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ORIGINAL ARTICLE

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Properties of gypsum particleboard reinforced with polypropylene fibers

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Abstract This paper details the influence of the length and content of polypropylene (PP) fibers on the physical and mechanical properties of gypsum particleboard (GPB). The length and amount of PP fibers added had a significant effect on the internal bond strength (IB) and the modulus of rupture (MOR) of GPB. The highest IB value was shown at 9mm length and 9% content of PP fibers. The MOR was highest when the board was made with PP of 12mm fiber length and 12% content. Suitable contents of PP fibers were advantageous in that they reinforced the properties of GPB so it achieved high performance. In contrast, a high content of PP fibers reduced the IB, MOR, and modulus of elasticity (MOE) of GPB. The thickness swelling was reduced with an increase in PP length and content. It was concluded that the combination of 12mm length and 12% content or 3mm length and 9% content was optimum for producing good performance of GPB.

Key words Gypsum particleboard · Polypropylene (PP) fiber · Reinforcing material · Target density

Introduction

Gypsum particleboard (GPB) is an inorganic-bonded panel product manufactured from wood particles (as the strengthening material) and gypsum (as the adhesive). It is a relatively new building construction material.[1] GPB has been used primarily for residential construction, such as for wall decorating and roof sheathing, where a specific engineering design is not required. As a good building construction material, it has nonformaldehyde emission and a high fire-retardant property. Furthermore, wood particles do not need to be dried, and GPB is pressed in the cold condition during the production process so consumption of thermal energy is low. Tannin has little effect on gypsum curing in most wood species.[2,3] As a consequence, the GPB costs little to produce and is easy to manufacture.

There are some drawbacks with GPB, though, such as high thickness swelling, high water absorption, and low mechanical properties compared with those of cement-bonded board. These factors hinder its application as a building construction material. Reinforcing fiber materials were added to improve these properties. The aim of this study was to determine whether the use of reinforcing fiber materials could lead to more advantageous properties of GPB. Variations in the physical and mechanical properties with respect to three processing variables (length and amount of polypropylene fibers, and target density level) were analyzed.

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Materials and methods

Test materials

The gypsum studied was a commercial type used for a plaster cast,[4] and the wood particles were obtained from a particleboard manufacturer (Okura Industrial Corporation, Marugame, Japan). The proportions of screen analysis (S) of particles (opening) were 9.7% in $S < 0.71$ mm, 11.2% in $0.71\,mm < S < 1.00\,mm$, 15.7% in $1.00\,mm < S < 1.40\,mm$, 35.5% in $1.40\,mm < S < 2.00\,mm$, and 27.9% in $2.00\,mm < S$, respectively. Polypropylene (PP) fibers (TUFLITE FF type) were provided by TESAC Corporation (Osaka, Japan). Their general properties are as follows: width $\geq$0.3mm, thickness 30–35μm, fineness 80 $\geq$denier, specific gravity 0.91, melting point 168°C–170°C, tensile strength $\geq$490MPa. Four fiber lengths were applied to the test (3, 6, 9, and 12mm); and the five fiber contents were 3%, 6%, 9%, 12%, and 15% based on the weight of the particles. Citric acid 0.05% ($C_6H_8O_7$) was added as a buffer based on the weight of the gypsum.

Test methods

Each material was weighed at a wood/gypsum ratio of 0.25 and a water/gypsum ratio of 0.35 in the laboratory.[5,6] The mixture of particles [moisture content (MC) 12%] and PP fibers was put in a blender, and water containing citric acid was added. After mixing the particles, PP fibers, and water for about 1–2 min, the gypsum was added. Consequently, sample boards (46 pieces) of 10 × 400 × 400 mm were formed. Sample boards with a target density of 1.2 g/cm^3, six levels of PP fiber content (0%–15%), and four fiber lengths were produced in the laboratory. In addition, sample boards with three target densities of 1.1, 1.2, and 1.3 g/cm^3 (fiber content 9% at 3 mm length and 12% at 12 mm length) were also produced.

