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The Study of Effecting Factors on Cement Wafer Board Manufacturing*1

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Cement Wafer Board 製造에 미치는 影響因子에 관한 硏究*1

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요 약

木質 Cement board製造를 위하여 지금까지 톱밥, 木片 및 木毛(excelsior)가 사용되어 왔으나, Wafer를 사용한 製品은 아직 開發되지 않고 있는 실정이다. 따라서, 本 硏究는 Cement wafer board를 壓力別, Wafer 길이別, Cement와 木材의 配合比別, Wafer 排列別로 製造하여 그 影響因子를 調査하고 이에 따른 製品의 物理的, 機械的 性質을 究明하고자 實施하였으며 다음과 같은 結論을 얻었다.

1. Cement Wafer board 製品의 적정壓力은 30kg/cm^{2}이었고, 30kg/cm^2 以上의 압에서는 board의 기계적 성질에 나쁜 영향을 미쳤다.
2. Cement와 木材의 配合比가 2 : 1을 넘을 경우에는 board의 성질에 나쁜 영향을 끼쳤다.
3. 한쪽 方向으로 Cement-Wafer가 배열된 조건에서 제조된 CWB가 최고의 曲强度를 나타내었다.
4. CWB의 曲强度는 다른 木質 Cement board보다 높은 값을 나타내었으나 剝離强度에 있어서는 목편 Cement board보다 약간 낮은 값을 나타내었다.
5. CWB의 難燃性 試驗은 難燃3級을 만족시켰다.

1. INTRODUCTION

The petroleum-based synthetic binders, such as phenolic and urea-formaldehyde, have become costly items in the processing of wood panel products. One of the alternative is the use of mineral binder—portland cement. Cement is a low cost binder and is plentiful in this country. Cement Wafer Board (CWB) will offer an application of using cement as a binder in wood panel products. There is a Cement Excelsior Board (CEB) that is being produced commercially. CEB was first used in Europe primarily as termo-insulating material in housing. CEB offer dimensional stability, structural capability, thermal insulating, and fire-retardant characteristics. It has been successfully used as roof decking, ceiling, and wall panels. But CEB has problem of uneven distribution that creates ununiform properties. For getting rid of this phenomenon, wafer was selected as a raw material that is shorter than excelsior in length.

Wood is an organic material, and when used in

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various forms as an aggregate in cement water mixture presents certain unfavorable reactions to the setting of the mixture [2,4,5,6,8,10,21]. Sandermann found starches, tannins, sugars, and certain phenols to be inhibitory. Lignosulfonic and hydroxylated carboxylic acids are used commercially as retarders of cement setting. The inhibitory effect of various organic compounds can be neutralized or minimized by the addition of various chemical substances in the mixture. Christensan and Lyneis [4] noted that calcium chloride solutions of 1.0 to 3.0 percent are necessary to neutralize the effects of 0.1 percent sugar on the setting time. According to Kleinlogel[10] more than 4 percent calcium chloride into the mixture reduces strength of the concrete. Using the calcium chloride is to expedite the cement hydration[1]. Shmidt[17] reported that the inhibitory effect of sugar can be minimized by addition of 4 to 5 percent aqueous aluminum sulfate into the cement mixture.

A preliminary study indicated that wood-cement composite board made from wood slivers, sawdust, and cement had a higher mechanical strength when the cement to wood ratio was increased from 3/4 to 3/2[14]. For checking out appropriate cement to wood ratio, cement-wood was mixed with ratio of 1.5:1, 2:1, and 2.5:1 (oven-dry weight basis).

There is no information about the price of wafer, so excelsior price is taken to compare with that of wafer. A ton of southern pine excelsior currently costs $135, while a ton of portland cement costs only $53 (Cement Products 1984). Obviously, the use of more cement and less wood can reduce the manufacturing cost.

In the U.S standard industry practice, a constant pressure of 28kg/cm^2 is applied to the material. As there is no published literature about optimum pressure, three conditions were practiced to check out proper pressure–20kg/cm^2, 30kg/cm^2, and 40kg/cm^2.

When layering the mixture, three arrangements were taken to investigate which one has best properties.

