J Wood Sci (2009) 55:74–79
DOI 10.1007/s10086-008-1000-6

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Manufacture of composite board using wood prunings and waste porcelain stone

Received: May 23, 2008 / Accepted: September 26, 2008 / Published online: December 11, 2008

Abstract The objective of this study was to develop a method for the effective use of both pruned wood and porcelain stone scrap. Thus, we manufactured a wood–porcelain stone composite board, which has excellent waterproof property and incombustibility properties. In addition, we examined the conditions needed to manufacture the wood–porcelain stone composite board as a construction material and evaluated the physical and mechanical properties of this board based on the Japanese Industrial Standard. The main results obtained were as follows: the wood–porcelain stone composite board made from pruned wood and porcelain stone scrap had excellent thickness swelling performance and the board had incombustibility properties that were better than commercial oriented strand board. In both single-layer and three-layer composite boards with weight ratios of porcelain stone particles of 40%, the internal bond strength exceeded the standard value of type 18 particleboard of JIS A 5908. However, the bending properties of the composite board were inferior to the type 18 particleboard standard. Therefore, it will be necessary to improve the bending properties of the board by changing the particle sizes of both the porcelain stone scrap and the pruned wood component.

Key words Pruned wood · Porcelain stone · Composite board · Incombustible properties

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Part of this article was presented at the 57th Annual Meeting of the Japan Wood Research Society at Hiroshima, August 2007

Introduction

Pruned wood from trees is generally processed into wood particles by using an industrial grinder after crushing with a chipper. In Japan, wood particles from pruned wood are used as compost, animal bedding, mulching material, and as a soil-improvement agent.[1,2] However, the majority is still incinerated or put into landfills.[3] Therefore, the recycling rate of scrap wood including pruned wood and demolition wood in Japan remains limited to about 68% according to the Ministry of Land, Infrastructure, Transport, and Tourism of Japan.[4] For this reason, new uses for pruned wood are desirable.

In the porcelain stoneware manufacturing process, when porcelain stone raw material is made brown by drying and oxidation, it can no longer be used in its intended application. The level of ceramic wastes, including porcelain stone scrap, in the ceramic manufacturing industry equates to about 30% of daily production,[5] which is a large amount of material with no commercial use. However, this scrap material is durable, hard, highly resistant to biological, chemical, and physical degradation, and shows extremely low water absorption.[5–7] Therefore, the development of effective uses for brown porcelain stone scrap is desired.

Some studies on utilization of low-quality wood materials, such as construction wood scrap, thinning wood, and branch wood including pruned wood, as raw materials for wood composite board have been conducted.[8–14] However, no study has been conducted on the utilization of waste porcelain stone for the manufacture of wood composite board.

In this study, we were able to make effective use of both pruned wood and porcelain stone scrap by manufacture of a wood–porcelain stone composite board, which has excellent waterproof and incombustibility properties. In addition, we examined the conditions needed to manufacture the wood–porcelain stone composite board properly as a construction material and evaluated the physical and mechanical properties of the board.

Materials and methods

Raw material preparation

Pruned wood collected around Koga City, Fukuoka Prefecture, Japan, was prepared as raw material for the board. After crushing with a chipper, the pruned wood was processed into wood particles by pressurizing and kneading using an industrial grinder (Shinko-zoki, SM-30–110). Wood particles were then classified by using a sieve with screen aperture of 2.36 mm; wood particles remaining on the sieve were used to manufacture the board. Wood particles were oven-dried at 105°C for 24 h and then cured at room temperature for 2 weeks. In manufacturing the board, the average moisture content (MC) of wood particles was 6.8%.

Porcelain stone mined in Amakusa City, Kumamoto Prefecture, Japan, was prepared as raw material for the board. In this research, we used porcelain stone scraps that had been made brown by drying and oxidation. The average specific gravity of the scrap was 2.6. The main chemical elements of the scrap were: SiO_2 (77.20%), Al_2O_3 (15.39%), and Fe_2O_3 (0.73%). Scrap was classified by using a sieve with a screen aperture of 2 mm; scraps passing the sieve were assumed to be porcelain stone particles and were used to manufacture the board.

Poly (diphenylmethane diisocyanate) (p-MDI) resin was used as adhesive. In our preliminary studies, porcelain stone particles hardened when the resin content was 12% based on the weight of oven-dry particles for manufacture of the face layer of the three-layer composite board. Therefore, in this study, a resin content of 12% was used in the manufacture of both the single-layer and three-layer composite boards.

