J Wood Sci (2001) 47:437–444

ORIGINAL ARTICLE

Yi Min Wei · Bunichiro Tomita

Effects of five additive materials on mechanical and dimensional properties of wood cement-bonded boards

Received: August 11, 2000 / Accepted: December 1, 2000

Abstract There is a growing desire to improve the properties and use of nonwood plant materials as supplements to wood materials for wood cement-bonded boards (WCBs). This study was conducted to determine the comparative properties of WCBs containing various amounts of discontinuous inorganic fiber materials, such as alkali-resistant glass fiber, normal glass fiber, mineral wool, and nonwood plant materials such as retted flax straw and wheat straw particles. Tested cement-bonded boards were made at wood/additive compositions of 100/0, 90/10, 80/20, 70/30, 60/40, and 50/50 (weight percentages). Seventy-eight laboratory-scale WCBs were produced. Various board properties, such as the modulus of rupture (MOR), internal bonding strength (IB), water absorption (WA), thickness swelling (TS), and linear expansion (LE), were studied. The test results showed that three types of discontinuous inorganic fiber used as reinforcing materials in composites significantly enhanced and modified the performance of WCBs. The mechanical properties and dimensional stability of cement-bonded board were significantly improved with increasing amounts of the additives. MOR and IB were increased; and WA, TS, and LE of boards were reduced by combination with the inorganic fiber materials. The results also indicated that combination with retted flax straw particles only slightly increased the MOR of boards, and wheat straw particles led to marked decreases in all the mechanical properties and the dimensional stability of WCBs.

Key words Glass fiber · Mineral wool · Wheat straw · Flax straw · Wood cement-bonded board

Y.M. Wei (✉) · B. Tomita
Institute of Agricultural and Forest Engineering, University of Tsukuba, Tsukuba 305-8577, Japan
Tel. +81-29-853-4578; Fax +81-29-855-2203
e-mail: s995176@ipe.tsukuba.ac.jp

Part of this report was presented at the 50th Annual Meeting of the Japan Wood Research Society, Kyoto, April 2000

Introduction

The particles or fibers of wood or nonwood used as reinforcement materials bonded and held together by an inorganic binder such as ordinary Portland cement are referred to as inorganic-bonded composites. As a member of the inorganic-bonded composite family, wood cement-bonded board (WCB) has been considered to be strong, stiff, and resistant to moisture, fire, fungi, and insect attack. A major advantage of WCB is its light weight and its ability to withstand outdoor exposure conditions, leading to its wider potential application for replacing traditional building materials such as brick and concrete. With its low density and good heat insulation quality, compared with concrete products, WCB is mostly produced as flat panels; and it has usually been used for structural and nonstructural applications, being suitable for interior and exterior use.[1–7]

For actual building application, there is still a worry about the long-term behavior of WCB when used as exterior composite-wall material, especially in regions that experience long-term harsh climate conditions. Therefore, to improve WCB further, giving in better mechanical strength and dimensional stability, would undoubtedly result in higher-quality assembly precision, edge jointing, and surface finishing (painting or coating); less warping and fever surface cracks or splits; and increased ability to resist changes due to exterior temperatures and humidity.

Many studies have been conducted to understand the mechanical and physical properties of inorganic fiber-reinforced cement-based composites such as glass fiber-reinforced concrete (GRC). The use of such inorganic fiber materials as glass fiber and mineral wool could fundamentally alter the nature and improve the mechanical and physical properties of cement-based composites.[8–10] Because these inorganic fibers have desirable mechanical strengths and dimensional stability to water and humidity exposure, addition of the discontinuous fiber strands in wood composites such as WCB would not only improve its mechanical properties but also increase its resistance to water and humidity. Thus, the influence of swelling and shrinkage of board made from wood due to its intrinsic instability to water and humidity would be reduced.[11,12]

Fibers, usually in the form of inorganic glass fiber reinforcement, have been used successfully to reinforce wood composite materials. Considerable improvements in the strength and dimensional stability were obtained. There is a possibility that holds some promise. Reinforcing particleboard with discontinuous fibers such as glass fiber that could be placed in the mat during the felting operation might prove useful.[13,14]

Faced with an increasing worldwide shortage of wood resources, there has been a strong trend to produce composite panel products making use of nonwood plant materials and agricultural residues. Some research has been conducted on retted flax straw and wheat straw particleboard bonded with synthetic organic adhesives.[15–20] These natural plant materials can be used as a reinforcing material bonded with inorganic binder such as cement in cases of total or partial replacement of wood materials. Many studies have been carried out on the composites of natural plant materials bonded with cement and have shown that many of the nonwood plant materials and agricultural residues are in fact suitable for a wide range of cement composites.[21,22]

We studied the mechanical properties and dimensional stability [modulus of rupture (MOR), internal bonding strength (IB), water aborption (WA), thickness swelling (TS), linear expansion (LE)] of WCBs containing various percentages of three inorganic reinforcing fibers (alkali-resistant glass fiber, normal glass fiber, mineral wool) and two nonwood plant material particles (retted flax straw and wheat straw). The objectives of this study were to determine whether the mechanical properties and dimensional stability of boards were modified and improved by adding these inorganic reinforcing fibers and to evaluate the effects and conduct feasibility studies using these nonwood plant materials in the manufacture of WCBs.

