 ^a	11.3 ± 1.5 ^a	6.4 ± 2.2 ^b
V _t (m/s)	585 ± 85 ^a	601 ± 64 ^a	665 ± 151 ^a

PMDI/PF ratio , ratio of particles sprayed with PMDI to particles sprayed with PF, w/w.

Results are given as the mean ± SD. In the same row, means with the same superscript letter(s) do not significantly differ at $p = 0.05$.





Results

Bending properties and ultrasonic velocity

Sample	Y = AX + B					
	Y	X	A	B	r ²	F
Fire-retardant-treated	FR	PMDI/PF	-0.0070	0.787	0.98	142**
	MOR	VI	0.01	-3.28	0.79	307**
low-formaldehyde-emission	MOE	VI	0.01	1.51	0.60	121**
	IB	Vt	0.0008	-0.178	0.78	200**
particleboard	SH	Vt	1.2	-293.8	0.83	269**

FR, quantity of formaldehyde emissions (mg/L); PMDI/PF ratio, ratio of particles sprayed with PMDI to particles sprayed with PF, w/w; MOR, modulus of rupture; MOE, modulus of elasticity; IB, internal bond strength; SH, screw holding strength; VI, ultrasonic velocity propagated through the lengthwise direction of the particleboard; V_t, ultrasonic velocity propagated through the thickness of the particleboard.

** Significant difference at the 1% level ($p < 0.01$).





Results

Surface fire-retardant performance

Sample	PMDI/PF ratio	Thickness (mm)	tc (s)	tdθ (min □ °C)	C _A	tl (s)
FR1-treated	100:0	12.4	219	4.1	30.0	2
low-formaldehyde-	70:30	12.1	225	3.9	28.5	3
emission particleboard	50:50	12.3	211	4.6	31.5	2
FR2-painted	100:0	12.7	>360	0	10.5	0
low-formaldehyde-	70:30	12.6	>360	0	10.5	0
emission particleboard	50:50	12.5	>360	0	10.5	0

FR1 was a mixture of ammonium phosphate, diammonium phosphate, ammonium sulfate, borax, boric acid and ammonium bromide, in a ratio of 20: 23: 40: 1: 1: 15. FR2 was an oil-based paint. Its ingredients included chloride, inflammable emulsion resin, phosphide, titan white, and other volatile components.





Conclusions

- Results showed that 0.48 mg/L of formaldehyde was released for group FD samples (with a **PMDI/PF ratio of 50/50**), which met the F2 standard of CNS 2215, whereas for samples with a PMDI/PF ratio of up to **70/30**, less than 0.3 mg/L formaldehyde was released
- **The bending properties of FR1-treated particleboards were influenced by the FR treatment. However**, the MOR values for samples in groups FD and FC met standard 13 of CNS 2215. Furthermore, the MOR values for group FA met standard 18 of CNS 2215. With regard to MOE values, group FA samples met standard 13, whereas groups FD and FC could only meet standard 8 of CNS 2215. The IB, TS, and SH results for all FR1-treated particleboard samples could meet standards 13, 8, and 18 of CNS 2215, respectively





Conclusions

- The VI increased linearly with increasing MOR and MOE values. However, the V_t increased linearly with increasing IB and SH values. Furthermore, the FR1-treated and FR2-painted low-formaldehyde-emission particleboards fabricated in this study could pass the third grade standard of surface FR performance as specified by CNS 6532

