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Improvement on the properties of gypsum particleboard by adding cement*

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Abstract Gypsum particleboard (GPB) has high thickness swelling (TS), high water absorption (WA), and low mechanical properties compared with cement-bonded particleboard. The properties of GPB were improved by adding cement. The experimental results showed that GPB with the added cement had good physical and mechanical properties compared with those of gypsum particleboard with no added cement. The TS and WA of gypsum particleboard with added cement were reduced by 10%. The mechanical properties of GPB, such as internal bond strength (IB), modulus of rupture (MOR), and modulus of elasticity (MOE), increased when the GPB was made with added cement. The properties of GPB improved relative to the quantity of cement added. With an increase of cement content from 5% to 10%, the TS and WA were reduced, and the IB, MOR, and MOE were increased. In contrast, the TS and WA increased and the IB, MOE, and MOR decreased when the cement content was increased from 15% to 30%. Thus the physical and mechanical properties of GPB were successfully improved when the added cement content was 10%.

Key words Gypsum particleboard · Cement · Thickness swelling · Internal bond strength · Initial curing

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Introduction

Gypsum particleboard (GPB) is a wood-based panel developed in recent years in Germany. A good building construction material,[1] it has the features of high resistance to fire and nonformaldehyde emission. GPB shows lower friability than gypsum board. The effect of tannin on gypsum curing is low in some wood species.[2] As a consequence, gypsum particleboard can be produced using most wood species.[3] Natural and chemical gypsum can be used to produce gypsum particleboard.[4] Gypsum resources are rich in the world.[5]

The chemical formula of gypsum is $CaSO_4 \cdot 0.5H_2O$. When water is added to gypsum, it makes $CaSO_4 \cdot 0.5H_2O \rightarrow CaSO_4 \cdot 2H_2O$. The formula reverts to $CaSO_4 \cdot 0.5H_2O$ when the water evaporates. Due to weak resistance against water, gypsum particleboard shows low mechanical properties and high thickness swelling when absorbing water. We investigated the effects of adding cement on the physical and mechanical properties of GPB.

Materials and methods

Test materials

The test materials were commercial gypsum used for a plaster cast and white Portland cement (Chichibu Onoda Cement, Tokyo, Japan); particles were obtained from particleboard manufacture (Dantani, Kita-Kyushu, Japan). The proportions of screen analysis (S) of particles (opening) were 9.2% in $S < 0.71$ mm, 10% in $0.71\,mm < S < 1.00$ mm, 16.6% in $1.00\,mm < S < 1.40$ mm, 34.2% in $1.40\,mm < S < 2.00$ mm, and 30% in $2.00\,mm < S$, respectively.

Production method and conditions of GPB

Each material was weighed at a wood/gypsum ratio of 0.25 and a water/gypsum ratio of 0.35 in the laboratory.[6,7] The particles were then put in a blender, and water and the mixture of gypsum and cement were added. After being blended, sample boards of 10 mm × 40 cm × 40 cm were formed. Sixteen sample boards possessing a target density of 1.2 g/cm^3 and eight levels of cement content (5%–30% based on the weight of the gypsum, using 100% gypsum and 100% cement) were produced. For decreasing the effect of density on the physical and mechanical proprieties of GPB, the average GPB density was controlled within 1.19–1.23 g/cm^3.

To measure the effect of density on internal bond strength (IB) and the thickness swelling (TS), 12 sample boards were produced based on densities of 1.18, 1.20, 1.24, and 1.28 g/cm^3 at each cement addition of 10%, 20%, and 25%.

All mats were pressed at 3 MPa in a cold press for 4 h. The moisture contents of GPB mats were reduced to about 2%–3% at 45°C in a dryer. After being removed from the dryer, the mats were stored at room temperature for 1 week. There were four specimens per treatment.

Measurement of physical and mechanical properties of GPB

The physical and mechanical properties were measured according to the JIS (Japanese Industrial Standard) A 5908.[8] The specimens for measuring IB to determine the effect of adding cement were divided into two groups. The IBs for one group were measured directly. The specimens for another group were soaked in water (21°C) for 24 h and the thickness due to swelling and water absorption (WA) then measured. The specimens were dried to a moisture content of about 2%–3% at 45°C in the dryer. Finally, the IBs were measured.[7]

The reduction ratio (K) of the IB of specimens soaked in water compared with the specimens without being soaked in water was calculated using the following formula.

$$K = \left(1 - \frac{IB_2}{IB_1}\right) \times 100\,(\%)$$

where IB_1 is the internal bond strength without being soaked in water and IB_2 is the internal bond strength after being soaked in water. All the data for the physical (TS, WA) and mechanical (IB, MOE, MOR) properties are shown as average values.