Experimental

Materials

The wood species used for this study was birch (*Betula platyphylla* Suk.) owing to its rich resources in northern China. It is known to produce the least inhibitory effect when mixed with ordinary Portland cement according to a prior study (submitted for publication). The logs, 2m in length, were first flaked using a disk flaker and the flakes then milled using a hammer-mill. Flakes were screened to an average size of 2–3 × 1 × 0.2cm. The screened flakes were air-dried to an average moisture content (MC) of 14% before they were used.

Commercial ordinary Portland cement was prepared and stored in sealed plastic bags to avoid hydration. For each WCB, the composite chemical additive consisted of aluminum sulfate [$Al_2(SO_4)_3$] and sodium silicate (Na_2SiO_3), accounting, respectively, for 5% and 2% of the weight of cement; this was added as a mineralizing agent to accelerate the setting and hardening of the cement-bonded composite.

Three inorganic fiber materials were selected: alkali-resistant glass fiber (HYKF-B), normal glass fiber (HYF-40), and mineral wool (XJ-1). These commercial fiber strands were cut into samples 2.0–3.0cm in length and then chopped into discontinuous short fibers. The alkali-resistant glass fibers have been widely used as a reinforcing material (e.g., in GRC) to enhance mechanical behaviors. Its high antialkali ability, even in solutions (pH > 12) of cement and water, is due to its richness in ZrO_2.[23] However, extractives from wood particles would decrease the wood–cement–water interface pH value to a lower level closer to the neutral condition.[24] Therefore, normal glass fiber was also selected for comparison in this study, as its mechanical strength is no markedly different from that of alkali-resistant glass fiber.

The two nonwood plant materials used were retted flax straw (*Linum usitatissimum* Linn.) and wheat straw (*Triticum aestivum* Linn.) with air-dried densities of 0.41 and 0.31 g/cm^3, respectively. They were collected from a flax mill and agricultural residues in local areas. The retted flax straw and wheat straw were first cut and further refined using a ring flaker. Both types of nonwood particles were then screened to an average length of 2–3cm. All the screened particles were air-dried to about 14% (MC) in preparation for use.

Board preparation

All the WCB materials were made with a 3:1 weight ratio for cement/wood and fiber (c/w+f) or cement/wood and nonwood particles (c/w+p), and a 1.00:0.52 weight ratio for cement/water (c/w_w+w_p) (the amount of water in the wood and nonwood particles was included). The three discontinuous inorganic fibers were added to wood–cement–water mixtures at five wood/additive compositions: 100/0, 90/10, 80/20, 70/30, 60/40, and 50/50 (weight percentages). The two types of nonwood particles were added to wood-cement-water mixtures at five wood/additive compositions: 100/0, 90/10, 80/20, 70/30, 60/40, and 50/50 (weight percentages). A total of 78 boards were manufactured: 5 (additive types) × 5 (additive compositions) × 3 (replications); in addition, three boards without additives were produced and studied as controls.

After the wood, additive, and ordinary Portland cement were fully mixed, the chemical solutions of $Al_2(SO_4)_3$ and Na_2SiO_3 were added to the mixtures. The raw material was hand-blended until it was uniformly mixed and wetted. The wet material was hand-felted, formed through a forming frame into a 42 × 42cm mat, and then laid on a stainless steel caul plate that had been coated with a small amount of mineral oil used as a release agent. The target density of the board was designed to be 1.2g/cm^3. The mats were cold-pressed to 12-mm stops between caul plates using distance bars and then were locked in a mold for maintaining pressure. The hardened mats were removed from the molds and caul plates and then stored for postcuring at an ambient temperature of about 20°C for 28 days. Before cutting into specimens for property testing, the boards were dried at about 70°C for 8h. The MC of the boards at the time of cutting was about 10%–12%.

Measurement of board properties

For the properties testing, specimens were cut from the cured boards and tested to determine the MOR, IB strength, WA, TS, and LE. The specimens used for determining the MOR and IB were 10 × 25 cm and 5 × 5 cm; and for WA, TS, and LE they were 10 × 10 cm, 5 × 15 cm, and 5 × 15 cm, respectively. WA, TS, and LE were determined by measuring changes in the specimens after immersing in 20°C water for 24 h. Six replications were conducted at each additive level.