Board manufacture

Two types of wood–porcelain stone composite board were produced. The first type was a single-layer composite board that contained mixed wood particles and porcelain stone particles. The other type was a three-layer composite board that had a surface layer of porcelain stone particles and a core layer of wood particles. This board had a three-layer structure of face–core–face layers. The manufacturing conditions of these boards are listed in Table 1.

In manufacturing of the single-layer composite board, porcelain stone particles, adhesive, and water were first mixed until the mixture formed a paste. Based on our preliminary study, it became clear that this form could be reached when the weight ratio between adhesive and water in the mixture was 1:2. The mixture was then blended with wood particles, and the board was formed.

In manufacturing of the three-layer composite board, porcelain stone particles, adhesive, and water were mixed the same as in the process used to make the single-layer composite board. The mixture was uniformly rolled out on two Teflon seats prepared as the face layers of the board. Next, wood particles were spread with adhesive for the core layer of the board. In the forming, these wood particles were arranged on the seat of the first piece, and the seat of the second piece was placed onto it.

The forming size of both the single-layer and three-layer composite board was 365 mm long by 255 mm wide, and the thickness was provided by using a distance bar of 10 mm thickness. In hot pressing conditions, the hot plate temperature was adjusted to 180°C, and the hot press time was adjusted to 300 s. Five boards ($n = 5$) were produced under each set of manufacturing conditions in this study. The boards were cured at room temperature for 1 month after hot pressing. The final dimensions of the wood–porcelain stone composite board were 300 mm long, 200 mm wide, and 10 mm thick. Figure 1 shows the nature of the composite boards manufactured in this study.

Board evaluation

The physical and mechanical properties of the boards were evaluated in accordance with the Japanese Industrial Standard for Particleboards (JIS A 5908, 2006).[15] A static

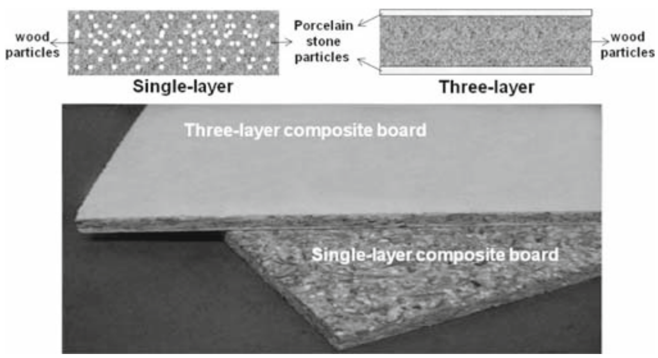

Fig. 1. Composite boards manufactured in this study

Table 1. Manufacturing conditions

Composite board type	Raw material	Weight ratio (%)	Resin content (%)	Target density (g/cm^3)
Single-layer	Porcelain stone particles : wood particles	40 : 60	12	0.80
		50 : 50	12	0.80
		60 : 40	12	0.80
Three-layer	Porcelain stone particles : wood particles : porcelain stone particles	20 : 60 : 20	12	0.80
		25 : 50 : 25	12	0.80
		30 : 40 : 30	12	0.80

bending test was conducted using a Universal Testing Machine. Four specimens (220 × 30 × 10 mm) were prepared four each type of board for the static bending test in the dry condition. Three-point bending was applied over an effective span of 150 mm at a loading speed of 5 mm/min. The loading speed in this test was adjusted to be slower than the loading speed required in JIS A 5908. This is because we used porcelain stone scrap as raw material, which is more brittle than particleboard. Four specimens (50 × 50 × 10 mm) were prepared for each type of board for internal bond (IB) strength tests. Four specimens of the same size from each type of board were also prepared for thickness swelling (TS) tests.

