RAPID COMMUNICATION

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New technology for manufacturing high-strength cement-bonded particleboard using supercritical carbon dioxide

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Introduction

The setting and curing time of cement involves a succession of overlapping crystallization stages, unlike the curing of thermosetting resins, which is dependent on heat-activated molecular polymerization and crosslinking. During conventional manufacturing of Portland cement-bonded particleboards, the setting/curing time is reduced by the use of additives and incremental temperatures during the setting and curing periods.[1] In recent years the authors have developed a few methods of rapid curing systems for cement-bonded particleboards (CBP) using additives such as $MgCl_2$, $CaCl_2$, $NaHCO_3$, and Na_2SiO_3, together with steam-injection pressing or hot platen pressing for the initial setting of cement, followed by autoclaving or heating treatment for the subsequent curing.[2–4]

The injection of carbon dioxide (CO_2) gas during pressing is one of the methods currently being applied to reduce the pressing (setting) time of cement. However, the disadvantages of this method include the almost similar board properties as those produced by conventional method,[1] and requirement of at least 14 days to achieve complete curing.[5]

This research aims to improve the quality of cement-bonded particleboard and to reduce its curing time using a conventional cold-pressing method for setting the cement followed by curing treatment using supercritical CO_2.

Materials and methods

Mixtures with equal proportions of Japanese cypress (*Chamaecyparis obtusa* Endl.) and Japanese cedar (*Cryptomeria japonica* D. Don) particles were used to produce CBP. Ordinary Portland cement (Osaka Sumitomo Co.) was used as a binder. Three types of CBP with a targeted density of 1.2 g/cm^3 were produced at cement/particle (oven-dry weight)/water weight ratios of 2.2:1.0:1.1. The three production methods were (1) supercritical CO_2 curing treatment; (2) conventional curing treatment; and (3) no curing treatment (control). A total of four hand-formed mats of 300 × 300 mm were cold-pressed to a targeted thickness of 12 mm and kept in an oven set at 45°C for 24 h. Three to six specimens of 50 × 200 mm prepared from these boards were then used for each treatment condition.

For treatment with supercritical CO_2, the specimens were placed in a reaction cell surrounded by a water jacket set at 60°C. CO_2 was maintained in liquid phase by passing through a condensor. The liquid CO_2 was then pumped into the reaction cell at a predetermined pressure. In this experiment, the specimens were subjected to a pressure of 7.4 MPa at about 50°C for 90 min and further placed in an oven set at 80°C for 10 h, followed by conditioning at ambient temperature prior to further testing.

The CBP for conventional curing treatment was wrapped with a polyvinylchloride (PVC) sheet immediately after clamping and kept for 2 weeks at room temperature. This step was followed by drying and conditioning under the same conditions as mentioned above.

For the control, the CBP was produced without curing. It was immediately dried at 80°C for 10 h, followed by 1 week of conditioning at room temperature.

The mechanical and dimensional properties of the boards were then tested in accordance with the Japan Industrial Standard, JIS A 5908.

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Results and discussion

The results showed that the mechanical properties of the CBP were improved significantly by the curing treatment with supercritical CO_2; the moduli of rupture (MOR) and elasticity (MOE) of supercritical treated board were 22 MPa and 4.7 GPa, respectively, as shown in Fig. 1, which were almost twice the values recorded for the board with conventional curing treatment and the control board. The MOR and MOE of the board produced by the conventional curing method were 10.5 MPa and 3 GPa, respectively; and those of the control board were 9.7 MPa and 2.7 GPa, respectively. The mechanical properties of the control board were lowest owing to the incomplete curing of cement.

The addition of CO_2 in the supercritical condition might have enhanced the hydration of cement and hence the board strength properties. This improvement may be attributed to the production of high calcium carbonate ($CaCO_3$) content during the hydration process of cement. During the cement hydration process, dicalcium and tricalcium silicates are hydrated to form tobermorite gel and calcium hydroxide.[6] When CO_2 is added to cement, calcium carbonate is formed,[1,5,7] as shown in the following equations.

$$2Ca_3SiO_5 + 6H_2O \rightarrow Ca_3Si_2O_7 \cdot 3H_2O + 3Ca(OH)_2$$

tricalcium silicate (C_3S) tobermorite gel calcium hydroxide

$$2Ca_2SiO_4 + 4H_2O \rightarrow Ca_3Si_2O_7 \cdot 3H_2O + Ca(OH)_2$$

dicalcium silicate (C_2S)

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O + \text{energy}$$

carbon dioxide calcium carbonate

$CaCO_3$ provides the initial strength necessary for the board taken early out of the press.[1] In this experiment, the CO_2 was applied during the curing of cement. The addition of CO_2 in supercritical condition after the pressing stage allowed more rapid curing of cement, as an increase in $CaCO_3$ content could strengthen the mechanical properties of the board.

