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Porosity of Cement-Bonded Particleboards Hardened by CO_2 Injection and Cured by Hydration

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Abstract

The purpose of the porosity measurements was to compare the boards made by two different methods: the conventional, hydration curing method and the CO_2 injection method, and to find out how their porosity affects water absorption. The specific pore-surface area of the CO_2-hardened boards was much smaller than that of the hydrated cement-bonded particleboards. Regarding the pore size distribution diagram, in the case of the CO_2-hardened boards, there were two peaks on the graph (one peak at a pore diameter of around 6–8 μm, and a second peak at around 2 μm), and in the case of the conventional boards there was only one peak at 2 μm. The total pore volume of the CO_2-hardened boards was larger than that of the hydrated boards. Water absorption of the CO_2-hardened boards was lower than that of the hydrated particleboards. There was no relationship between the specific pore-surface area and water absorption, and between the total pore volume and water absorption. The use of CO_2 did not affect water absorption and these boards still displayed a higher initial strength.

Discipline: Forestry and forest products
Additional key words: inorganic wood composites, accelerated hardening, water absorption

Introduction

Carbon dioxide (CO_2)-hardened cement-bonded particleboards have several technological and physical advantages compared with conventional hydrated cement-bonded particleboards, such as smaller thickness tolerance, lower energy requirement and higher production capacity. The major advantage of this method is the rapid hardening (5 min) compared with the conventional method (8 h)[3].

In the conventional production lines, the cement-wood mats are pressed together with steel-plates between them. About 25–40 boards (depending on the thickness) are pressed and fixed in a clamp, with fixed internal height, by a press. This packet is left in a curing chamber (~70ºC and ~100% relative humidity), for 8 h until the boards become self-supporting. Thereafter, the boards are taken out from the clamp. The main reaction that the cement undergoes is hydration: the reaction between calcium silicates and water results in the formation of calcium silicate hydrates, e.g.:

$$2\,(3\,CaO \cdot SiO_2) + 6\,H_2O \rightarrow 3\,CaO \cdot 2\,SiO_2 \cdot 3\,H_2O + 3\,Ca(OH)_2$$

In the CO_2 injection method, the mats are pressed in a cold press, and during this process, CO_2 gas is injected into the board. It takes only 5 min for the board to become self-supporting. Here CO_2 reacts with calcium hydroxide and calcium silicate hydrates as follows:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

$$3\,CaO \cdot 2\,SiO_2 \cdot 3\,H_2O + 3\,CO_2 \rightarrow 3\,CaCO_3 + 2\,SiO_2 + 3\,H_2O$$

In both cases (hydration and CO_2 injection), it is necessary to store the boards for 2 additional weeks until the cement reaches the so-called "28-day-strength"[1,5].

Since these products are used outdoors in many cases (siding, roofing, etc.), their porosity is an important property, in terms of surface treatment and water absorption. Earlier measurements of water absorption showed differences between the boards made by the two methods. On the other hand, for practical use, in some cases, the CO_2-hardened boards absorbed water very easily and behaved like hydrophilic materials. In other cases, on the same type of boards, water drops built large contact

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angles and the boards acted like hydrophobic materials. Since it was considered that the difference in water absorption was related to their porosity, as a first step, we examined the porosity of the CO_2-hardened boards[6,7].

Materials and methods

1. Main properties of test pieces

CO_2-hardened cement-bonded particleboards with different cement/wood ratios and target densities under absolute dry conditions (Table 1), were prepared to examine their porosity. The raw materials used in the experiments were as follows: Scotch pine particles (*Pinus silvestris*, particle size: about 0.25–2.5 mm mesh) with an average moisture content of 18%, CEM I. 42.5 Portland cement, calcium hydroxide, water, and CO_2 gas. The basic properties of the CO_2-hardened boards (in the figures we used the values of the cement/wood ratio and the target density to identify the test pieces) are shown in Table 1. In the production of the experimental boards, we omitted the combination of 3.5 cement/wood ratio and 1,250 kg/cm^3 density, because in our previous experiments, this combination showed very low mechanical properties, which did not meet the standard requirements.