Three different wafer length ranges–3.00 to 5.00 centimeters, 5.00 to 7.00 centimeters, and 7.00 to 9.00 centimeters were taken to find out the appropriate wafer length.

This study was undertaken to investigate the effecting factors on CWB manufacturing, the physiomechanical properties of CWB (tests according to KS F3104), and the fire retardant characteristics (tests according to KS F2271).

2. PROCEDURE

2.1 Material

A 48-year-old red pine tree was used in this study. It was cut in late summer to minimize the content of sugar[3]. Since the type and percentage of inhibitory organic substances in wood vary between sapwood and heartwood, this additional factor was eliminated by mixing it. The wafer was approximately 0.05 to 0.07 centimeters thick, 1.00 to 2.00 centimeters wide. The average moisture content of wafer for this study was about 13 percent (based on oven-dry weight basis).

The cement used in this study was type I portland cement confirmed to KSL5201-1A specifications. Sodium silicate and calcium chloride were diluted with water to 2 percent and 3 percent solutions (weight basis), respectively, before being added to the mixer.

2.2 Manufacturing Process

The process for manufacturing of CWB is shown in Figure 1. Wafer was coated with 2 percent sodium silicate solution. To adequately coat the wafer proper amount of sodium silicate solution was taken and kneaded with wafer to every treatment instead dipping the wafer into a dip tank. Proper amount of sodium silicate solution means that taken sodium silicate solution makes 130 percent moisture content of wafer (ovendry weight basis)[14]. The coated wafer was dumped into the mixer. In the meantime, a predetermined weight of cement was added to the wafer in the mixer. Water was added to achieve a consistent mixture. Calcium chloride, 3 percent based on cement weight, is added to accelerate the cement hydration[4].

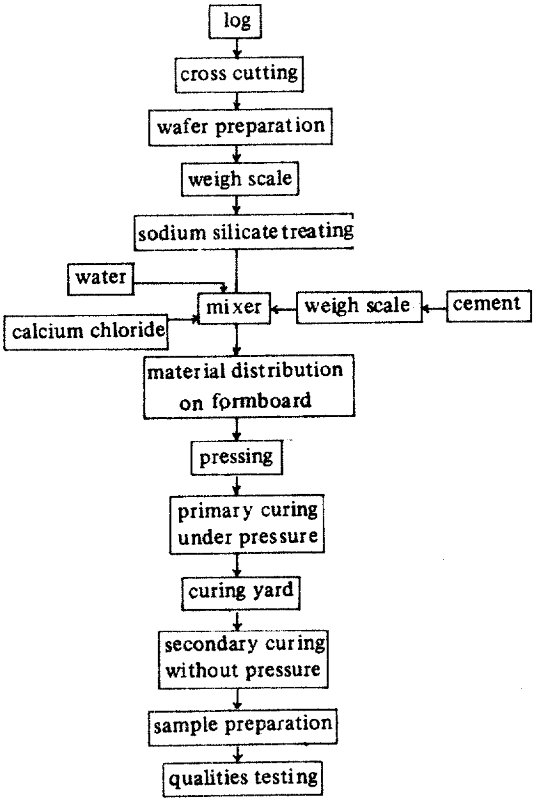


Figure 1. Experimental procedure of cement wafer board.

The mixed material is distributed on the formboard (high density phenolic coated plywood). The boards were initially cured under pressure for 24 hours and stripped out for a final cure of 4 weeks.

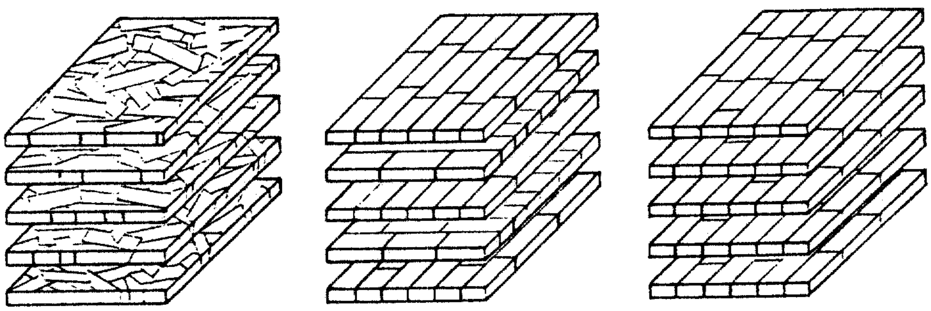
2.3 Formation Methods of Cement-Wafer Mixture

As discribed earlier, three arrangements were taken to investigate which one has best properties. These are illustrate in Figure 2.

