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Temperature and moisture effects on selected properties of wood fiber-cement composites

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Abstract

The effects of moisture cycling on the dimensional stability and temperature cycling on the compressive strength of treated wood fiber-cement composites were investigated. The Kraft softwood fibers and the hardwood fibers were treated with an aqueous acrylic emulsion or alkylalkoxysilane prior to manufacturing into wood fiber-cement composites. Moisture cycling results indicated that the treated fiber-cement composites were more resistant to deterioration than the neat cement specimens. The alkylalkoxysilane-treated fiber-cement composites resisted deterioration more than the acrylic emulsion-treated fiber-cement composites. Treated hardwood fiber-cement composites were more resistant than the treated Kraft fiber-cement composites. The effects of temperature cycling on the compressive strength values produced similar results. The treated fibers were more resistant to deterioration than the neat cement. The alkylalkoxysilane-treated Kraft and hardwood fiber-cement composites had higher average compressive strength values than the acrylic emulsion-treated wood fiber-cement composites.

Keywords: Composite; Fiber reinforcement; Organic materials; Compressive strength; Freezing and thawing

Wood fibers including secondary wood fibers from recycled paper may be used as a reinforcement in cement. Secondary wood fibers from recycled paper are wood fibers that have been processed through a pulping digester. This process removed most of the hemicelluloses and lignin from the cell wall leaving the cell wall comprised primarily of cellulose. Wood cells are hollow and will collapse after most of the hemicelluloses and lignin are removed from the cell wall. These flattened tubes are laid randomly on top of each other during the papermaking process.

Soroushian and colleagues [1] reported that the flexural strength and flexural toughness values of wood fiber-cement composites were higher than the values for neat cement. In the same study, Soroushian and colleagues [1] also reported that the dynamic modulus of elasticity of neat cement decreased with increasing freezing and thawing cycles while the dynamic moduli of wood fiber-cement composites remained relatively constant over the same number of freezing and thawing cycles. In another study, Souroushian and Marikunte [2] reported the effects of moisture on the flexural properties of wood fiber-cement composites. Flexural strength decreased with increasing moisture contents. In addition, dry wood fiber-cement specimens appeared to have lower flexural toughness values compared to wet wood fiber-cement specimens [2].

Processing secondary wood fibers into fibrous form is helpful in dispersing the wood fiber in the cement matrix [3–7]. Enhanced reinforcement of some mechanical properties by the wood fibers has been reported by chemically modifying the surface of the wood fiber [4] using high shear mixing [5] and modifying the cement matrix [5]. Limited dimensional stability test results have been reported by Lin et al. [4]. This paper will discuss the effects of long-term moisture cycling on dimensional stability and long-term temperature cycling on the compressive strength of wood fiber-cement composites.

1. Experimental

1.1. Materials

Wood fibers used in this study were bleached hardwood pulp and unbleached recycled Kraft paper. Kraft paper is composed of softwood fibers. The cement used in this study was ASTM Type III Portland cement obtained from Lehigh

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Portland Cement Company (Allentown, PA, USA). The composition of the cement is given in Table 1.

1.2. Preparation of fibers

Recycled paper fiber or pulp was soaked in deionized water at room temperature for more than 0.5 hours before mechanical beating in water using a Valley Beater. The wood fibers were then removed from the slurry by vacuum filtration. The fibers were separated by milling after air drying. The wood fibers were passed through a 2-mm screen after milling.

The pulp fibers that were treated with the aqueous chemicals were placed in the aqueous solution (by volume) of diluted chemicals for 30 min. After treating the surface of the wood fibers, the fibers were air-dried and milled so that they passed a 2-mm screen.

1.3. Wood fiber-cement specimen preparation

The pulp fibers and treated pulp-fiber composites used in this study were as follows:

1. neat cement = Type III Portland cement
2. untreated newspaper mixed with Type III Portland cement [8]
3. untreated hardwood pulp mixed with Type III Portland cement
4. untreated Kraft pulp mixed with Type III Portland cement
5. A60-Kraft pulp = 10% aqueous solution (by volume) of Acryl-60 (acrylic emulsion)-treated Kraft pulp fiber (Thoro System Products, Miami, FL, USA) mixed with Type III Portland cement
6. A60-Hardwood pulp = 10% aqueous solution (by volume) of Acryl-60 (acrylic emulsion)-treated hardwood pulp fiber mixed with Type III Portland cement
7. Si-Kraft pulp = 10% aqueous solution (by volume) of Environseal 20 (solution of 20% alkylalkoxysilane in water)-treated Kraft pulp fiber (Hydrozo, Inc., Lincoln, NE, USA) mixed with Type III Portland cement
8. Si-Hardwood pulp = 10% aqueous solution (by volume) of Environseal 20 (solution of 20% alkylalkoxysilane in water)-treated hardwood pulp fiber mixed with Type III Portland cement