Calculation and data analysis

For the calculation and statistical data evaluation, one-factor analysis of variance (ANOVA) on the mechanical properties and dimensional stability of WCBs, with addition of five additives at different contents, were undertaken to estimate the effects of the additive composition on board properties. Whether the contents of each additive level significantly influenced the board properties, therefore, was determined based on the results obtained after analysis. Linear regressions were also fitted to the data for assessing variations in the board properties with additive content.[25]

Results and discussion

Modulus of rupture and internal bonding strength

The average values for MOR, IB, WA, TS, and LE are shown in Figs. 1–5, respectively. The ANOVA results and expressions of linear regression related to the additive amounts and property changes are also presented in Table 1.

As shown in Table 1 and Figs. 1 and 2, the mechanical properties of WCBs were strongly influenced by addition of the inorganic discontinuous fibers (alkali-resistant glass fiber, normal glass fiber, mineral wool). The control boards had the lowest MOR and IB values. With the increase in additive contents, the values were significantly increased compared with control ones: hence the good linear changes

Table 1. Analysis of the effects of additive materials on wood cement-bonded boards

Wood/additives composition	*F* value	*P*	Linear regression	r^a
MOR				
Wood/glass fiber[b,c]	4.5113	<0.01	$y = 0.8749x + 93.125$	0.9018
Wood/glass fiber[d]	3.8182	<0.01	$y = 0.7487x + 88.868$	0.9335
Wood/mineral wool	10.9858	<0.01	$y = 0.6470x + 89.084$	0.9566
Wood/flax straw	1.6159	NS	$y = 0.2033x + 90.237$	0.9179
Wood/wheat straw	3.7508	<0.01	$y = -0.3610x + 91.00$	0.9417
IB				
Wood/glass fiber[c]	2.9535	<0.05	$y = 0.0277x + 6.1111$	0.9064
Wood/glass fiber[d]	3.0145	<0.05	$y = 0.0200x + 6.1294$	0.9401
Wood/mineral wool	9.3354	<0.01	$y = 0.0427x + 6.3056$	0.9277
Wood/flax straw	5.9347	<0.05	$y = -0.038x + 5.9278$	0.9383
Wood/wheat straw	11.2305	<0.01	$y = -0.0681x + 6.1619$	0.8964
WA				
Wood/glass fiber[c]	4.0395	<0.01	$y = -0.1968x + 22.762$	0.9686
Wood/glass fiber[d]	3.0145	<0.05	$y = -0.1402x + 23.694$	0.9535
Wood/mineral wool	10.4243	<0.01	$y = -0.2395x + 22.921$	0.9066
Wood/flax straw	2.2224	<0.05	$y = 0.1130x + 23.598$	0.9821
Wood/wheat straw	2.7520	<0.05	$y = 0.1206x + 23.782$	0.9616
TS				
Wood/glass fiber[c]	4.6066	<0.01	$y = -0.0555x + 5.7563$	0.9526
Wood/glass fiber[d]	2.7520	<0.05	$y = -0.0415x + 5.8119$	0.9712
Wood/mineral wool	6.8562	<0.01	$y = -0.0561x + 5.3246$	0.9266
Wood/flax straw	2.5903	<0.05	$y = 0.0315x + 5.8214$	0.8902
Wood/wheat straw	6.2243	<0.01	$y = 0.0732x + 5.5397$	0.9397
LE				
Wood/glass fiber[c]	4.1684	<0.01	$y = -0.0041x + 0.4431$	0.9585
Wood/glass fiber[d]	3.9451	<0.01	$y = -0.0040x + 0.4337$	0.9236
Wood/mineral wool	4.9887	<0.01	$y = -0.0043x + 0.4418$	0.9578
Wood/flax straw	2.3413	<0.05	$y = 0.0023x + 0.4565$	0.9412
Wood/wheat straw	3.2531	<0.05	$y = 0.0031x + 0.4694$	0.9007

MOR, modular of rupture; IB, internal bond strength; WA, water absorption; TS, thickness swelling; LE, linear expansion

[a] Correlation coefficient

[b] Six additive composition level (% wood particle/% additives). Alkali-resistant glass fiber: normal glass fiber and mineral wool 100/0, 90/10, 80/20, 70/30, 60/40, and 50/50. Retted flax straw and wheat straw particles: 100/0, 90/10, 80/20, 70/30, 60/40, and 50/50