The supercritical fluid (SCF) technique process has unique features, such as liquid-like densities, gas-like viscosities, and diffusivities intermediate to typical gas and liquid values. Even though the diffusion coefficients of SCF are lower than those of gases, it does not mean that the diffusivities are less in SCF, as the concentration gradient and molar densities are usually much greater than those of gases.[8] SCF has superior mass transfer characteristics. The mass transfer is further enhanced by very high buoyant forces, which cause significant density gradient across the interface. In addition, the low surface tension of SCF enables facial penetration into microporous materials.[9,10] Therefore, the SCF might allow more rapid penetration and uniform CO_2 distribution, which cause more rapid curing of cement – hence the board strength properties. Further fundamental research is necessary for establishing the production technology of the products.

The presence of CO_2 is believed to reduce or eliminate the retardation effect of wood extractives during cement hardening.[5,7,11] This beneficial effect may be caused by the

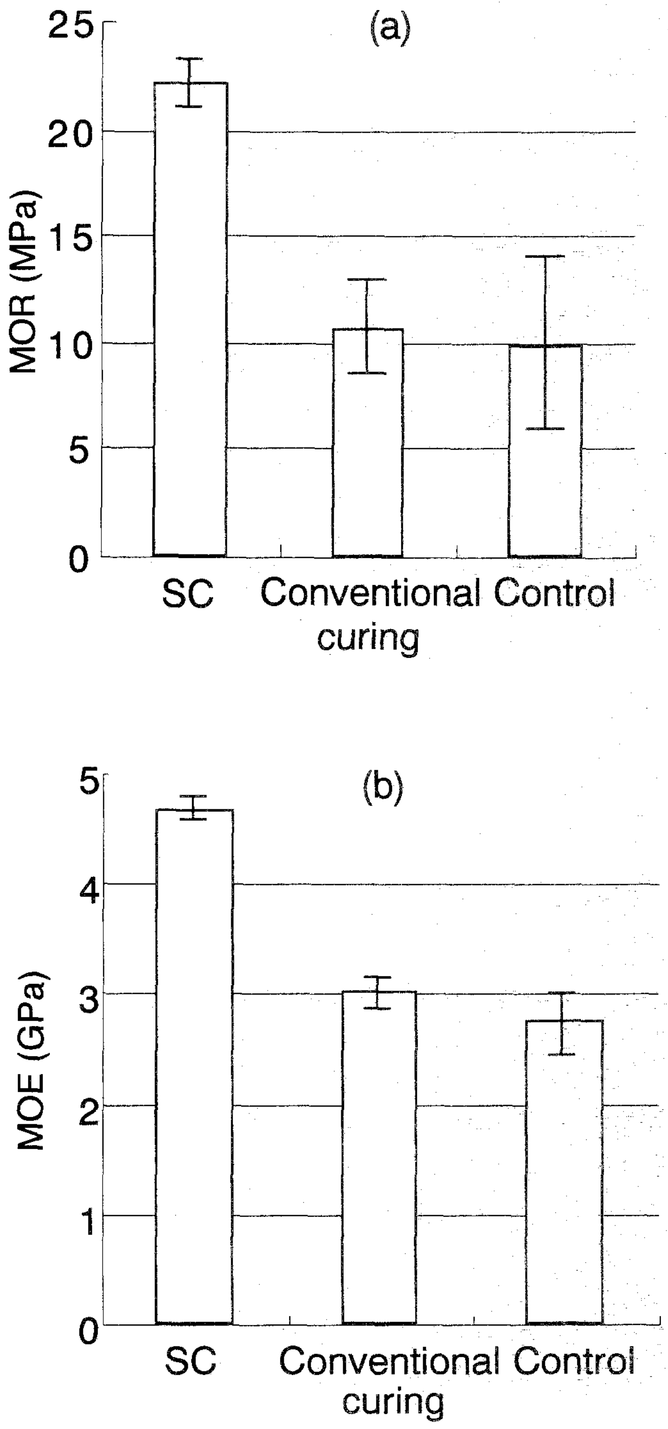

Fig. 1. Bending properties of various boards with supercritical CO_2 curing treatment (*SC*), with conventional curing treatment, and without curing treatment (*Control*). **a** Modulus of rupture (*MOR*). **b** Modulus of elasticity (*MOE*). *Bars* show the standard deviation in Figs. 1–4