3. RESULTS AND DISCUSSION

3.1 Determination of the Appropriate Pressure

The physical and mechanical properties (MOR, MOE, internal bonding strength, specific gravity, moisture content, and water absorption) of CWB



(a) (b) (c)

Figure 2. Cement-wafer mixture formation by three arrangement methods.

(a) Randomised direction. (b) Aligned direction. (c) Cross direction.

made at three pressures are presented in Table 1.

The MOR and IBS (internal bonding strength) according to the pressures on the randomized and cross direction are illustrated in Figure 3 and Figure 4, respectively. Cement to wood ratio and wafer length are constants–2:1 for cement to wood ratio and 5-7cm for wafer length. On the pressure of 30kg/cm^2, MOR and MOE showed utmost values. The pressure of 40kg/cm^2 had an adverse effect on mechanical properties (MOR, MOE, and IBS) of CWB. We can consider that there are two major reasons for this phenomenon. First, the higher pressure was applied to the mat thus more water was extracted. It could defect cement hydration. Second, cement was squeezed out with water when higher pressure, 40kg/cm^2, was applied. It reduced cement amount. On this results, the pressure of 30kg/cm^2 was proper for CWB manufacturing. The IBS showed the same trend as MOR and MOE, but randomized direction had higher values than that of cross direction. This suggests that randomized distribution is recommended to improve the IBS. The uniform trends of physical properties on CWB could not be investigated because uneven voids distribution existed within the cement-wood mixture. Due to the large variations in property, a further improvement in mixture distribution is needed.

3.2 Determination of the Appropriate Length

The physical and mechanical properties of CWB made at three length ranges were listed in Table 2. The MOR and IBS according to the lengths on the randomized and cross direction are illustrated in Figure 5 and Figure 6, respectively. Pressure and cement to wood ratio are constants-30kg/cm^2 for pressure and 2:1 for cement to wood ratio.

The randomized and cross direction had

Table 1. Physical and mechanical properties of CWB made at three pressures [a]

Pressure (kg/cm^2)	Length (cm)	Cement to wood ratio	Direction	MOR (kg/cm^2)	MOE (kg/cm^2) (x 1,000)	IBS (kg/cm^2)	Specific gravity	M.C (%)	Water absorption (%)
20				141.46 (9.84)[b]	1045 (60)	2.69 (0.59)	1.12 (0.02)	14.35 (0.31)	12.52 (0.80)
30	5-7	2:1	Random	172.73 (32.42)	1298 (530)	2.49 (0.83)	1.19 (0.06)	13.48 (0.39)	13.18 (2.52)
40				137.73 (30.27)	773 (198)	2.29 (0.22)	1.19 (0.04)	14.05 (0.17)	13.15 (1.60)
20				159.77 (46.39)	1214 (516)	1.68 (0.30)	1.16 (0.04)	14.80 (0.91)	10.24 (0.77)
30	5-7	2:1	Cross	180.72 (22.49)	1455 (228)	2.48 (0.57)	1.17 (0.03)	13.93 (0.25)	14.37 (2.60)
40				140.53 (25.21)	902 (248)	1.70 (0.34)	1.17 (0.02)	13.88 (0.33)	16.03 (1.22)

a : Each value is the average of four specimens.

b : Numbers in parentheses indicate standard deviation.