[c] Alkali-resistant glass fiber

[d] Normal glass fiber

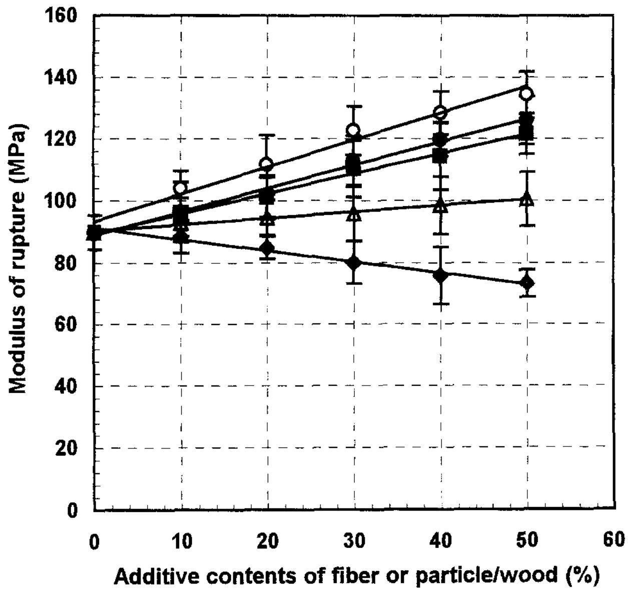

Fig. 1. Effects of additive fibrous materials on the modulus of rapture (MOR) of wood cement-bonded boards. *Open circles*, alkali-resistant glass fiber; *filled circles*, glass fiber; *squares*; mineral wool; *triangles*, flax straw; *diamonds*, wheat straw

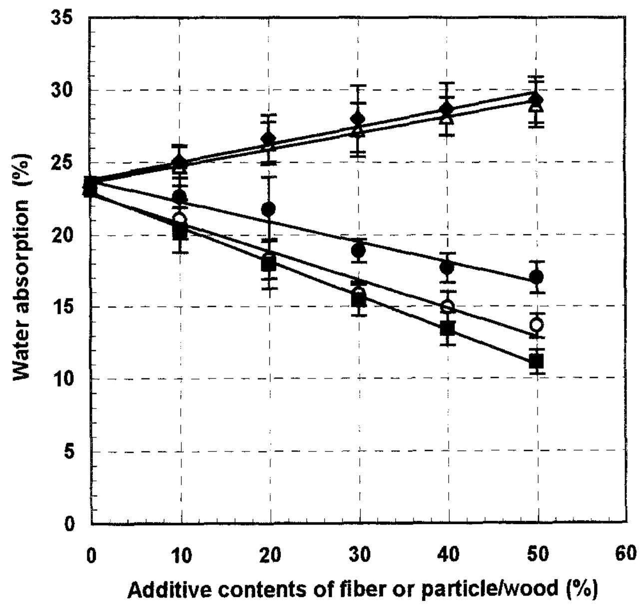

Fig. 3. Effects of additive fibrous materials on water absorption of wood cement-bonded boards

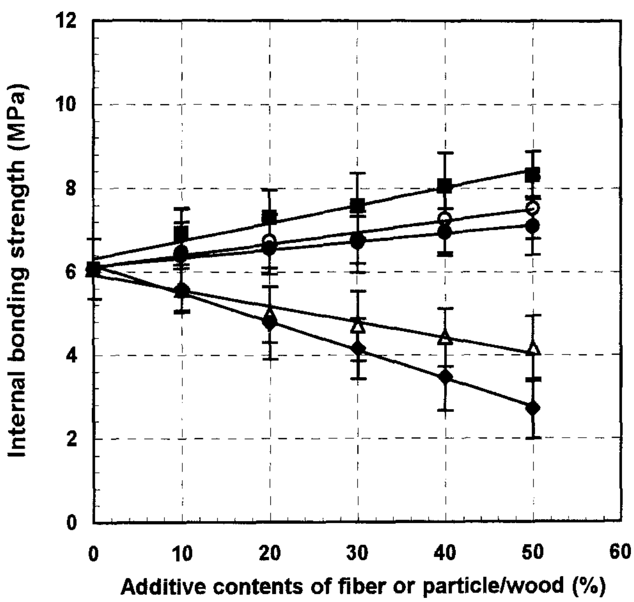

Fig. 2. Effects of additive fibrous materials on internal bond strength of wood cement-bonded boards

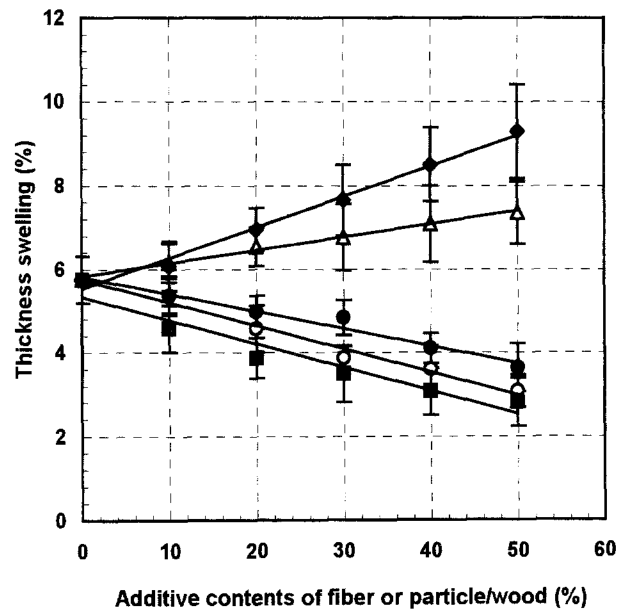

Fig. 4. Effects of additive fibrous materials on thickness swelling of wood cement-bonded boards