All mats were pressed at 3 MPa in a cold press for 4 h. The GPB mats were dried to about 2%–3% MC at 45°C in a dryer. After being removed from the dryer, the mats were stored at room temperature for 1 week. The physical and mechanical properties of GPB were measured according to Japanese Industrial Standard JIS A5908.[7] All the physical and mechanical properties data show average values for eight specimens.

Aging tests,[8] such as thickness swelling (TS) and water absorption (WA), were done for the different contents and lengths of PP fibers and without fibers. The specimens used to determine the effect of adding PP fibers on the properties of GPB were divided into three groups for the aging test. Three groups were treated prior to measuring TS and WA by the following methods. The specimens of the first group were soaked in water (20°C) for 24 h and then oven-dried. The specimens of the second group were soaked in water (70°C) for 24 h and then oven-dried after they had undergone the same treatment as the first group. The specimens of the third group were boiled in water (100°C) for 4 h and then oven-dried after they had undergone the same treatment as the second group.

The increase ratio (K) of the internal bond strength (IB), modulus of rupture (MOR), and modulus of elasticity (MOE) of specimens adding PP fibers compared with the specimens without fiber addition were calculated using the following formula.

$$K = \left(\frac{Z_X}{Z_i} - 1\right) \times 100(\%)$$

where Z_i represents the IB, MOR, and MOE without addition of fibers, and Z_x is each value of these properties after the various contents and lengths of PP fibers were added.

Results and discussion

Effect of PP fiber length and content on the IB of GPB

The length and amount of PP fibers added had a significant effect on the IB of GPB, as shown in Fig. 1. The IB of boards increased with an increase in fiber content at any fiber length when their contents were ≤ 9%–12%. The effect of the 3-mm fiber on the IB of GPB appeared more significant with 9%–12% content compared with the other fiber lengths, showing the highest IB among the four fiber lengths. When 15% fiber content was added, the IB began to decrease for any fiber length. Especially for the 3-mm fiber length, the IB was much lower than that for GPB with no fiber addition.

The increase ratios of the IB had a relation with the length and content of PP fibers, as presented in Fig 1. The increase ratios of IB were the highest when PP fiber contents of 9%–12% at any fiber length were added. The highest increase ratio was 39.2% at the 3-mm length and 9% PP fiber content.

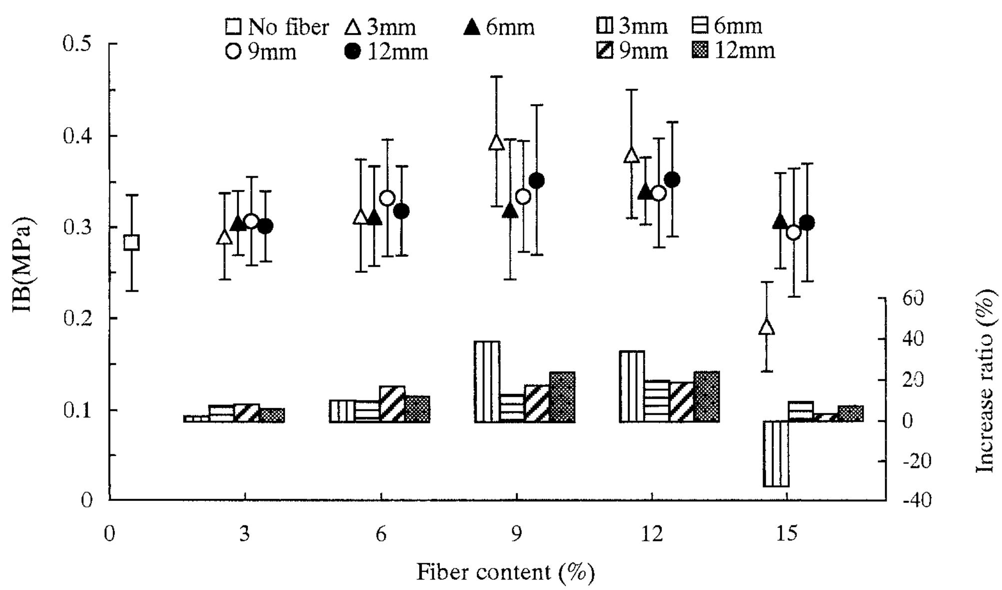

Fig. 1. Effect of polypropylene (PP) fiber length and content on internal bond strength (*IB*). *Clubs*, increase ratio (%); *mark*, average value of IB