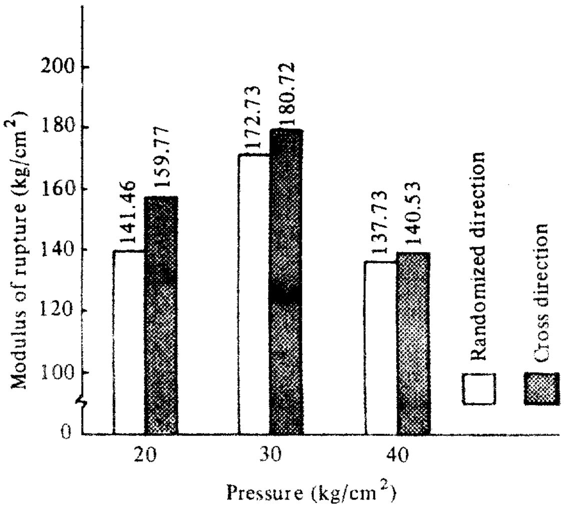


Figure 3. MOR according to the pressures on the randomized and cross direction.

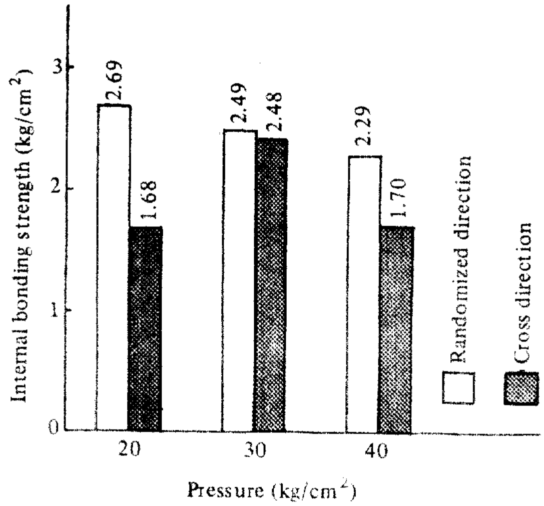


Figure 4. Internal bonding strength according to the pressures on the randomized and cross direction.

different trends in accordance with length. In randomized direction, 5-7cm had the highest value in MOR and MOE, but cross direction had it at 7-9cm. However, IBS had adverse value on the 7-9cm.

3.3 Determination of the Appropriate Cement/Wood Ratio.

The physical and mechanical properties of CWB made at three cement/wood ratios are listed

Table 2. Physical and mechanical properties of CWB made at three length ranges [a]

Pressure (kg/cm^2)	Length (cm)	Cement to wood ratio	Direction	MOR (kg/cm^2)	MOE (kg/cm^2) (x 1,000)	IBS (kg/cm^2)	Specific gravity	M.C (%)	Water absorption (%)
30	3-5	2:1	Random	126.81 (9.06)[b]	644 (117)	2.26 (0.42)	1.18 (0.07)	13.10 (0.14)	16.32 (0.86)
	5-7			172.73 (32.42)	1298 (530)	2.47 (0.83)	1.19 (0.06)	13.48 (0.39)	13.18 (2.52)
	7-9			113.95 (34.65)	640 (331)	1.88 (0.47)	1.14 (0.01)	14.20 (0.44)	15.99 (3.72)
30	3-5	2:1	Cross	205.72 (20.75)	1703 (381)	2.37 (0.73)	1.18 (0.08)	14.83 (0.29)	12.35 (1.94)
	5-7			180.72 (22.49)	1455 (228)	2.48 (0.57)	1.17 (0.03)	13.93 (0.25)	14.37 (2.60)
	7-9			247.58 (31.05)	2126 (474)	1.83 (0.67)	1.20 (0.03)	14.40 (0.12)	10.69 (1.05)

a : Each value is the average of four specimens.

b : Numbers in parentheses indicate standard deviation.

in Table 3. The MOR and IBS according to wafer direction on the randomized and cross direction are illustrated in Figure 7 and Figure 8, respectively. Pressure and wafer length are constants-30kg/cm^2 for pressure and 5-7cm for wafer length. At the ratio of 2:1, the bending properties of CWB were the best. It accorded with Lee[14). On the high cement to wood ratio, the compaction ratio (mat-to-board thickness ratio) was reduced. Consequently, lower bending properties were occured.