An incombustibility test of the wood–porcelain stone composite board was performed in accordance with the Japanese Industrial Standard for incombustibility of thin materials for buildings (JIS A 1322, 2006).[16] The thickness of the composite board evaluated in accordance with this standard test method was larger than the thickness of the specimen required in JIS A 1322. Nevertheless, we adjusted this standard test method because this test was considered to be a relatively easy and reliable method to examine the fireproof performance of the surface area of the board. Figure 2 shows the layout of the incombustibility test. Three specimens (300 × 200 × 10 mm) were prepared for each type of board for this test. Before the test, the specimens were dried at 50° ± 2°C for 48 h and left in desiccators with silica gel for 24 h. Each specimen was then set in the support frame and fixed at an angle of 45° as shown in Fig. 2. The flame length of the Meker burner was set to 65 mm, and the specimen was heated for 3 min. After the test, the time for which the surface of the specimen burned in flame was measured as the after-flaming time. In addition, beginning 1 min after the test ended, the presence of no-flame combustion in the specimen was confirmed. After brushing the surface of the specimen, we evaluated the length of the charred surface as the char length. In the measurement of weight loss, the weight of each specimen was measured before and after the test, and the difference was evaluated as a loss in weight. For the sake of comparison, the incombustibility properties of gypsum board and commercial oriented strand board (OSB) were also measured. The average values of density and thickness of gypsum board were 0.67 g/cm^3 and 9.5 mm, respectively. In case of OSB, the average density and thickness were 0.70 g/cm^3 and 9.7 mm, respectively.

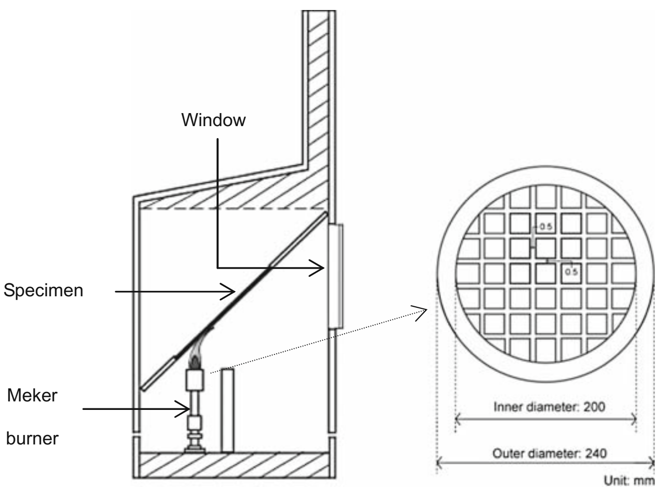

Fig. 2. Layout of the incombustibility properties test

Results and discussion

The average density and MC of single-layer composite board were 0.78 g/cm^3 and 3.3%, respectively. For the three-layer composite board, the average density and MC were 0.88 g/cm^3 and 3.9%, respectively. The density of the board after manufacturing was different from the target density. Therefore, the physical and mechanical properties obtained by various evaluation tests were multiplied by the value in which the target density was divided by the density obtained after manufacturing, and the physical and mechanical properties under the target density were evaluated.[17] In addition, for the sake of comparison of the physical and mechanical properties of the manufactured composite board in this study, the standard values of type 18 particleboard (PB) of JIS A 5908 are also shown.

Bending properties

The effects of the weight ratio of porcelain stone particles on the modulus of rupture (MOR) and on the modulus of elasticity (MOE) of the composite board are shown in Fig. 3. The MOR values of both the single-layer and three-layer composite boards tended to decrease as the weight ratio of porcelain stone particles increased. The MOR values of both the single-layer and three-layer composite boards were smaller than that of type 18 PB standard. On the other hand, the MOE of the three-layer composite board tended to increase slightly as the weight ratio increased. This is because the clearance between the porcelain stone particles in face layer decreases as the weight ratio increases. However, the value was smaller than that of type 18 PB standard. In the case of the single-layer composite board, the MOE showed a similar tendency to that of MOR, and the value was smaller than those of the other boards. The MOE of the three-layer composite board showed a relatively large value compared with those of the single-layer composite boards. Therefore, it was considered that the properties of porcelain stone particles provided the best bending strength for the layer structure of the board. This is considered to be due to the nature of SiO_2, which, as the main chemical component of porcelain stone scrap, has a high Young's modulus of 95 GPa.[18] Thus, the deflection of the three-layer composite board in the bending test was small due to the elastic behavior of the porcelain stone particle layer in the face layer of the board. From these results, it can be concluded that the bending properties of these boards were inferior to those of type 18 PB standard.