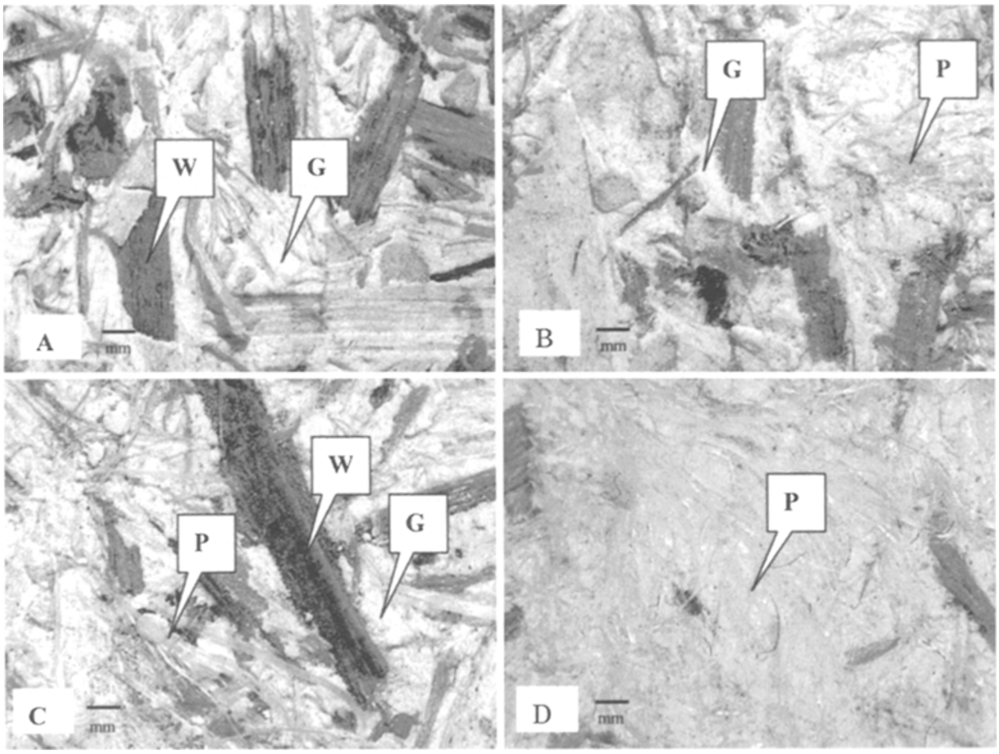

Fig. 2. Distribution of PP fibers on the ruptured surfaces of boards. **A** No addition of fibers. **B** Length 3 mm and 9% content of PP fibers. **C** Length 12 mm and 12% content of PP fibers. **D** Length 3 mm and 12% content of PP fibers. *G*, gypsum; *P*, PP fibers; *W*, wood particles

The possible cause of this phenomenon might be the uniform distribution of PP fibers over particles when certain amounts of fibers were added, and it was advantageous to the properties of board. The IB increased with an increase in fiber content in the range of ≤12% at any length of fiber; 9%–12% fiber content obtained the higher IB because the fibers were uniformly distributed over the particles (Fig. 2B, C). The PP fibers and particles were well bonded by the gypsum. For this reason, a higher IB was attained at 9%–12% fiber content of 3 mm length. In contrast, at higher fiber content the PP fibers were not uniformly distributed over the particles. Fibers did not bond to each other owing to the lack of gypsum in the presence of such a large amount of fibers. Therefore, the IB of boards declined when 15% fiber content was added. The gathering of a large amount of fibers was most serious at 3 mm length and 15% content (Fig. 2D), resulting in the obviously reduced IB value.