Table 3. Physical and mechanical properties of CWB made at three cement to wood ratios [a]

Pressure (kg/cm^2)	Length (cm)	Cement to wood ratio	Direction	MOR (kg/cm^2)	MOE (kg/cm^2) (x 1,000)	IBS (kg/cm^2)	Specific gravity	M.C (%)	Water absorption (%)
30	5-7	1.5:1	Random	116.06 (32.26)[b]	551 (315)	1.81 (0.53)	0.94 (0.09)	14.00 (0.49)	23.59 (5.45)
		2:1		172.73 (32.42)	1298 (530)	2.49 (0.83)	1.19 (0.06)	13.48 (0.39)	13.18 (2.52)
		2.5:1		140.71 (27.43)	935 (287)	1.52 (0.40)	1.21 (0.03)	14.65 (0.34)	15.18 (3.58)
30	5-7	1.5:1	Cross	158.40 (25.93)	983 (279)	2.34 (0.73)	1.05 (0.04)	14.70 (0.54)	13.93 (1.60)
		2:1		180.72 (22.49)	1455 (228)	2.48 (0.57)	1.17 (0.03)	13.93 (0.25)	14.37 (2.60)
		2.5:1		168.20 (28.38)	1467 (370)	2.62 (0.88)	1.27 (0.05)	13.50 (0.22)	12.51 (0.95)

a : Each value is the average of four specimens.
b : Numbers in parentheses indicate standard deviation.

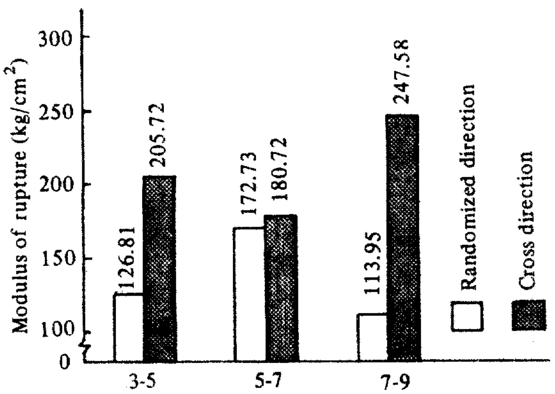


Figure 5. MOR according to the lengths on the randomized and cross direction.

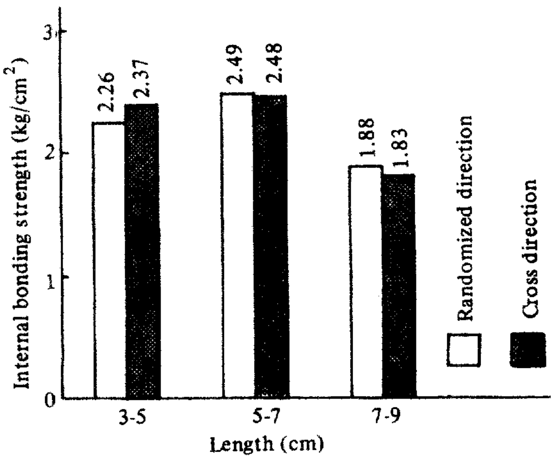


Figure 6. Internal bonding strength according to the lengths on the randomized and cross direction.

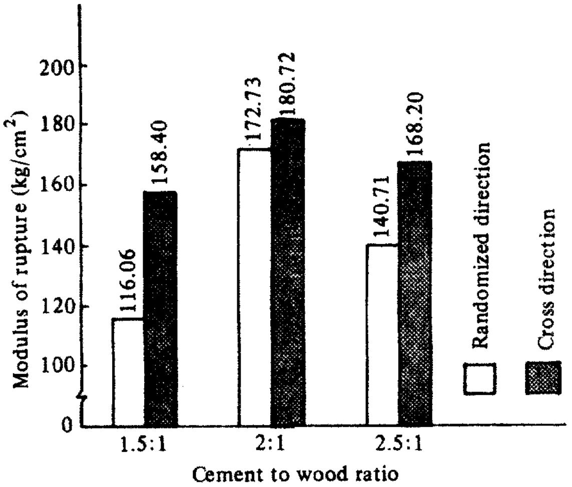


Figure 7. MOR according to the cement/wood ratios on the randomized and cross direction.

