EFFECT OF CEMENT/WOOD RATIOS AND WOOD STORAGE CONDITIONS ON HYDRATION TEMPERATURE, HYDRATION TIME, AND COMPRESSIVE STRENGTH OF WOOD-CEMENT MIXTURES

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ABSTRACT

This study investigated the effect of cement/wood ratios and wood storage conditions on hydration temperature, hydration time, and compressive strength of wood-cement mixtures made from six wood species: southern pine, white oak, southern red oak, yellow-poplar, sweetgum, and hickory. Cement/wood ratios varied from 13/1 to 4/1. Wood storage conditions consisted of air-dried and cold-stored wood. Results indicate that hydration temperature was drastically reduced, hydration time was prolonged, and compressive strength was reduced as cement/wood ratio was decreased. This effect was more pronounced for hardwood species and at lower cement/wood ratios. Cold storage of wood slightly increased hydration temperature and shortened hydration time of white oak and sweetgum but did not have any beneficial effect on the other four species. Results also indicate that mixtures with high cement/wood ratios used traditionally in laboratory for research purposes may not truly reflect the wood-cement compatibility at lower cement/wood ratios used in commercial production.

Keywords: Cement/wood ratio, air-dried and cold-stored wood, southern pine, white oak, southern red oak, yellow-poplar, sweetgum, hickory, hydration temperature, hydration time, compressive strength, Portland cement, calcium chloride, cylindrical compression sample.

INTRODUCTION

Mineral-bonded wood products were initially developed in Europe nearly half a century ago. The first product was magnesite-bonded light-weight wood wool (excelsior) board, which was later modified to adopt Portland cement as a binder. Currently, cement-bonded excelsior boards are produced in the United States and some other countries for roof decking and wall paneling applications. This product

TABLE 1. *Maximum hydration temperature (°C) of 6 wood-cement mixtures at 5 different cement/wood ratios.*[1]

Species		Cement/wood ratio				
		13/1	10/1	7/1	5/1	4/1
		°C				
Southern pine	Air-dried	66.8	61.1	54.0	43.4	38.7
	Cold-stored	66.7	60.9	53.4	45.0	38.4
White oak	Air-dried	61.7	55.9	44.0	35.0	30.9
	Cold-stored	66.7	61.0	52.5	40.8	30.1
Red oak	Air-dried	64.2	56.7	44.9	32.5	26.7
	Cold-stored	65.9	55.1	46.0	30.0	—[2]
Yellow-poplar	Air-dried	65.0	56.7	44.8	35.0	—
	Cold-stored	65.0	55.9	43.4	30.0	—
Sweetgum	Air-dried	63.4	55.0	42.5	26.7	—
	Cold-stored	65.9	57.6	48.4	36.0	—
Hickory	Air-dried	59.3	52.6	39.2	30.9	—
	Cold-stored	62.5	54.1	39.2	28.4	—

[1] Each value is the average of 3 samples.
[2] — designates that temperature did not rise above room temperature of 25 C within 96 hours of observation.

has good acoustic and fire resistance properties, but its strength and thermal insulation capabilities are only moderate (Lee 1984, 1985).

In the early 1950s, an American firm (Elmendorf, Inc. 1954) obtained several patents on cement-bonded wood particleboard which was made from wood particles, planer shavings, and cement. The density and strength of this product were very high in comparison with excelsior board. Its resistance to fire, fungi, weathering, and its dimensional stability were excellent. Since that time, researchers have attempted to identify suitable wood species and select effective additives and treatments to improve this product (Biblis and Lo 1968; Liu and Moslemi 1985; Moslemi et al. 1983; Moslemi and Lim 1984).

Past research on wood-cement compatibility has typically been carried out in the laboratory using mixtures with high cement/wood ratio of 13.3/1 (Weatherwax 1964, 1967). This ratio is far above that used in commercial production, and the high cement/wood ratio can overshadow the effect of species and treatments on hydration characteristics, especially when an effective additive is added to the mixture (Lee and Hong 1986). The purpose of this study was to investigate the effect of cement/wood ratios on hydration temperature, hydration time, and compressive strength of wood-cement mixtures.

MATERIALS AND METHODS

Six species of wood tested in this study were: southern pine (loblolly pine), white oak, southern red oak, yellow-poplar, sweetgum, and hickory. Two trees from each species, approximately 9 inches in diameter at breast height, were felled, debarked, and cut into bolts 24 inches in length. One half of the bolts were sawn into 1-inch-thick boards and air-dried in the summer for 2 months. Planer shavings produced from these boards were refined in a Wiley mill so that only the material passing through a 20-mesh screen and remaining on a 40-mesh screen

TABLE 2. *Time (h) required to reach maximum temperature of 6 wood-cement mixtures at 5 different cement/wood ratios.*[1]