Effect of PP fiber length and content on the MOR of GPB

The bending strength properties of boards made with various lengths and contents of PP fibers are shown in Fig. 3. The MOR increased with an increase in fiber content and reached its highest values at a fiber length of 12 mm and 12% content or at 3 mm length and 9% content. After adding 15% content of 3-mm fibers the MOR was lower than that after no addition of fibers. At other fiber lengths the MOR had a tendency to decrease, but it was still higher than that without PP fibers.

The increase ratios of the MOR for GPB were almost all higher than those for IB at any fiber length and content (Fig. 3). The highest increase ratios for the MOR were 66% at 12 mm length and 12% content and 65% at 3 mm length and 9% content.

Because the destruction of tested board samples occurred in both PP fibers and particles, the superior increase ratios of the MOR of boards might be due to the high tensile strength of the PP fibers themselves. The tensile strength of PP fibers is 490 MPa, whereas the tensile strengths of softwood and hardwood[9] are 50–150 and 20–260 MPa, respectively. Addition of PP fibers with the higher tensile strength is advantageous for producing the high bending strength of the board. Thus PP fiber length seems to play a key role in improving the MOR of GPB under the bending condition. The high MOR was produced at a fiber length of 12 mm and 12% content. The MOR of the GPB decreased obviously at a fiber length of 3 mm and 15% content owing to the low bonding strength (Fig. 1).

Effect of PP fiber length and content on the MOE of GPB

The effects of PP fiber length and content on the MOE of GPB are as illustrated in Fig. 4. Though the MOE tended to increase slightly when the fiber content was increased up to 12% at any fiber length, the increase ratios were lower than those of the MOR (Fig. 3). When 15% fiber content was added, trends similar to those seen for IB and MOR were found: The MOE of board at 3-mm length fiber was lower

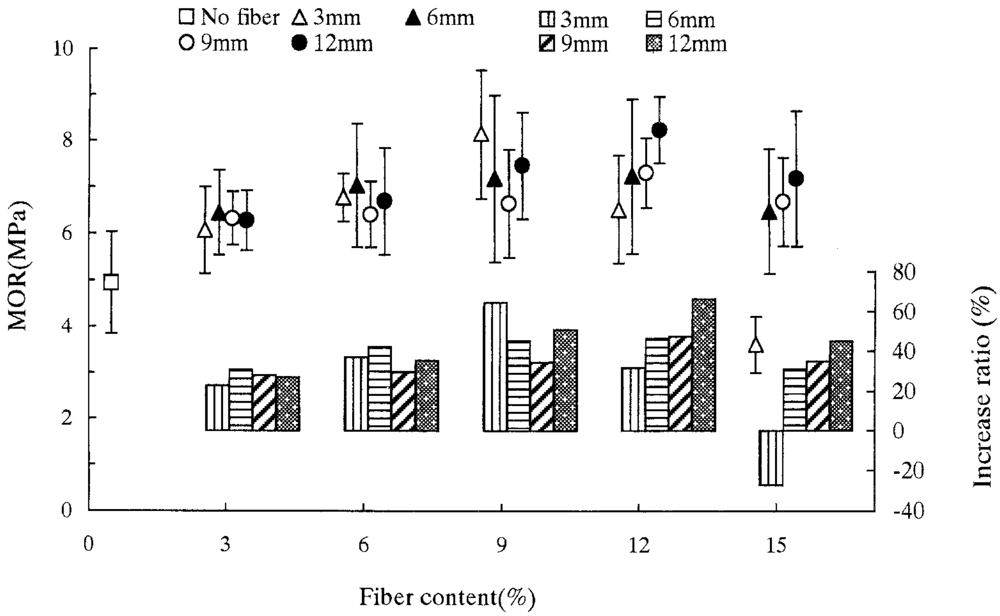

Fig. 3. Effect of PP fiber length and content on modulus of rupture (*MOR*). *Clubs*, increase ratio (%); *mark*, average value of MOR