Measurement of the initial curing time, exothermic temperature, and exothermic time

The initial curing time (IC), the time until gypsum started to cure after water was placed in the gypsum, was measured according to DIN (Deutsches Institute für Normung) 1168. The particles, water, cement, and gypsum were treated for 1 day under conditions of constant temperature and humidity. The materials were mixed at the same wood/gypsum ratio and the same water/gypsum ratio as described above. They were then placed in a hermetically sealed vacuum flask. Two thermometers were positioned in the middle of the mixture. The highest temperature and time achieved in the mixture were measured as the exothermic temperature (ET) and the exothermic time (Et), respectively.

Results and discussion

Effect of adding cement on TS and WA

Figure 1 shows the effects of adding cement on thickness swelling and water absorption of GPB after specimens were soaked in water (21°C) for 24 h. The results indicate that the TS and WA were markedly reduced in cement contents of 5%–15%. The reduction ratios of TS and WA were highest at a cement content of 10% (Fig. 1).

It is well known that cement has a high resistance to water and produces a high bonding strength between particles when it cures in the appropriate condition.[9] When the GPB was produced by adding an appropriate amount of cement, the cement acted to increase the bonding strength of GPB, so the strength of the board was high. When the specimens were soaked in water, the high bonding strength resisted absorption of water into the boards. For this reason, the GPB showed the lowest TS and WA values at 10% added cement. An excessive amount of cement caused the TS and WA of GPB to increase. Because the cement-bonded particleboard at a cement content of 100% was produced in the same way as GPB, it exhibited lower mechanical properties and higher TS and WA values, as shown in Table 1, resulting from the fact that the cement could not achieve good bonding strength between particles when it was cured at higher cement contents. Consequently, when the GPBs were produced by adding cement at 20%–30%, the mixture of gypsum and cement as an adhesive could not produce a good bonding strength between particles at higher cement contents. The GPB easily absorbed water and produced higher TS and WA values when the bonding strength of the board was low. Therefore the increases and decreases in TS and WA at higher and appropriate cement contents can be considered to cause the decrease and increase of IB of board.

Effect of adding cement on IB

Figure 2 shows the effect of adding cement on the IB of GPB under conditions of water-soaking and no soaking.

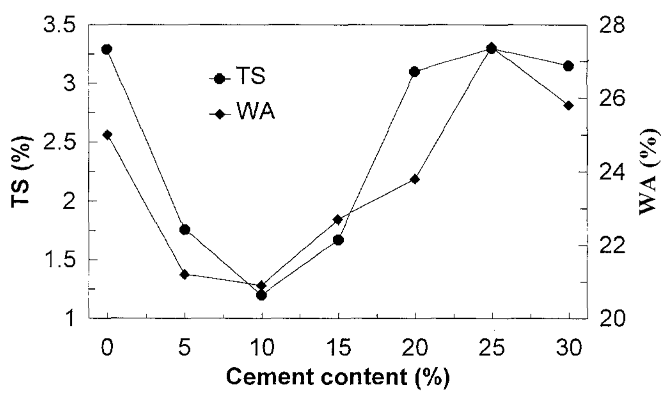

Fig. 1. Relations between thickness swelling (*TS*), water absorption (*WA*), and cement content

Table 1. Effect of adding cement on properties of gypsum particleboard

Quantity of added cement (%)	Properties									
	Den (g/cm^3)	TS (%)	TS_m	WA (%)	MOE (MPa)	MOE_m	MOR (MPa)	MOR_m	ET (°C)	Et (min)
0	1.21	3.29	0.376	25.0	1978	124.4	3.14	0.232	46.0	55
5	1.19	1.76	0.255	21.2	2126	95.6	3.29	0.222	39.0	50
10	1.22	1.20	0.231	20.9	2599	96.7	3.78	0.217	39.5	51
15	1.20	1.67	0.270	22.7	2112	108.3	3.29	0.220	39.0	50
20	1.21	3.10	0.410	23.8	2414	105.1	3.54	0.211	38.5	49
25	1.23	3.30	0.480	25.2	2277	101.5	3.29	0.242	39.0	50
30	1.21	3.15	0.312	24.5	2356	99.7	3.57	0.217	39.0	50
100	1.22	3.00	0.258	27.0	1762	94.9	3.39	0.156	32.0	110

Den, density; TS, thickness swelling; TS_m, mean square deviation of TS; WA, water absorption; MOE, modulus of elasticity; MOE_m, mean square deviation of MOE; MOR, modulus of rupture; MOR_m, mean square deviation of MOR; ET, exothermic temperature; Et, exothermic time.