We used a Siempelkamp laboratory press to make the boards. The mat size was 375 × 470 mm, and steel bars with a height of 12 mm were used to ensure the density and thickness of the boards. The specific pressure was around 4.8 MPa. The press-plates had bored holes, similar to those of hot-presses for steam injection. In this case, instead of steam, CO_2 gas was injected into the pressed boards alternately once from the bottom, and once from the top. The total pressing/injection time was 5 min. Thereafter, the boards were stored for 14 days at room temperature to ensure complete curing of the cement.

The density of the conventional boards (also under absolute dry conditions) was 1,300 kg/m^3 and the cement/wood ratio was 3.0. These samples were taken from factory-produced boards.

To determine the amount of carbon dioxide used in the reaction (CO_2 consumption), the weight of the mats was measured before insertion into the press, and the weight of the boards was measured right after pressing. The difference corresponded to the approximate CO_2 consumption, because during the pressing process, a certain amount of water had evaporated, which we could not measure. The 24-h water absorption of the boards was measured based on EN 317 standard[8].

2. Porosity

Cement stone, used as binding material in cement-bonded particleboards, is a material with a high porosity. The pores of the binding material of cement-bonded particleboards can be classified into 3 groups: (1) *Gel pores* : the spaces in the cement gel and between the microcrystals of hydrate products, which were formed during the reaction of the cement and water (1–10 nm). (2) *Capillary pores*: the spaces, which were filled with water originally (20 nm–10 µm). Their size depends on the stage of hydration. (3) *Air pores*: the spaces, which were formed due to inadequate compression or by pore-forming additives (20–300 µm, or greater)[3,4].

In this case, pores were formed by the CO_2 injection too, because during the treatment, the gas generates spaces through penetration into the board.

The volume of the liquid required to fill the pores determines the total porosity of cement stone. The pores with a diameter of 3.7 nm–300 µm can be measured using a mercury-penetrating porosimeter.

The total porosity can be calculated by the equation[6]:

$$P = \left(1 - \frac{\rho}{\rho_t}\right) \cdot 100$$

Table 1. Cement/wood ratio and target density of the boards under absolute dry conditions

Method of curing	Cement/wood ratio	Target density under absolute dry conditions (kg/m^3)
CO_2 injection	2.5	1,250 1,300 1,350
CO_2 injection	3.0	1,250 1,300 1,350
CO_2 injection	3.5	1,300 1,350
Hydration curing	3.0	1,300

where P: porosity (%),

ρ_t: density of the cement-bonded particleboard without pores (kg/m^3),

ρ: density of the cement-bonded particleboard (kg/m^3) .

This equation may define the porosity and all the properties of the cement stone depend on the porosity.

3. Determination of the porosity

During these studies, the porosity was measured with a MICROMETICS 900 type, mercury-penetrating equipment, with a pressure range of 7 kPa–345 MPa, which enabled to measure pores with a diameter of 4 nm–177 μm.

Using this equipment, the size and the amount of pores, cavities of porous materials, and the absolute density of solids and dust can be determined. Besides, the pore-surface area and size distribution of elemental particles and pores can be measured. The maximum diameter of the pores can be calculated from the pressure values, which corresponds to the pore volume. The cumulated pore volume for a given pore diameter can be calculated from the quasi-volume shrinkage[2].

Results and discussion

The results of the study showed that the specific pore-surface area of the CO_2-hardened particleboards was smaller than that of the conventional boards (Fig. 1). The specific pore-surface area corresponds to the total surface of the pores in 1 g of the observed material. The average specific pore-surface area of the standard, factory-made, hydrated boards (18.64 m^2/g) was 17% larger than the largest average value of the CO_2-hardened boards (w/c = 3.0; r = 1,350 kg/m^3: 15.9 m^2/g). The total pore volume of the different board types is shown in Fig. 2. It was observed that the total pore volume of the conventional boards was the lowest.