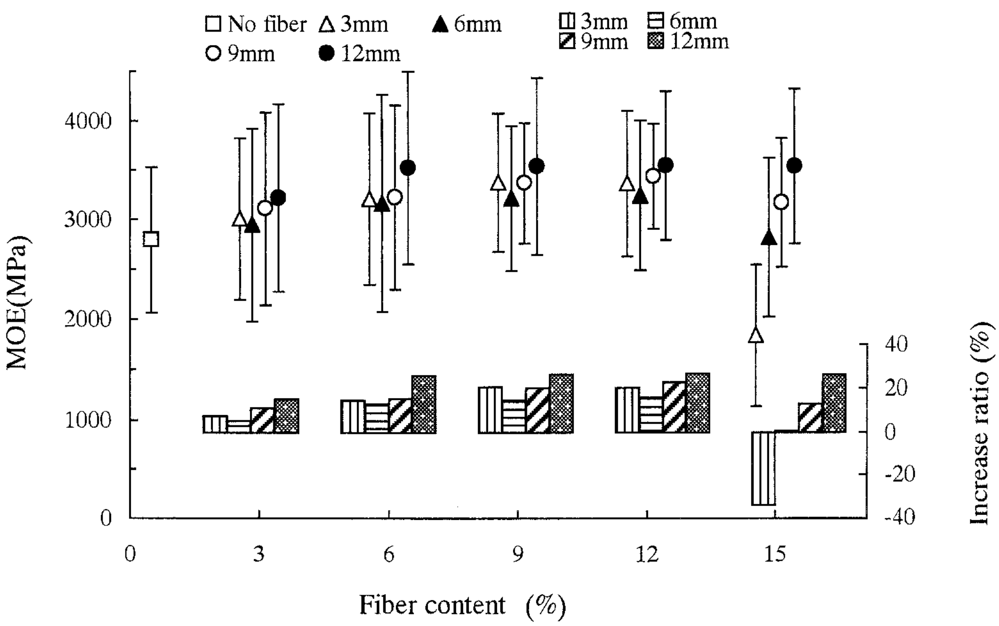

Fig. 4. Effect of PP fiber length and content on modulus of elasticity (*MOE*). *Clubs*, increase ratio (%); *mark*, average value of MOE

than that without addition of PP fibers. The MOE with other fiber lengths had a tendency to decrease slightly, but the values were still high compared with the board without fibers.

GPB is a well known reinforced composite material. Consequently, the MOE and MOR values are related to not only the bonding strength of GPB but also the strength of the reinforcing materials (particles and PP fibers). When the bonding strength of boards was within a certain range, the influence of the strength of the reinforced materials on the MOR and MOE was dominant.[9] In addition, the MOE value is related to compression and tensile deformations under the bending condition. The PP fibers in boards could decrease the tensile deformation of boards, but it could not change the compression deformation. For this reason, the increase ratio of the MOE was lower than that of the MOR (Figs. 3, 4), and the MOE was almost unchanged at 6%–12% PP fiber content. Moreover, when fibers of 3mm length and 15% content were added, the MOE decreased because the PP fibers could not be distributed uniformly over particles after additing such a large amount of PP fibers, causing the lower MOR and IB values.

Effect of PP fiber length and content on the TS of GPB

Figure 5 shows that all the specimens at any fiber length had almost the same tendency regarding the TS of GPB after the specimens were soaked in water (20°C) for 24h. The shorter fibers had slightly higher TS values compared with

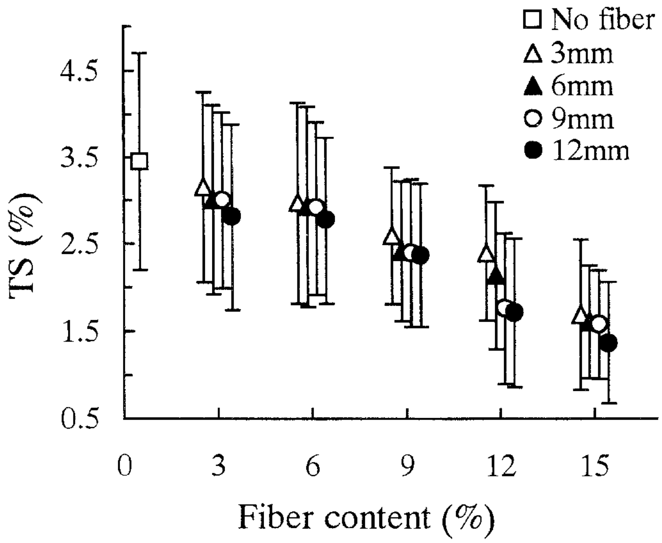

Fig. 5. Effect of PP fiber length and content on thickness swelling (*TS*)

the longer fibers. The results of the experiment indicated that the TS in 12-mm length fiber was lowest. In addition, the amount of PP fibers added had an effect on the TS, decreasing it markedly when the fiber content was increased from 3% to 15%.