(Table 1). The results of the ANOVA in Table 1 indicate that the changes in additive content had significant effects on MOR and IB as well. There were noticeable differences between the alkali-resistant glass fiber and normal glass fiber used as the supplementary reinforcing materials for improving the strength properties of WCBs. The alkali-resistant glass fiber provided a relative large improvement in the MOR of boards compared with the other two kinds of fiber. However, mineral wool appeared to be markedly superior to the other two glass fibers in terms of the IB.

Many studies have been conducted to understand the reinforcing behaviors of inorganic fibers in cement and concrete. The three inorganic fibers used in this study are usually applied as reinforcing materials and fundamentally improve such properties as the bending and bonding strengths and the product's dimensional stability. These fibers have high compatibility and lead to good bonding behavior when mixed with ordinary Portland cement paste.[9,22,26] Therefore, with the addition of these inorganic fibers to WCBs, there were no noticeable negative effects

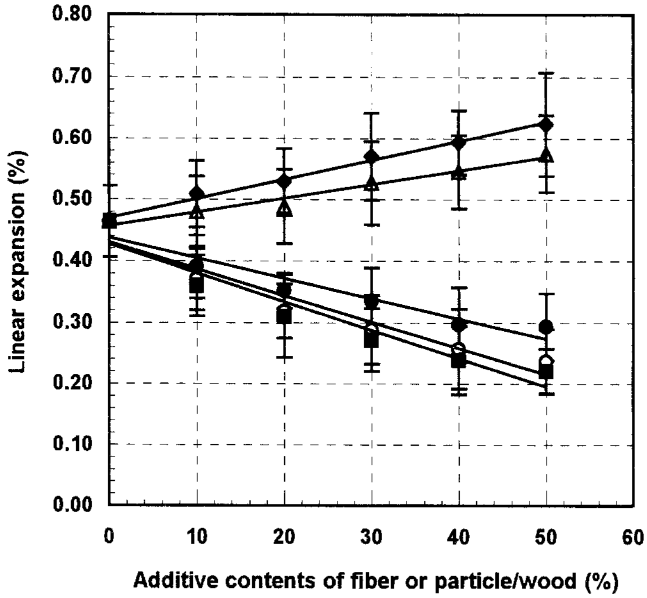

Fig. 5. Effects of additive fibrous materials on linear expansion wood cement-bonded boards

on board strengths due to their reinforcing mechanism and behaviors similar to that in GRC. With addition of the discontinuous inorganic fibers at a certain content, the high tensile strengths, enormous specific surface, and good interweaving ability would result in further improvement to the properties of WCBs using wood particles as a unified reinforcing material. The three discontinuous inorganic fibers have a larger length/thickness ratio than do wood particles in WCBs. When comparing mechanical properties of WCB, the three discontinuous inorganic fibers developed significant MOR at different levels; it appears that these fibers with a long, thin dimension have more surface area than wood particles and can thus sustain or transmit the extreme shear stresses imposed on a WCB during static bending. WBC is similar to wood particleboard in that the MOR can be increased by either increasing particle length or decreasing particle thickness. Longer, thinner fibers have more surface area to withstand the shear stress and can "bridge" the area where the bending moment is greatest. The increased IB strength could be attributed to the additional surface area, good fiber interweaving ability, and good adhesive properties between the cement and inorganic fibers, leading to increased adhesive spots and coverage. Furthermore, after reinforcement with inorganic fibers, the WCB maintains its specific properties such as relatively low density and heat-insulating characteristics when used as a building material and cannot be replaced by other additive materials.