The relationship between water absorption and the different board types is shown in Fig. 3. Although the

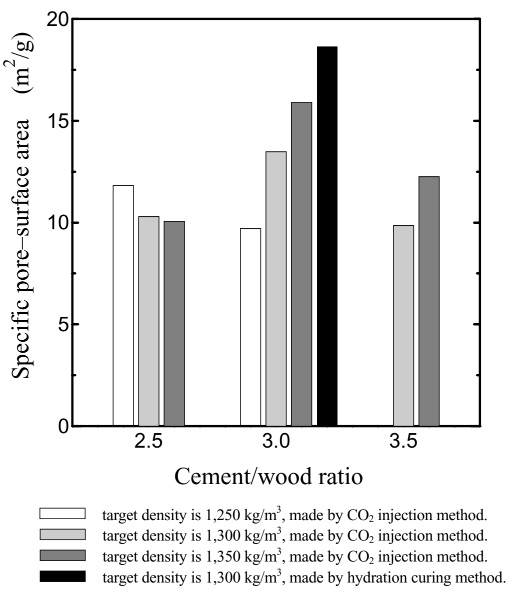

Fig. 1. Comparison of the specific pore-surface area of different board types

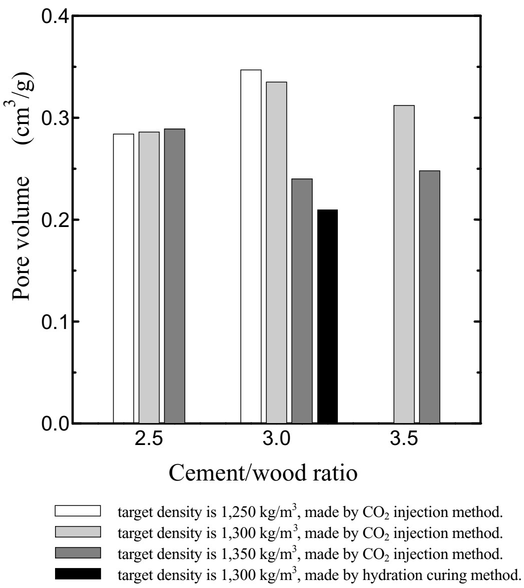

Fig. 2. Comparison of the pore volume of different board types

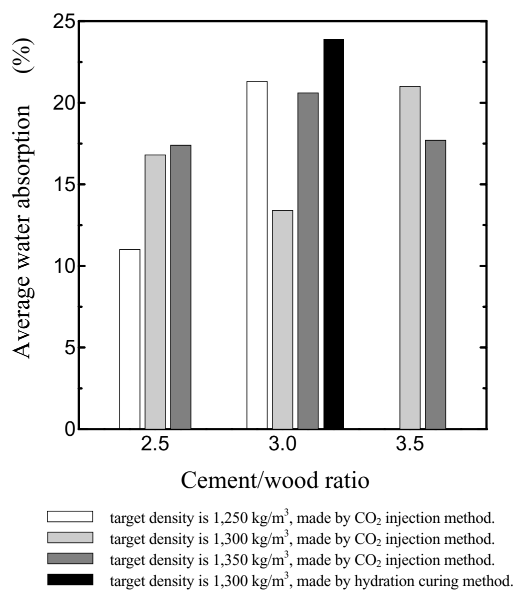

Fig. 3. Comparison of the water absorption depending on the board types

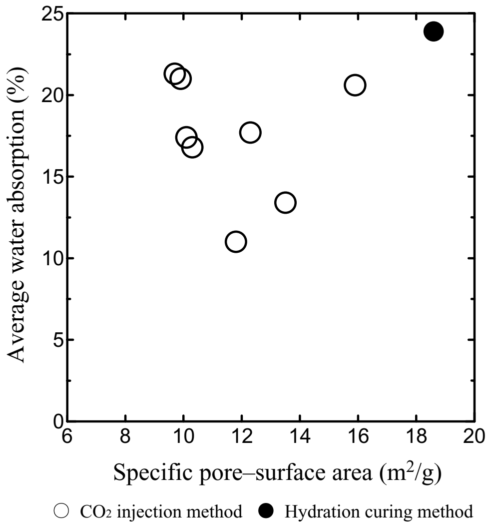

Fig. 4. Relation between water absorption and specific pore-surface area of the boards