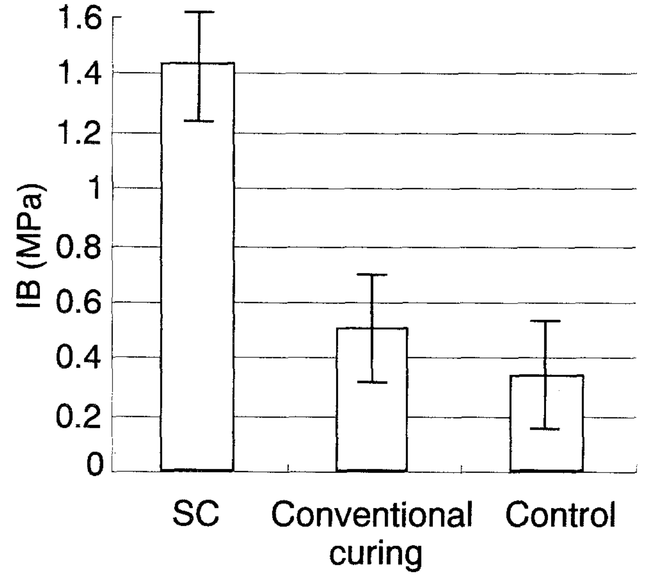

Fig. 2. Internal bond strength (*IB*) of various boards. See Fig. 1 for explanation of board types

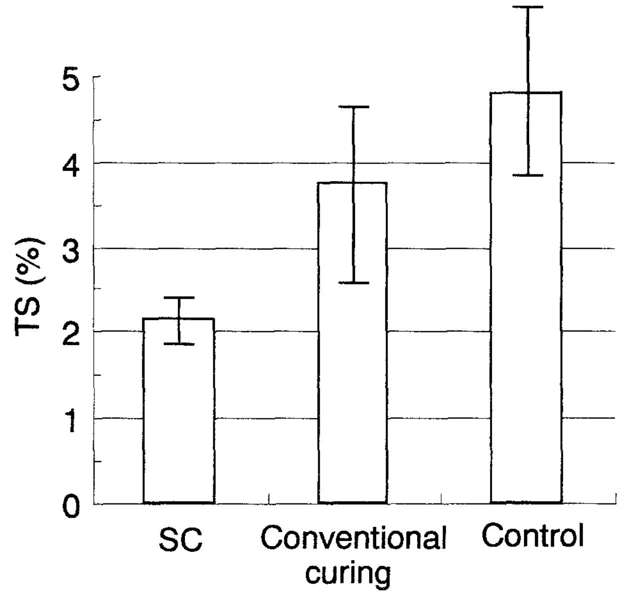

Fig. 3. Thickness swelling (*TS*) of various boards. See Fig. 1 for explanation of board types

quick curing of cement and promotion of the high bondability of cement, as reflected in the high internal bond strength (IB) of supercritical cured board, as shown in Fig. 2. The IB value of the supercritical treated board was 1.44 MPa, whereas the values for board with conventional curing treatment and the control board were 0.5 and 0.3 MPa, respectively.

The thickness swelling (TS) and water absorption (WA) of the board after 24 h of soaking in water are shown in Fig. 3 and 4, respectively. As well as other properties, the TS value of supercritical cured board was the lowest and almost twofold better than that of the control board due to a higher degree of compaction, curing, and hardening of cement. A release of internal stresses within and between wood particles during the exposure to supercritical CO_2 might also have contributed to improved TS.[12] A same trend was obtained for the WA test, where supercritical CO_2 imparted a favorable effect on the board; and only a small amount of water was absorbed after soaking in water for 24 h. This suggests that the treatment under supercritical condition may result in improved dimensional stability, apparently through reduced hygroscopicity. This reduction in hygroscopicity could be the result of either pressure-heat stabilization or the accelerator effect of CO_2 on cement hydration. Boards not treated with supercritical CO_2 were found to be porous, and the pores might have absorbed more water resulting in higher WA values.

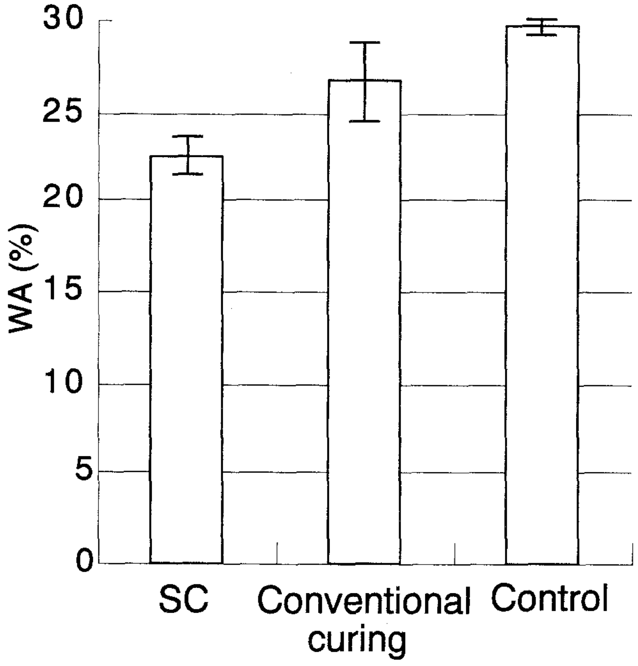

Fig. 4. Water absorption (*WA*) of various boards. See Fig. 1 for explanation of board types

Further study on the application of supercritical CO_2 to the production technology of cement-bonded particleboard is necessary to identify the optimum treatment conditions, induding time, temperature, and pressure.

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