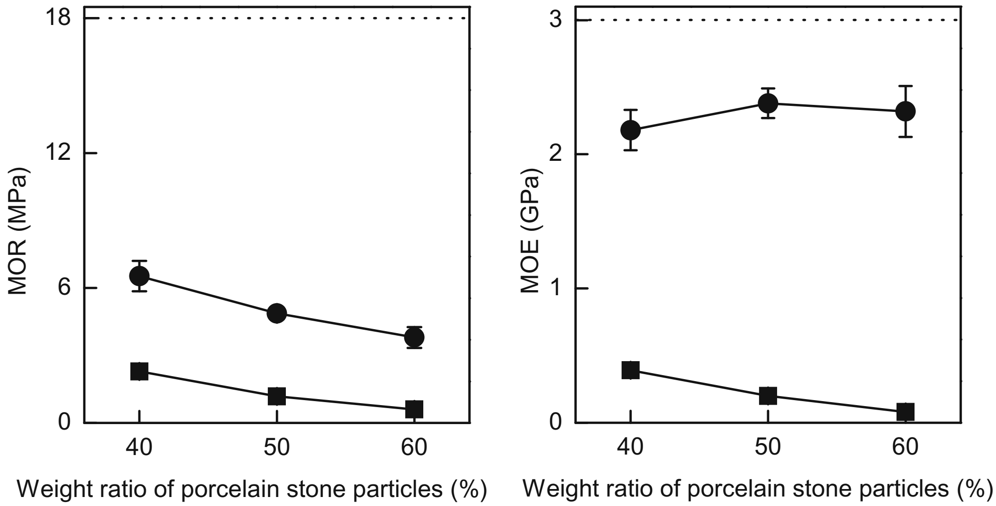

Fig. 3. Effect of the weight ratio of porcelain stone particles on the modulus of rupture (*MOR*) and the modulus of elasticity (*MOE*). *Filled squares*, single-laryer composite board; *filled circles*, three-layer composite board; *dotted line*, type 18 particleboard JIS A 5908

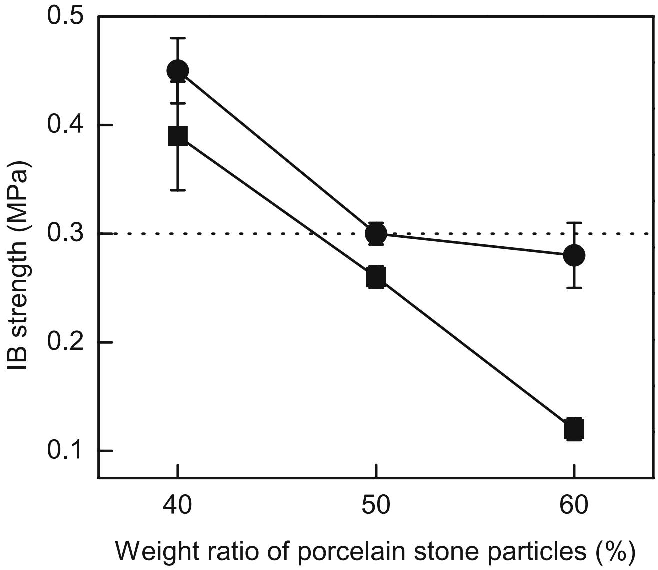

Fig. 4. Effect of the weight ratio of porcelain stone particles on internal bond (*IB*) strength. *Filled squares*, single-layer composite board; *filled circles*, three-layer composite board; *dotted line*, type 18 particleboard JIS A 5908

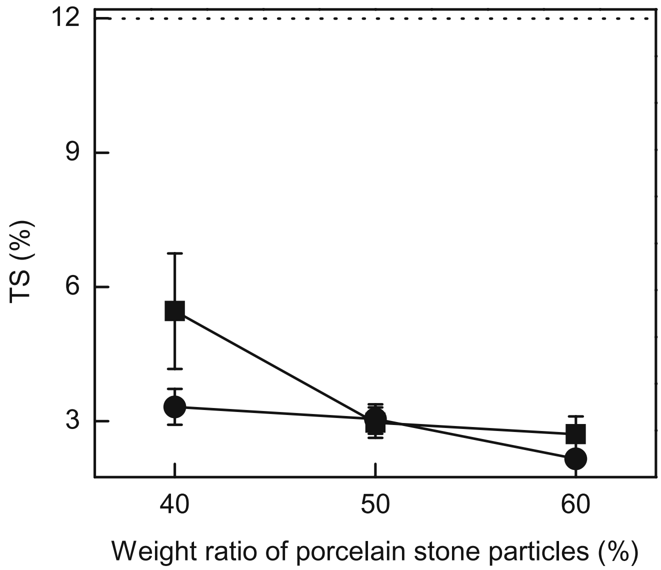

Fig. 5. Effect of the weight ratio of porcelain stone particles on thickness swelling (*TS*)