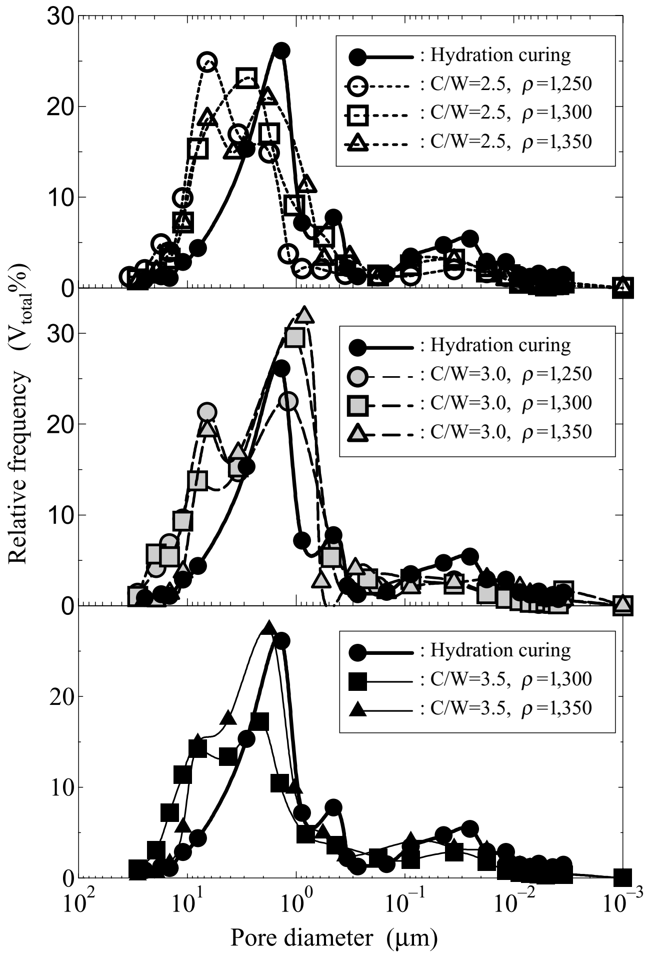

Fig. 5. Distribution of the pore size of the boards

pore volume of the CO_2-hardened boards was larger than that of the hydrated boards, water absorption of the former was smaller than that of the latter. Regardless of the cement/wood ratio and density, there was no relationship either between the specific pore-surface area and water absorption (Fig. 4), or between water absorption and the total pore volume.

At the same time, we have to consider the pore size distribution, because the size of the pores would have an influence on water absorption too, in a given sample. It had an influence on the capillary behavior of the materials. The distribution of the pore size of the boards is shown in Fig. 5. In the case of the CO_2-hardened boards, there was a maximum peak at a pore diameter of around 6–8 μm, and a second peak at around 1–2 μm. In the case of conventional hydrated boards, a high peak was observed at a pore diameter of around 2 μm and two low peaks at around 0.6 μm and 0.03 μm. In the case of the CO_2-hardened boards, the maximum peak at a higher pore diameter was caused by gas injection. During the production of the CO_2-hardened boards in the first phase of pressing (30 s), we applied a so-called pore process to facilitate the injection of the gas into the board. With this pore process, higher initial strength of the board could be ensured, but additional hydration was necessary to obtain the full strength of cement. It was also observed that the peaks at a pore diameter of around 1 μm were higher than those at around 6–8 μm in many cases, which implied that there were more pores with such diameters. That is to say, the chemical reactions between CO_2 and the cement were also caused by the injection of CO_2 gas.

If the diameter of the capillaries is large, the speed of water penetration is also high. It remains to be determined why the CO_2-hardened boards, which showed a peak at a larger pore diameter, absorbed less water than the conventional boards, which contained only pores with a small diameter.

The CO_2 consumption, i.e. the amount of reacted CO_2 during the gas injection in the press is important for determining the physical and mechanical properties of the hardened and cured boards. Earlier it was found that the larger CO_2 consumption ensured the higher initial strength of the board[1]. For the reaction of CO_2 with the cement, CO_2 must penetrate into the board, thereby creating more pores. It was, therefore, considered that the higher CO_2 consumption could account for the higher porosity, leading to increased water absorption. In this study, we compared the specific pore-surface area as a function of CO_2 consumption. As shown in Fig. 6, the specific pore-surface area increased slightly as the CO_2 consumption increased, although it was smaller than the specific pore-surface area of the hydrated boards (Fig. 4). This result seems to verify the above-mentioned hypothesis that higher CO_2 consumption results in a larger spe-