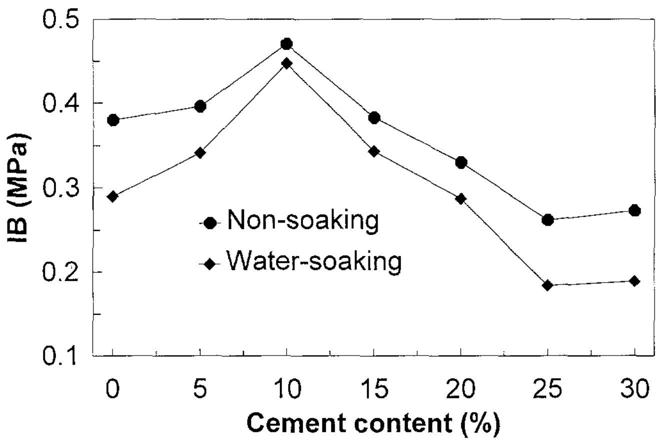

Fig. 2. Relations between internal bond strength (*IB*) and cement content

Regardless of the soaking or no soaking in water, the boards exhibited the highest IB when the cement content of 10% was added to the boards. Compared with a cement content of 10%, boards produced with other cement contents had lower IB values. The IB of GPB was reduced at higher cement contents because the excessive cement affected the curing of gypsum. For this reason, IBs of boards at cement contents of more than 20% were lower, and the IB improvement was insignificant. An appropriate amount of cement could increase the bonding strength of GPB, working as a reinforcing material. That is, the IBs of GPB showed high values when adding cement of 5%–10%.

The reduction ratios (*K*) of IB of the specimens soaked in water (21°C) for 24 h were varied, depending on the cement content, as shown in Table 2. The IBs for no soaking and water-soaking conditions were 0.470 and 0.447 MPa, respectively, at a cement content of 10%, giving a reduction ratio of 4.9%; the IBs without added cement were 0.38 and 0.29 MPa for no soaking and water-soaking conditions, respectively, giving a reduction ratio of 23.7%. As indicated above, when GPB was produced by adding an appropriate amount of cement, the cement acted to increase the bonding strength of boards and to resist the absorption of water into particles and gypsum; hence the reduction ratio of IB was smallest when cement of 10% was added. Excessive cement and the lack of cement resulted in weak bonding strength between particles when the specimens were soaked in water because the particles had to absorb much water to reduce the IB of GPB.

Table 2. Effect of adding cement on internal bond strength of gypsum particleboard

Quantity of added cement (%)	Properties						
	IB_1 (MPa)	Density (g/cm^3)	IB_{1m}	IB_2 (MPa)	Density (g/cm^3)	IB_{2m}	*K* (%)
0	0.380	1.20	0.096	0.290	1.21	0.135	23.7
5	0.396	1.21	0.087	0.341	1.20	0.125	13.9
10	0.470	1.23	0.085	0.447	1.21	0.103	4.9
15	0.383	1.22	0.089	0.343	1.22	0.096	10.4
20	0.330	1.20	0.090	0.287	1.19	0.087	13.0
25	0.260	0.19	0.093	0.184	1.21	0.095	29.8
30	0.273	1.21	0.085	0.189	1.21	0.109	30.7
100	0.230	1.21	0.052	0.168	1.20	0.049	36.9

IB_1, internal bond strength (no soaking); IB_2, internal bond strength (water-soaking); IB_{1m}, mean square deviation of IB_1; IB_{2m}, mean square deviation of IB_2; *K*, $[(IB_1 - IB_2)/IB_1] \times 100$.

Effect of adding cement on MOE and MOR

The effects of adding 5%–30% cement on the modulus of elasticity (MOE) and modulus of rupture (MOR) are significant, as shown in Fig. 3. The results indicated that the MOE and MOR of GPBs increased abruptly when the cement content was increased from 5% to 10%. The MOR and MOE of boards had a tendency to decrease at a cement content of more than 15%, but they were higher than in the boards without the added cement. GPB is a well known reinforcing composite material. For this reason, the MOR and MOE of GPB are important not only to the bonding strength of board but also to the particle size and the quality of gypsum itself. When the bonding strength of boards was within a certain range, the influence of the particle size on the MOR and MOE was primary.[3] In this study the size of the particles was not changed so the effects on the MOR and MOE of adding cement were not obvious at higher cement contents.