The two nonwood plant materials (retted flax straw and wheat straw particles) did not produce satisfactory results when added to WCBs at various concentrations as reinforcing material. As shown in the accompanying tables and figures, with the increase in additive content of retted flax straw particles the MOR values of boards presented a nonsignificant increase (Table 1) owing to the fact that the fiber strands of flax straw have a relatively high strength.[9,24,27] The IB strength was obviously decreased due to the cross-bonding strength of fibers in the retted flax straws, which were much lower than that of wood fibers, and consequently led to fiber tearing prior to that seen with wood when under a loading condition. After close observations about the failure of destroyed IB specimens, the phenomenon of this fiber tearing was clearly demonstrated. The control boards had the highest values after wheat straw was added; both the MOR and IB strength values of WCBs were obviously decreased. The outer surface of wheat straws was believed to be richly covered with silica and wax.[18] This smooth, hard, waxy material might be one of the undesirable factors that probably resulted in difficulty and failure of adhesion between the cement and the wheat straw particles. With hydration of cement the metal-hydroxy groups, such as —Ca—OH, —Al—OH, and —Fe—OH, are present at the surface of wheat straw particles to form chemical bonding; however, based on the results of this study, the bonding strength did not benefit with the existence of silica at the surface of wheat straw particles. From the tested IB specimens, it was also observed that the adhesive failure mostly took place on the surface of the wheat straw particles rather than on the wood particles. It seemed to be related to the bonding strength of hydrogen bonding or hydroxide bridges at the interface of the cement and wheat straw particles. Hence the existence of wax and the surface properties of wheat straw particles may play a major role in the bonding of WCB. On the other hand, the bonding strength of cement and wheat straw particles was considered weaker than that between cement and wood particles. When under the loading condition, stress concentration was first experienced at the interface of the cement and the wheat straw particles; hence there were destructive tendencies due to adhesive failure, which resulted in a reduction of the bending and bonding properties of WCBs.

Water absorption, thickness swelling, linear expansion

The results of the 24-h water-soaking test for WA, TS, and LE regarding the dimensional stability of modified WCBs are shown in Figs. 3, 4, and 5, respectively. The control boards had the highest average WA, TS, and LE values at the five additive levels. The three inorganic fibers effectively reduced the average values of WA, TS, and LE of boards to a varying extent compared to the control values. The boards with increasing additions of alkali-resistant glass fiber yielded lower WA, TS, and LE values than did normal glass fiber. Among the inorganic fibers added, the best improvement in the WA, TS, and LE (decreased values) of boards after 24 h of soaking was obtained with mineral wool. In the inorganic fiber reinforced concrete, the three inorganic fibers were usually used as reinforcing materials mainly to enhance the mechanical qualities of the composites. However, because these inorganic fibers have natural stability to water and humidity,[9,26] their dimensional behaviors under high water and humidity conditions are essentially different from those of wood particles because of the unsteady reaction of hemicellulose to water. Therefore, the improved dimensional stability of the WCBs might be attributed to the addition of fibers and the reduction of wood particles. In addition, the inorganic fibers have a high affinity for cement; for example, mineral wool has a relatively large specific surface and good affinity for cement,[9,22] resulting in more perfect adhesive conditions and a strong bonding strength among the wood, fibers, and cement. This then increases its resistance to water and humidity. Moreover, the higher bonding strength would improve the dimensional stability of WCBs. In addition, the improved dimensional stability of the WCB after addition of inorganic fibers, decreasing the content of wood particles (which the have greatest absorption and swell when exposed to water) also could be explained on the basis of a decreased amount of end-grain surface of wood particles available for rapid water absorption. Moreover, the higher strengths (e.g., IB) may play a more dominant role in reducing water absorption owing to more resin spots and coverage than existed in the heterogeneous structure, leading to blocking the flow of water in WCB.

The test results indicated a significant negative effect of the various nonwood plant materials and their content on the dimensional changes in the WA, TS, and LE of boards. The control boards had the lowest WA, TS, and LE values. The WA, TS, and LE were found to increase with increasing content of retted flax straw and wheat straw particles. Especially with wheat straw particles at five additive levels, the boards showed significant increases in WA, TS, and LE. On average, the boards with added retted flax straw particles were slightly more stable than those with wheat straw particles. The unsatisfactory results, showing reduced dimensional stability of the boards, might be due to the following causes: The lower bonding strength between the straw particles and cement led to a tendency for more springback after 24h of water immersion. In addition, like other nonwood plant materials, the retted flax straw and wheat straw particles have higher hemicellulose content,[18,21,27] resulting in a higher water absorption rate. This then affects the TS and LE and could be considered an important reason for the reduced dimensional stability of WCBs.