It is well known that PP fibers have a water-resistant property (hydrophobicity). When the specimens were soaked in water, GPB showed lower TS values at higher PP fiber content because the wood particle content was reduced with the increase in PP fiber content.

Effect of board density on GPB properties

Boards with three target densities (1.1, 1.2, and 1.3 g/cm^3) were produced at 3 mm length and 9% fiber content and at 12 mm length and 12% fiber content. The effects of density on the IB and MOR are shown in Fig. 6. According to the experimental results, the effect of board density is apparent; that is, increasing the density improved the MOR and IB of GPB markedly.[10] The MOR of 12-mm fiber board was higher than 3-mm fiber board, and the IB of 3-mm fiber board was better than that of 12-mm fiber board at the three target densities.

As the density of the board increased, so did the wood particles and PP fibers in a unit volume.[11] The high compressibility brought high bonding strength between the particles and PP fibers and caused the high mechanical properties of GPB.[12,13] Thus the density of the board exhibited a significant effect on the IB and MOR.

Water-resistant properties of GPB

The specimens with and without PP fibers were treated under three dry–wet conditioning cycles to evaluate dimensional stability. The TS and WA values of GPB are summarized in Fig. 7 and Table 1. Addition of PP fibers produced lower WA and TS compared to those parameters with no

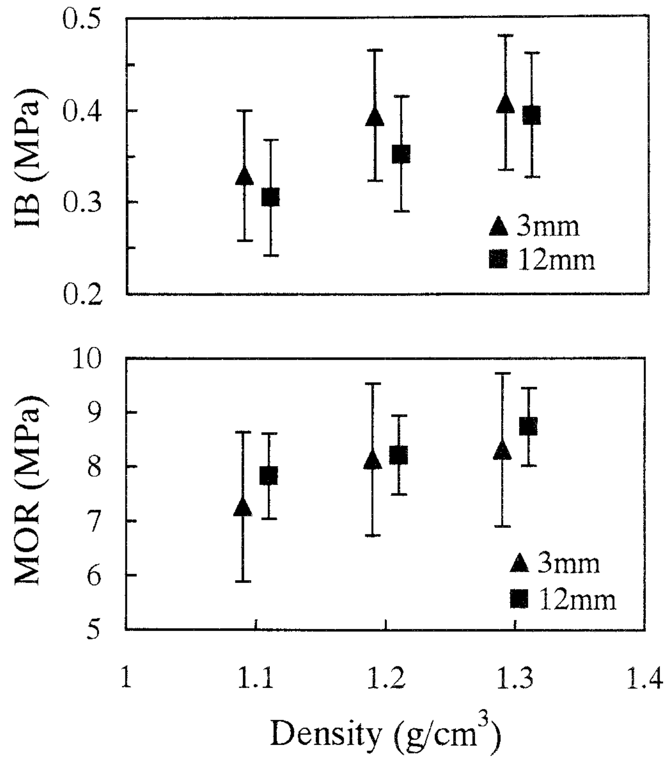

Fig. 6. Effect of the density of gypsum particleboard (GPB) on the IB and MOR

fiber addition. TS and WA increased with an increase in temperature during treatment. This result was in agreement with the study reported by Zhang[8] in which the TS had a tendency to increase with increasing treatment temperature. TS and WA were associated with the fiber content for any fiber length. Their values decreased as the fiber content increased; the lowest TS and WA values were seen at a fiber content of 15% and the highest values were for the boards without fibers (Fig. 7, Table 1).