Effect of board density on IB and TS

The effect of the density of boards on IB and TS was marked. The IB and TS of boards increased with increased density, as shown in Fig. 4: the higher the density of the board, the more particles and gypsum were seen in a unit area.[10] Hence there was higher bonding strength between the particles and gypsum, enhancing the mechanical properties of GPB. For this reason, the higher the density of the board, the higher was the IB. In contrast, due to weak resistance to water, water absorbed at a unit area caused more swelling of the boards when the specimens were soaked. Consequently, higher-density board resulted in higher IB and TS. The density of board thus exhibited a significant effect on IB and TS.

Effect of adding cement on IC, ET, and Et during GPB curing

The initial curing time, exothermic temperature, and exothermic duration of GPB were influenced by the addition of cement, but they were not related to the cement contents (Figs. 5, 6). The ICs of GPB with and without the addition of cement were about 10 and 17 min, respectively. The IC was reduced by the addition of cement. That cement works as a promoter[11] helped accelerate the curing speed of the solution of $CaSO_4 \cdot 0.5H_2O$. The IC of GPB was thus shortened when cement was added to gypsum.

According to the report on GPB produced by cold pressing,[12] gypsum generated heat when it cured with the addition of water. Hence the curing of gypsum was an

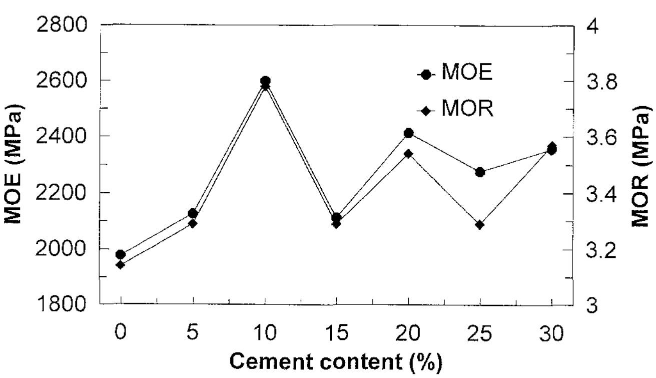

Fig. 3. Relations between modulus of elasticity (*MOE*), modulus of rupture (*MOR*), and cement content