Comprehensive understanding of the effects of additives

Taking advantage of the reinforcement principle using inorganic fibers to improve cement and concrete qualities as reinforcing materials, three discontinuous inorganic fibers were added to the WCBs. Table 2 shows the percent change in the mechanical and dimensional properties of WCBs after these inorganic fibers were added. The results demonstrated that, generally, the performance of WCBs was significantly enhanced with addition of these fibers. With 20% addition of the three inorganic fibers, the quality of the composites was entranced by their mechanical strength or their dimensional stability; and they were obviously better than those of WCBs with no additions. Some differences existed among the three inorganic fibers. The alkali-resistant glass fiber was confirmed to be a better alternative than normal glass fiber, considering its beneficial role in improving the strengths and dimensional stability. Mineral wool was superior to alkali-resistant glass fiber and normal glass fiber and exhibited a more significant influence on the quality of composites because of its high surface activity resulting in good compatibility with cement.[22] Generally, the inorganic fiber materials used for reinforcement, such as in GRC, comprised 5%–10% of the weight of the cement paste.[9,22] Notable results included the fact that in reinforced WCB the properties of the board were continuously improved with an increasing content of inorganic fiber, even to more than 15% of the cement weight. This is attributed to the fact that with addition of these fibers the wood particle–cement interface behaviors of WCBs is affected by the properties of dispersion (wood particles, inorganic fibers) and cement. That is, the reinforcing effects from these inorganic fibers become more obvious than those of wood particles. As shown in Table 2, the 20% inorganic fibers, which accounted for about 6.7% of the cement weight, led to an outstanding improvement in the properties of WCBs. Thus it is believed to be an acceptable additive content based on the use of the smaller additives for better reinforcement in WCBs. Based on the test results, although more additives included in composites would undoubtedly further promote modification of the quality of the composites, it would also change the intrinsic characteristics of

Table 2. Change in properties of wood cement-bonded boards when five fibrous materials were added

Additive	Content	% Change				
	(%)	MOR (MPa)	IB (MPa)	WA	TS	LE
Glass fiber[a]	20[c]	23.2[d]	9.3	−19.2[e]	−19.9	−21.1
Glass fiber[b]	20	15.6	7.0	−10.4	−14.1	−23.1
Mineral wool	20	13.6	17.4	−22.2	−27.5	−21.8
Flax straw	30	7.3	−21.5	11.0	16.7	14.2
Wheat straw	30	−10.7	−32.5	17.6	33.4	22.3

[a] Alkali-resistant glass fiber
[b] Normal glass fiber
[c] The additive content of 20% is referred as 80/20 (% wood particle/% additive fiber)
[d] Increased percentage of board properties compared with control specimen
[e] Decreased percentage of board properties compared with control specimen

WCBs, such as the lower density and higher heat insulation (compared with general building materials such as concrete and brick products) owing to the larger reduction in wood particles.

Addition of the two nonwood plant particles had a strongly negative influence on both mechanical strength and dimensional stability. The results of five combinations of straws and wood particles showed that the control boards with 100% wood particles usually had the highest values, and the mechanical strength and dimensional stability were decreased, except for the MOR of boards mixed with retted flax straw particles. The combination of wheat straw and retted flax straw particles led to a marked reduction of mechanical strength and dimensional stability, but there was no possibility of reaching the level of those in WCBs due to the fact that the quality of these nonwood plant particles was much lower than those of wood particles. This was also found in similar studies that dealt with straw particleboard bonded with synthetic organic adhesives.[17–19] For this reason the addition of nonwood plant particles to WCBs must comply with minimum standard values (e.g., strength and dimensional stability) within a narrow margin to avoid failure to reach these standards. It is commonly believed that with a higher content of retted flax straw and wheat straw particles the quality of cement-bonded board is worse. The values (Table 2) with 30% retted flax straw and wheat straw particles added to WCBs could still be considered acceptable within the experimental condition conducted in this study, though the addition led to a serious reduction in the properties. In general, although collected data showed that retted flax straw and wheat straw particles could be incorporated in WCBs, these two nonwood plant materials are not ideal partners to form composite materials. Much more consideration should be given before their addition. However, there is certainly the possibility of further improving the qualities of the WCBs when partially mixed with these nonwood plant materials by other processes, such as adjusting the particle geometry, the content of chemical additives, and the cement/particles ratio. Adding inorganic fibers to WCB undoubtedly would bring about an increase in product cost and a more complicated production process. Moreover, more attention must be paid to the waste from a surface sanding process in which the dust of inorganic fibers would be contained.

Conclusions

Based on the results of this study, the following conclusions can be drawn. The tested samples from WCBs prepared in this study resulted in an obvious improvement in the strength and dimensional stability properties when each of three inorganic fibers was added and compared with the controls, depending on the fiber and additive content. The mineral wool was considered superior to alkali-resistant glass fibers and normal glass fibers. The test results showed that each of the three inorganic fibers was an acceptable reinforcing material and was demonstrated to be a practical, effective material for modifying the qualities, and preventing deterioration, of WCBs.