Internal bond strength

Figure 4 shows the relationship between IB strength and the weight ratio of porcelain stone particles in both the single-layer and three-layer composite boards. As the weight ratio of porcelain stone particles increased, the IB strength of the single-layer composite board tended to decrease. This is probably the result of the gaps in the single-layer composite board increasing because the density of porcelain stone particles is greater than that of wood particles. Moreover, wood particles and porcelain stone particles do not blend uniformly because the sizes and shapes of the wood particles and porcelain stone particles are different. In the case of the three-layer composite board, the gaps were not as large as in the single-layer composite board because each layer of the board consisted of the same material. However, the IB strength of the three-layer composite board decreased until the weight ratio of the porcelain stone particles increased up to 50%. When it increased from 50% to 60%, the IB strength was almost unaffected. In addition, in both the single-layer and three-layer composite boards with weight ratios of porcelain stone particles of 40%, the IB strength exceeded that of type 18 PB standard.

Thickness swelling performance

Figure 5 shows the relationship between TS performance and the weight ratio of porcelain stone particles in single-layer and three-layer composite boards. As the weight ratio of porcelain stone particles increased, the TS of both the

Table 2. Incombustibility properties of composite board, gypsum board, and oriented strand board (OSB)

Board type	Weight ratio (%)[a]	After-flaming time	Presence of no-flame combustion	Char length (mm)	Weight loss ratio (%)
Single-layer	40:60	No	No	177	3.05
	50:50	2	Yes	155	3.34
	60:40	No	Yes	163	2.94
Three layer	40:60	No	No	143	3.16
	50:50	No	No	133	2.85
	60:40	No	No	138	2.53
Gypsum board		No	No	130	1.95
OSB		58	Yes	163	4.15

[a] Porcelain stone particles:wood particles

single-layer and three-layer composite boards tended to decrease. In addition, the TS values of all boards were smaller than that of type 18 PB standard. Thus, our tests clarified that the waterproof property of the composite boards was excellent. It is considered that the degree of transformation in compressing the board with a hot press was slight because porcelain stone particles have a high specific gravity. Moreover, the boards contain porcelain stone particles, which show almost no water absorption.

Incombustibility properties

Table 2 shows the results of the incombustibility test of the boards. The after-flaming times of commercial OSB and single-layer composite board with a weight ratio of porcelain stone particles of 50% were 58 s and 2 s, respectively. The presence of no-flame combustion was confirmed for OSB and single-layer composite board produced under some manufacturing conditions. However, it was not confirmed for the three-layer composite boards produced under each of the manufacturing conditions used in this study. This is probably because the porcelain stone layer on the face layer of these boards is resistant to fire. The effect of the weight ratio of porcelain stone particles on char length was not recognized in either single-layer or three-layer composite boards. The char length of gypsum board was the shortest among the other boards. No effect of weight ratio of porcelain stone particles on the weight loss ratio was apparent in the single-layer composite board. However, in the three-layer composite board, the weight loss ratio tended to decrease when the weight ratio of porcelain stone particles increased. This is probably because the porcelain stone layer on the face layer of these boards is thick, and combustion of the board can be controlled when the weight ratio of the porcelain stone particles increases. The weight loss ratio of commercial OSB was higher than that of either type of wood–porcelain stone composite board.

From these results, we concluded that the incombustibility properties of wood–porcelain stone composite board were inferior to those of gypsum board but superior to those of commercial OSB. In particular, three-layer composite board with the porcelain stone particles on the face layer of the board had the best incombustibility properties.

Conclusions

In this study, in a search for an effective combined use of pruned wood and porcelain stone scrap, we manufactured a wood–porcelain stone composite board made from both materials. The results obtained are as follows:

1. The bending strength of the wood–porcelain stone composite board was inferior to the type 18 PB standard of JIS A 5908.
2. In both single-layer and three-layer composite boards with weight ratios of porcelain stone particles of 40%, the IB strength exceeded the type 18 PB standard of JIS A 5908.
3. The TS of all boards showed smaller values than the type 18 PB standard, which showed that the waterproof property of the composite board was excellent.
4. From the result of incombustibility test, it was clarified that the wood–porcelain stone composite board has incombustibility properties superior to those of commercial OSB.

Based on the test results, we conclude that we must improve the bending properties of the board by changing the particle size of both the porcelain stone scrap and the pruned wood component.

Acknowledgments The authors express their strong gratitude to Hayasida Sangyou Co. Ltd., Japan, for support in supplying pruned wood, and to Ueda Touseki, Japan, for support in supplying waste porcelain stone.

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