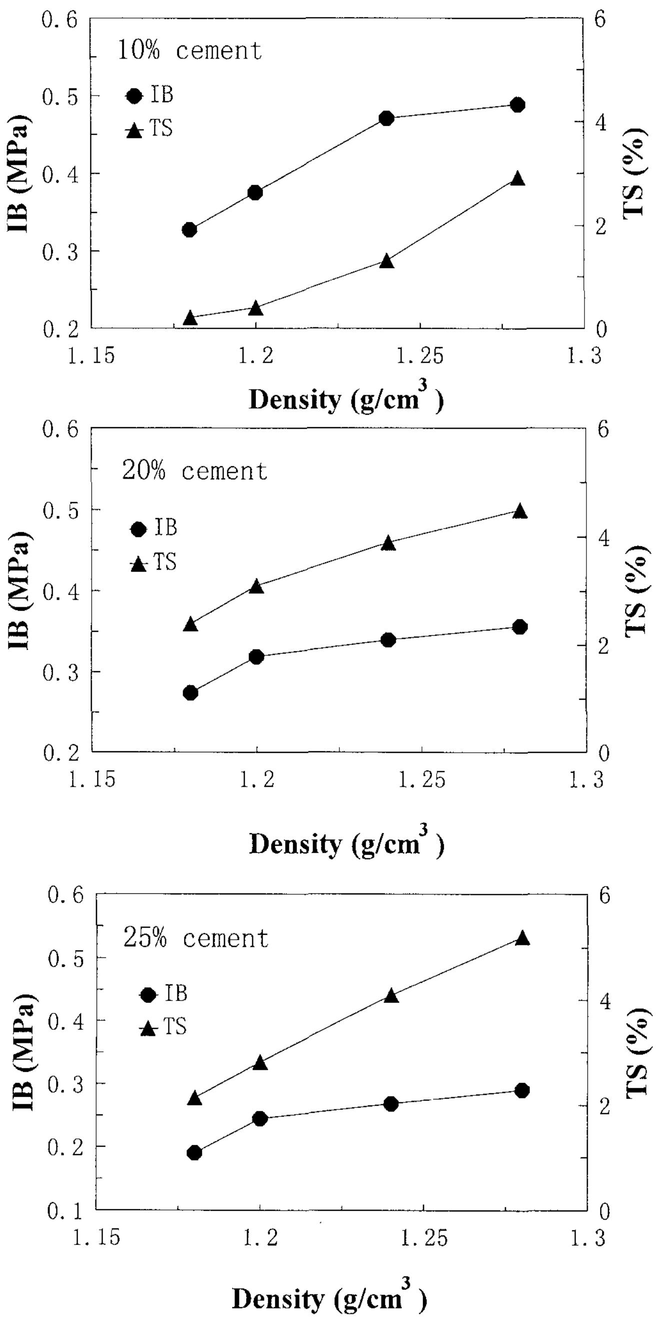

Fig. 4. Effect of density on internal bond strength and thickness swelling

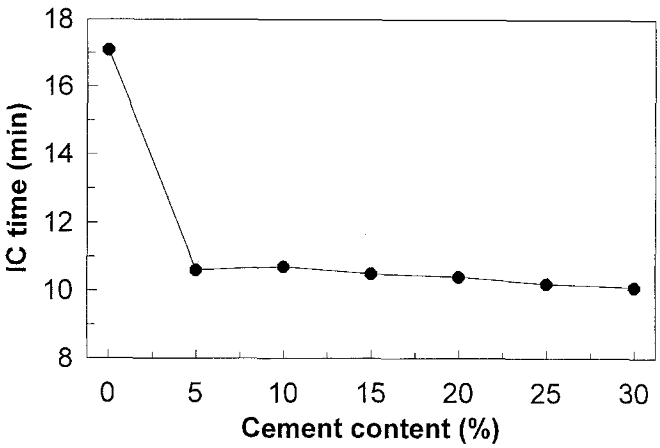

Fig. 5. Relations between initial curing (*IC*) times and cement content

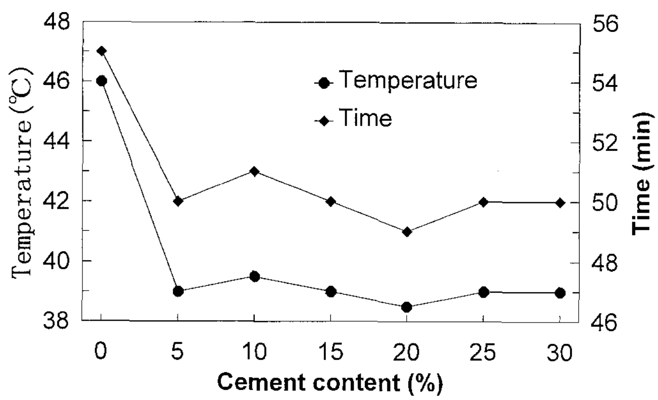

Fig. 6. Exothermic temperatures and duration of curing for gypsum particleboard with various cement contents

exothermic reaction. The ET and Et of gypsum and cement were 46°C and 55 min and 32°C and 110 min, respectively (Table 1). The ET of cement was lower than that of gypsum, so the ET of GPB was reduced by adding cement. Though the Et of cement was longer than that of gypsum, the cement worked as a kind of promoter in this study and reduced the exothermic duration of GPB when cement was added to gypsum.

Conclusions

The physical and mechanical properties of GPB were improved markedly by adding cement. When cement of 5%–15% was added, it successfully decreased the TS and WA and increased the IB of boards. The reduction ratio of IB with the addition of cement was also lower than that after no addition of cement when specimens were soaked in water (21°C) for 24 h. The improvement in MOE and MOR induced by adding cement was not as marked as that of the IB, TS, and WA. The test not only researched the effect of adding cement on the physical and mechanical properties of GPB, it also explored the effect of adding cement on the IC, ET, and Et of GPB. For samples with no wet treatment, cement content of ≤15% had a significant effect on the physical and mechanical properties of GPB, a result different from that reported by Li et al.[7] There was no significant effect induced by adding cement at ≥20%. Though the IC, ET, and Et were influenced by the addition of cement, the effects were not related to the cement content. The IB and TS of GPB were related to the density of the board, increasing with an increase in density.

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