Species		Cement/wood ratio				
		13/1	10/1	7/1	5/1	4/1
		hours				
Southern pine	Air-dried	2.4	2.8	3.7	4.8	6.2
	Cold-stored	2.8	3.7	4.4	6.4	9.6
White oak	Air-dried	3.9	5.9	11.6	25.2	31.7
	Cold-stored	3.5	5.0	6.8	11.1	15.6
Red oak	Air-dried	3.6	5.6	11.3	25.3	61.6
	Cold-stored	3.9	8.3	12.2	30.0	—[2]
Yellow-poplar	Air-dried	3.5	5.4	9.4	20.4	—
	Cold-stored	3.4	5.9	7.9	27.9	—
Sweetgum	Air-dried	4.1	7.3	15.1	38.5	—
	Cold-stored	3.9	4.6	8.2	10.7	—
Hickory	Air-dried	4.7	6.4	27.9	38.3	—
	Cold-stored	4.0	6.6	33.4	80.9	—

[1] Each value is the average of 3 samples.
[2] — designates that temperature did not rise above room temperature of 25 C within 96 hours of observation.

was used in this experiment. The other half of the bolts were stored in a cooler at a temperature of approximately 45 F for 2 months to simulate the winter storage condition in the southern USA. The cold-stored bolts were then sawn and reduced to shavings in the same manner as the air-dried wood.

Type I Portland cement (500 grams) and an appropriate amount of wood shavings were weighed to constitute the following cement/wood ratios (oven-dry weight basis): 13/1, 10/1, 7/1, 5/1, and 4/1. The amount of water used for mixing was

TABLE 3. *Compressive strength (psi) at 14 days curing age of 6 wood-cement mixtures at different cement/wood ratios.*[1]

Species		Cement/wood ratio				
		13/1	10/1	7/1	5/1	4/1
		psi				
Southern pine	Air-dried	3,332	2,552	1,732	954	691
	Cold-stored	3,666	2,844	1,873	934	647
White oak	Air-dried	4,329	3,528	2,154	1,106	709
	Cold-stored	4,340	3,332	2,122	1,044	614
Red oak	Air-dried	4,239	3,332	2,032	1,094	459
	Cold-stored	4,515	3,236	1,931	836	—[2]
Yellow-poplar	Air-dried	3,528	2,610	1,547	985	—
	Cold-stored	3,968	2,775	1,281	754	—
Sweetgum	Air-dried	3,650	2,801	1,594	764	—
	Cold-stored	3,830	2,844	1,798	912	—
Hickory	Air-dried	4,361	3,507	1,693	1,120	—
	Cold-stored	4,653	3,629	1,367	546	—

[1] Each value is the average of 3 samples.
[2] Compression test was not conducted.

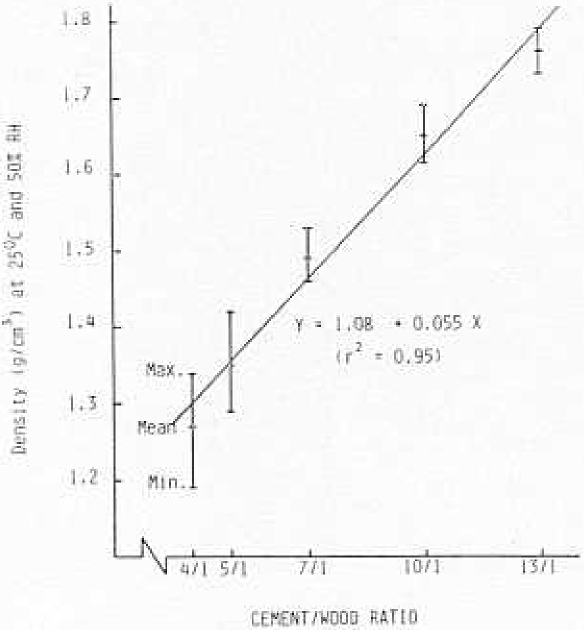

FIG. 1. Density of compression samples made of cement-wood mixtures at various cement/wood ratios.

2.7 milliliters per gram of wood (oven-dry basis) and 0.25 milliliter per gram of cement (Weatherwax 1964, 1967). Water came from 3 different sources: water in the wood, water in the calcium chloride solution, and added water. Three percent solid content calcium chloride (based on cement weight) in liquid form was added to each mixture. Since calcium chloride has been proven to be an effective and economical accelerator for cement hydration, it has been adopted widely in the wood-cement board industry.

The wood-cement mixture was then tamped into a cylinder mold, and one cylindrical compression sample was made (ASTM 1983). From the remaining mixture, 350 grams were placed in a styrofoam cup, which was then placed in a 2-quart thermal jar for hydration time and temperature measurements (Lee and Hong 1986). The sample was kept in the mold without pressure for 24 hours or until its respective temperature sample reached the maximum temperature, whichever was longer. Temperature recording was discontinued if no change was observed in 4 days.

After the removal of the compression sample from the mold, it was placed in a conditioning chamber at 25 C and 50% relative humidity for curing. The sample was later tested in compression at the age of 14 days, and compressive strength was calculated from maximum load and cross-sectional area of sample. Each test for hydration and strength was repeated 3 times.