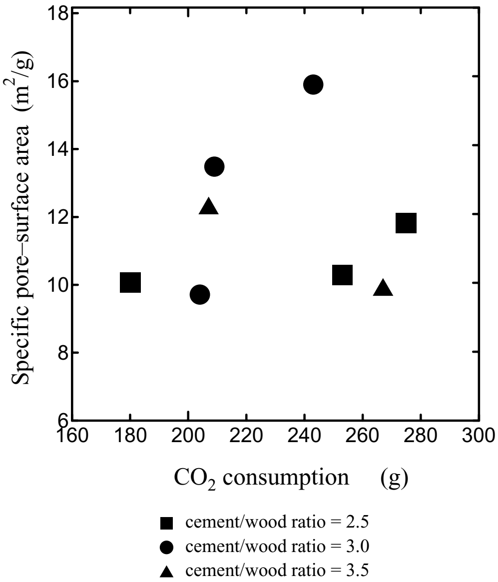

Fig. 6. Relation between specific pore-surface area and CO_2 consumption of the boards

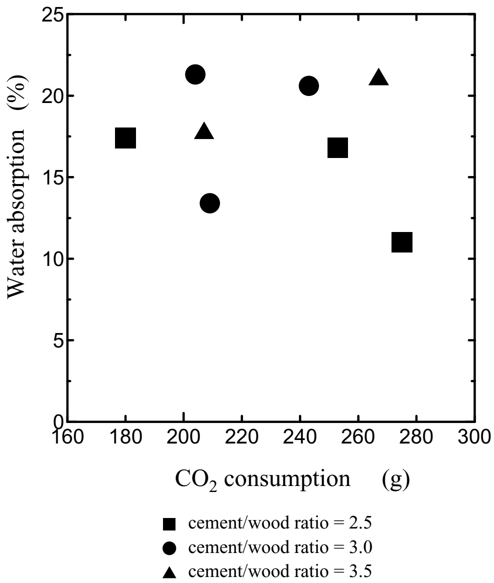

Fig. 7. Relation between water absorption and CO_2 consumption of the boards

cific pore-surface area. However, there was no relationship between CO_2 consumption and water absorption (Fig. 7). Therefore, it can be considered that the higher CO_2 consumption resulted in the higher initial strength and the larger pore-surface area, but that it did not adversely affect water absorption.

Finally, the pore volume as a function of the absolute dry density of the boards, regardless of the cement/wood ratios, was plotted in Fig. 8. It can be clearly seen that the pore volume decreased as the density increased,

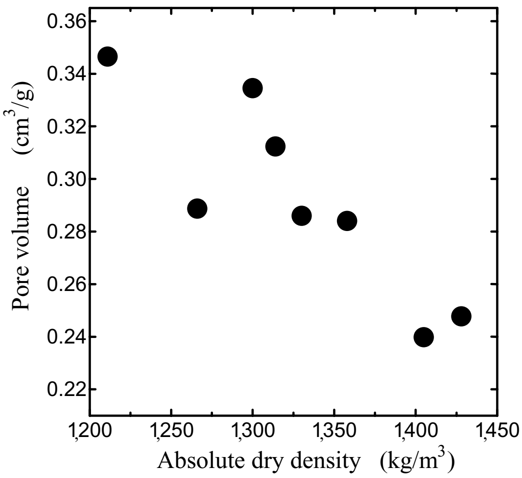

Fig. 8. Relation between pore volume and absolute dry density of the boards

although the correlation was only $R^2 = 0.7567$.

Conclusion

The purpose of the porosity measurements was to compare boards made by two different methods: the conventional, hydration curing method and the CO_2 injection method, and to find out how porosity affects water absorption.

The pore size distribution diagram of the CO_2-hardened boards show the presence of two peaks at a pore diameter of around 6–8 µm, and around 1–2 µm, while that of the conventional boards had only one main peak at 2 µm. The specific pore-surface area of the CO_2-hardened boards was smaller than that of the hydrated cement-bonded particleboards, the total pore volume of the CO_2-hardened boards was larger than that of the hydrated ones, and water absorption of the CO_2-hardened boards was smaller than that of the hydrated particleboards. It seemed that water absorption depended on the specific pore-surface area. However, among the CO_2-hardened boards, there was no relationship between water absorption and the specific pore-surface area, and also between water absorption and the total pore volume or the amount of CO_2 used.

The CO_2-hardened boards did not show any disadvantage in terms of water absorption in this experiment, and had the advantage of a higher initial strength.

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