1. The MOR and IB values for all board samples were significantly higher than those of the control when these fibers were added. Generally, addition of 20% alkali-resistant fiber resulted in about a 23.2% increase in the MOR value. However, addition of 20% mineral wool brought about an increase of about 17.4% in IB strength.
2. The 24-h water-soaking test showed that the WA, TS, and LE in the dimensional stability test were all significantly decreased by addition of each of the three fibers. The mineral wool had a more significant effect on improving dimensional stability. The WA, TS, and LE were decreased to about 22.2%, 27.5%, and 21.8%, respectively.
3. The two kinds of nonwood plant particles (retted flax straw and wheat straw) significantly affected the properties of WCBs. The mechanical properties and dimensional stability of board decreased with an increasing percentage of retted flax straw and wheat straw particles in the boards. The retted flax straw and wheat straw particles may be used as supplemental materials for partial replacement of wood materials in WCBs within a certain additive content range to meet the requirement for compromised board properties.
4. Combination with 30% retted flax straw particles only slightly increased the MOR of boards (to about 7.3%). In contrast, the IB was significantly decreased (to about 21.5%). The wheat straw particles brought about decreases in both MOR and IB (to about 10.7% and 32.5%, respectively).
5. With the addition of retted flax straw and wheat straw particles, the dimensional stability of the boards was decreased with increased additive content. When added with 30% retted flax straw particles the WA, TS, and LE of boards gave incremental values of about 11.0%, 16.7%, and 14.2%, respectively, whereas these values after addition of wheat straw particles were 17.6%, 33.4%, and 22.3%, respectively.

References

1. Moslemi AA (1974) Particleboard. Southern Illinois University Press, Carbondale, IL, pp 185–186
2. Prestemon DR (1975) Preliminary evaluation of a wood-cement composite. For Prod J 26(2):43–45
3. Ramirez-Coretti A, Eckelman CA (1998) Inorganic-bonded composite wood panel systems for low-cost housing: a Central American perspective. For Prod J 48(8):62–68
4. Goodell B, Daniei G (1997) Decay resistance and microscopic analysis of wood-cement composite. For Prod J 47(11–12):75–80
5. Moslemi AA (1988) Inorganically bonded wood composites. Chemtech 18:504–510
6. Rashwan MS, Hatzinikolas M, Zmavc R (1992) Development of a lightweight, low-cost concrete blocks using wood residue. For Prod J 42(5):57–64
7. Maloney TM (1996) The family of wood composite materials. For Prod J 46(2):19–26
8. Saha SP, Ouyang CS (1991) Mechanical behavior of fiber-reinforced cement-based composites. J Am Ceram Soc 74:2727–2738
9. Mashima M, Kousa K, Ohno S (1994) Fiber reinforced cement and concrete (in Japanese). Gihoudou Press, pp 165–182
10. Czernin W (1980) Cement chemistry and physics for civil engineer. Bauverlag, Wiesbaden, London, pp 177–179

11. Halligan AF (1970) A reviews of thickness swelling in particleboard. Wood Sci Technol 4:301–312
12. Mougel E, Beraldo LA, Zoulalian A (1995) Controlled dimensional variations of a wood-cement composite. Holzforschung 49:471–477
13. Bulleit WM (1984) Reinforcement of wood materials: a review. Wood Fiber Sci 16(3):391–397
14. Galligan WL (1982) Pacific Northwest meeting focuses on modern technology. For Prod J 32(2):5
15. Sampatharajan A, Vijayaraghavan NC, Swaminathan KR (1992) Mechanical and thermal properties of particleboards make from farm residues. Bioresource Technol 40:249–251
16. Odozi TO, Akaranta O, Ejike PN (1986) Particle boards from agriculture waste. Agric Waste 16:237–240
17. Troger F, Pinke G (1988) On the production of PMDI-glued particleboard containing various portions of straw. Holz Roh Werkstoff 46:389–395
18. Han GP, Zhang CG, Zhang DM, Umemura K, Kawai S (1998) Upgrading of urea formaldehyde-bonded reed and wheat straw particleboard using silane coupling agents. J Wood Sci 44:282–286
19. Irel M, Simpson H (1993) Agriculture residues for cement-bonded composites. In: Proceedings of a workshop on inorganic-bonded wood and fiber composite materials, vol 3. USDA Forest Products Laboratory, Madison, WI, pp 31–58
20. Troger F, Ullrich M (1994) Reinforcement of three-layer particleboards with retted flax straw. Holz Roh Werkstoff 52:230–234
21. Swamy RN (1988) Natural fibre reinforced cement and concrete: concrete technology and design, vol 5. Blackie, London, pp 173–206
22. Eusebio DA, Suzuki M (1990) Production and properties of plant-materials cement-bonded composites. Bull Exp For Tokyo Univ Agric Technol 27:27–38
23. Benedito RV, James BW, Paula HK (1980) Parameters affecting dimensional stability of flakeboard and particleboard. For Prod J 30(12):23–29
24. Hachmi MH, Moslemi AA (1990) Effect of wood pH and buffering capacity on wood-cement compatibility. Holzforschung 44:425–430
25. Ott L (1977) An introduction to statistical methods and data analysis. Duxbury Press, Belmont, pp 392–398
26. Bogue RH (1964) The chemistry of Portland cement. Reinhold, New York, pp 435–488
27. Takahashi T (1986) A feature of linen and ramie (in Japanese). Sen I Gakkaishi 42:319–321