RESULTS AND DISCUSSION

Maximum hydration temperatures of wood-cement mixtures, including 6 species at 5 cement/wood ratios, are listed in Table 1. Without exception, hydration

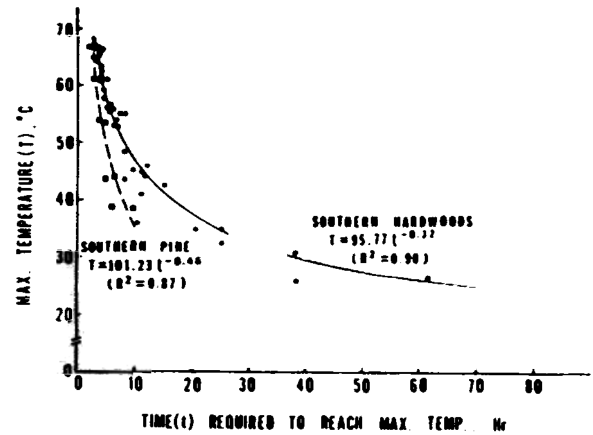

FIG. 2. Relationships between maximum hydration temperature and time required to reach maximum temperature of wood-cement mixtures (combined data from air-dried and cold-stored wood).

temperatures were drastically reduced when cement/wood ratios were decreased. Temperature reduction was due to the increase of wood (an inhibitory material) and the decrease of cement (a bonding and heat generating material), coupled with the reduced amount of calcium chloride. This reduction was greater for hardwood species than for southern pine. At cement/wood ratio of 4/1, yellow-poplar, sweetgum, and hickory did not reach a hydration temperature above 25 C (room temperature), while southern pine, white oak, and air-dried red oak did rise above room temperature. Cold storage of wood slightly improved the hydration temperatures of white oak and sweetgum, but did not significantly affect the hydration temperatures of the other four species.

Hydration time (time required to reach maximum hydration temperature) was drastically prolonged as cement/wood ratios were decreased, especially for hardwood species (Table 2). At cement/wood ratio of 4/1, all hardwood species failed to gain temperature within 96 hours, except white oak and air-dried red oak. Cold storage of wood generally prolonged the hydration time, but white oak and sweetgum had much shorter hydration times when the wood was cold-stored. Significant differences in hydration times between southern pine and hardwood species, at lower cement/wood ratios, indicate that hardwood species will require different processing techniques when used as raw materials for wood-cement board.

As shown in Fig. 1, density of the compression sample is linearly proportional to the cement/wood ratio. Wood species has very little effect on the density of wood-cement mixture. Compressive strengths of wood-cement mixtures were expressed in pounds per square inch (psi) and are listed in Table 3. Compressive strengths of wood-cement mixtures were significantly reduced as cement/wood ratios were decreased. This can be attributed to the reduced density. Despite the lower hydration temperature and longer hydration time, most mixtures with hardwood species had equal or higher compressive strength than southern pine at 14 days' curing age. For instance, at cement/wood ratio of 5/1, white oak and some air-dried hardwood species (red oak, yellow-poplar, and hickory) had greater strength than southern pine. However, at cement/wood ratio of 4/1, only air-

TABLE 4. *Percentage changes of maximum hydration temperature, hydration time, and compressive strength of wood-cement mixtures for each one part decrease in cement/wood ratios (combined data from air-dried and cold-stored wood).*

Species	Cement/wood ratio ranges			
	13/1–10/1	10/1–7/1	7/1–5/1	5/1–4/1
	Maximum hydration temperature change (%)			
Southern pine	−2.9	−4.0	−8.9	−12.8
Hardwoods	−4.2	−6.9	−13.5	−20.5
	Hydration time change (%)			
Southern pine	7.7	8.9	18.3	39.5
Hardwoods	19.6	34.1	59.3	62.3
	Compressive strength change (%)			
Southern pine	−7.7	−11.1	−23.8	−29.2
Hardwoods	−8.0	−15.7	−23.8	−44.1

dried white oak had strength equal to pine. These results indicate that a cement/wood ratio of approximately 5/1 was the lowest at which southern hardwood-cement mixtures can be cured naturally without heating or pressing.

In general, mixtures made of cold-stored wood were stronger than those made of air-dried wood at higher cement/wood ratios. But, at lower cement/wood ratios, mixtures with air-dried wood had higher compressive strength than those with cold-stored wood. This confirms that at lower cement/wood ratios used in commercial production, air-dried wood is more compatible with cement than cold-stored wood.

As shown in Fig. 2, the time required to reach maximum temperature was inversely proportional to the maximum temperature reached. A faster reaction time and higher hydration temperature occurred at higher cement/wood ratios. Southern pine and hardwood followed two different hydration time-temperature curves. Southern pine-cement mixtures required much shorter time than hardwood-cement mixtures to reach the same maximum hydration temperature.

A further analysis (Table 4) indicates that changing cement/wood ratios had a much greater impact on hardwoods than southern pine. This impact is more significant when cement/wood ratios approach the lower end. This implies that research results from mixtures with high cement/wood ratio may not apply directly to those commercial processes using lower cement/wood ratio.

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