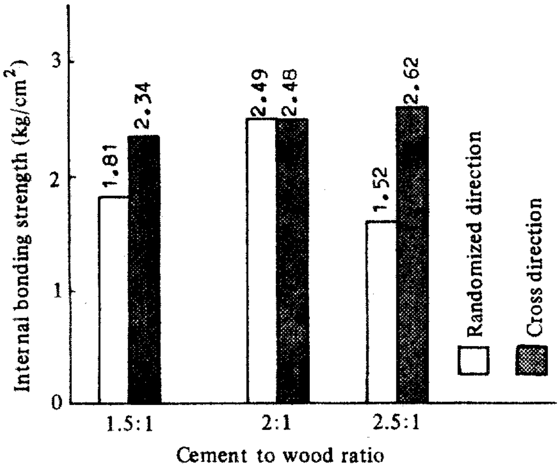


Figure 8. Internal bonding strength according to the cement/wood ratios on the randomized and cross direction.

3.4 Determination of the Appropriate Direction

The physical and mechanical properties of CWB made at three directions are listed in Table 4. MOR and IBS of CWB according to the wafer directions are illustrated in Figure 9 and Figure 10, respectively. Pressure, wafer length, and cement/wood ratio are constants-30kg/cm^2 for pressure, 5-7cm for wafer length, 2:1 for cement to wood ratio.

The direction of the aligned cement-wafer mixture of CWB provided much greater bending properties than those of randomized and cross direction wafers. It was in accord with theory of Masaki[9] and Maloney[19].

3.5 Comparison of Physical and Mechanical Properties of CWB, CEB, and CFB.

A comparison of physical and mechanical properties of CWB with other cement wood boards was necessary to find out which one is more

Table 4. Physical and mechanical properties of CWB made at tree directions [a]

Pressure (kg/cm^2)	Length (cm)	Cement to wood ratio	Direction	MOR (kg/cm^2)	MOE (kg/cm^2) (x 1,000)	IBS (kg/cm^2)	Specific gravity	M.C (%)	Water absorption (%)
30	5-7	2:1	Random	172.73 (32.42)[b]	1298 (530)	2.49 (0.83)	1.19 (0.06)	13.48 (0.39)	13.18 (2.52)
			Cross	180.72 (22.49)	1455 (228)	2.48 (0.57)	1.17 (0.03)	13.93 (0.25)	14.37 (2.60)
			Align	308.84 (48.52)	3898 (801)	1.72 (0.26)	1.15 (0.03)	14.15 (0.13)	11.06 (1.45)

a : Each value is the average of four specimens.
b : Numbers in parentheses indicate standard deviation.

appropriate for constructing material. This comparison is listed in Table 5.

The internal bonding strength of CWB showed slightly lower values than that of CFB. Its MOE and MOR, however, are much higher than those of CEB and CFB. For improving intensity of building construction, CWB is recommended.

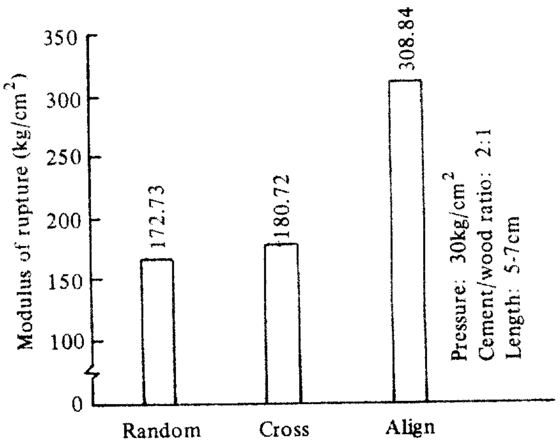


Figure 9. MOR of CWB according to the wafer direction.

3.6 Fire Retardant Characteristics

The investigation of fire retardant characteristics were carried out according to KSF2271.

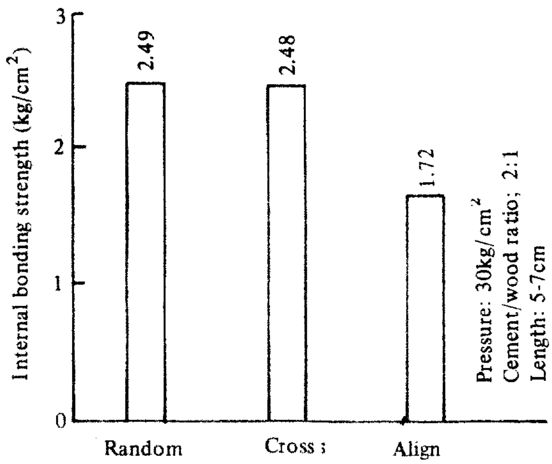


Figure 10. Internal bonding strength of CWB according to the wafer direction.