The reduction in TS and WA might be due to the addition of PP fibers. As mentioned, PP fiber is hydrophobic. Hence TS and WA decreased with an increase in PP fiber content owing to reduction of the wood particle content when the specimens were soaked or boiled in water.

Conclusions

The results of this study show that PP fibers significantly reinforce the properties of GPB and cause the boards to resist water absorption. The physical and mechanical properties of GPB were influenced differently by the length and content of the fibers. The most advantageous physical and mechanical properties of GPB could be produced at a fiber length of 12 mm and fiber content of 12% or at 3 mm length and 9% content. Less effective GPB properties began to appear at 15% PP fiber content for any fiber length. The effect of the longer fibers on the MOR and MOE of GPB was more significant than that of the shorter fibers. During

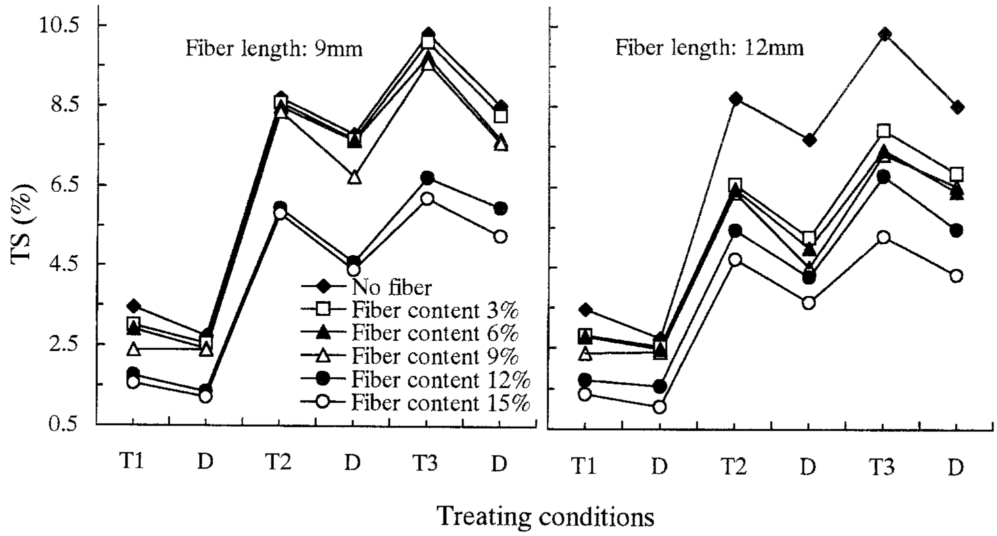

Fig. 7. Relation between dry–wet conditioning treatment and TS. *D*, oven-dried condition; *T1*, 24h soaking in water (20°C); *T2*, 24h soaking in water (70°C); *T3*, 4h boiling in water (100°C)

Table 1. Effect of length and content of PP fibers on water absorption of gypsum particleboard

Fiber length (mm)	Fiber content (%)	Water absorption (%)		
		20°C	70°C	100°C
	0	21.9	26.7	29.8
3	3	21.0	22.1	26.0
	6	20.9	22.1	26.1
	9	18.6	22.7	26.7
	12	17.9	22.7	26.7
	15	17.3	22.8	27.0
6	3	20.4	24.1	26.5
	6	20.2	24.3	26.8
	9	19.8	24.5	26.8
	12	19.6	24.9	26.8
	15	19.0	26.6	29.5
9	3	21.0	24.8	27.7
	6	20.6	24.4	27.4
	9	19.3	23.9	26.5
	12	18.7	22.7	26.1
	15	17.8	21.8	25.8
12	3	21.1	26.7	29.2
	6	21.0	26.4	29.1
	9	20.3	26.2	28.9
	12	19.4	25.9	28.7
	15	19.0	21.9	24.9

the aging test, the increase in TS and WA of GPB with PP fibers was slow with an increase in temperature compared to the values for GPB without PP fibers. The hydrophobicity of PP fibers may play a dominant role in resisting penetration of water into boards. The IB and MOR values of boards were associated with the target density and increased with an increase in target density. We concluded that PP fibers are a good reinforcing and water-resistant material for producing GPB when an appropriate amount of fiber is added.

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