Exhaust temperature curves of asbestos and CWB are illustrated in Figure 11.

The surrounding are of exhaust temperature curve was 120 (°C x Min.). There were no damages on the other side of tested boards and the lingering frame time did not exceed 90 seconds. On these results, CWB satisfied 3rd class of fire retardant characteristics.

Table 5. Comparison of physical and mechanical properties of CWB, CEB, and CFB

Property	CWB[a]	CEB[b]	CFB[c]
MOE (1,000kg/cm²)	1298.50	9.45	–
MOR(kg/cm²)	172.73	26.25	73.71
Internal bonding strength (kg/cm²)	2.49	–	4.43
Specific gravity	1.19	0.65	1.15
Moisture content (%)	13.48	22.07	9.16
Water absorption (%)	13.18	22.07	–

a : The manufacturing condition of CWB; pressure: 30kg/cm², length: 5-7cm; cement to wood ratio: 2:1, direction: random.

b : Data cited from reference[14].

c : Data cited from reference[12]; These values were extracted from the best manufacturing conditions (flake pretreated with 2.0% NaOH).

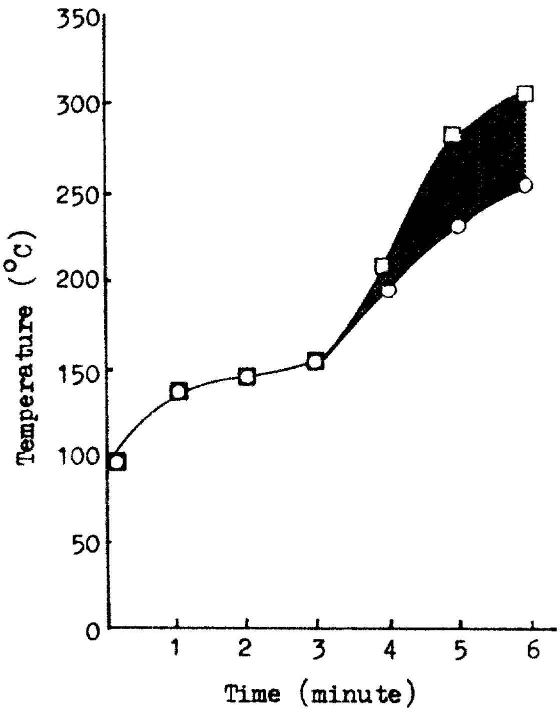


Figure 11. Fire retardant characteristic of CWB comparing to that of asbestos.

Exhaust temperature curve of asbestos. (○ – ○)
Exhaust temperature curve of CWB.* (□ – □)

*: The manufacturing condition of CWB; pressure: $30kg/cm^2$, length: 5-7cm, cement to wood ratio: 2:1, direction: random.

4. CONCLUSIONS

Sawdust, wood slivers, and excelsior are being used to produce cement wood board, but wafer has never used in the industry practice. The purpose of this study was to manufacture cement bonded wafer board, to investigate the effecting factors on CWB manufacturing. The physical and mechanical properties of CWB according to pressures, wafer lengths, cement/wood ratios, and wafer arrangements were evaluated. The results are as follows:

1. The pressure of $30kg/cm^2$ was proved as proper manufacturing condition for CWB. Pressure of more than $30kg/cm^2$ had adverse effects on mechanical properaties of CWB.
2. The increase of cement/wood ratio above 2/1 had an adverse effect on properties of CWB.
3. Aligned direction of cement-wafer mixture had the highest values on bending properties of CWB.
4. The bending properties of CWB were much higher than those of other cement wood boards. Its internal bonding strength, however, is slightly lower than that reported by the manufacturer for cement flake board.
5. CWB satisfied 3rd class of fire retardant characteristics.

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