The basic formulations for the specimens used in this study are given in Table 2. The wood-fiber composites were mixed using a paddle-style mixer. The dry wood fibers and cement with superplasticizer (Borem 100 HMP, supplied by Boremco Specialty Chemicals, Fall River, ME, USA) were mixed in a plastic bag. The dry mixture of wood fibers and cement was placed into the bowl containing the water for 0.5 min. The paste was mixed at slow speed for 0.5 min. After scraping down the sides of the bowl and the mixing paddle, the paste was mixed at medium speed for another 2.5 min.

Samples were molded in the size required for testing (e.g., 25.4 by 25.4 by 127-mm bars for dimensional stability and 50.8-mm cubes for compression specimens) demolded after 1 day of curing, and continuously cured (at ~100% relative humidity, ambient pressure, and temperature 25°C for 28 days) prior to temperature cycling and testing.

Table 1
Chemical composition of the cement used in this study

Chemical	ASTM Type III Portland cement (weight %)
CaO	63.70
SiO_2	20.70
Al_2O_3	4.20
MgO	3.70
Fe_2O_3	2.30
SO_3	3.10
Na_2O equivalent	0.57
LOI	2.00
Insoluble residue	0.20

1.4. Property measurements

The effects of moisture cycling on dimensional stability included measuring the length, width, thickness, and weight of three specimens at each treatment level after each wet or dry cycle. The wet/dry cycling started from the wet condition (7 days in 25°C water) to the dry condition (7 days in 40°C, 29–34% relative humidity). The dimensional stability property measurements were obtained every 7 days until each specimen broke due to expansion and contraction.

The effects of temperature cycling on the compressive strength of three specimens were measured for each treatment level at selected temperature cycle intervals. The compressive test specimens were submerged in water and placed in the temperature-controlled chamber. The chamber used for the temperature cycling was heated and cooled from approximately 1 to −1 to 1°C over approximately 5 h. The compression testing was conducted at intervals of 36 cycles up to 252 cycles. At the appropriate interval, three samples of each treatment were removed and tested according to ASTM C 109 (Compressive Strength of Hydraulic Cement Mortars). A total of 105 samples (seven cycle intervals, five treatments, and three replications) were prepared and tested to failure.

2. Discussion

2.1. Effects of moisture cycling

Lin [8] reported on the dimensional properties of newspaper, untreated Kraft fiber, and untreated hardwood fiber-cement composites subjected to wet-dry cycles. All of the untreated

Table 2
Basic specimen formulations

Sample	Weight % of components			
	Cement	Deionized water	Fibers	Superplasticizer
Control*	75.99	21.25	0.00	2.76
WFRC**	67.38	25.13	4.24	3.25

* W/C = 0.28, ** W/C = 0.37.

wood fibers provided improved dimensional properties in the wood fiber-cement composites compared to the neat cement (Type III Portland cement) specimens. Lin [8] reported that the neat cement specimens failed after five cycles, Kraft and hardwood fiber-cement composites failed after 22 cycles and newspaper fiber-cement composites failed after 25 cycles. Lin [8] stated that the effect of reinforcement by the wood fibers in the cement matrix might be attributed to: (1) the flexible and conformable structure of wood fibers allowing the fibers to accommodate a certain amount of volume change, which reduced the stress on the cement matrix, and (2) successful bridging role as the wood fiber restricted further extension of a crack in the cement matrix under stress from wet-dry cycles.

This study was designed to determine if additional enhancement of the dimensional properties could be achieved by modifying the surface of the Kraft and hardwood fibers. Wood fiber-cement composite specimens were prepared for wet-dry cycling using Type III Portland cement as controls and wood fiber-cement composite specimens using hardwood fibers treated with 10% (by volume) aqueous acrylic emulsion, hardwood fibers treated with 10% (by volume) aqueous alkylalkoxysilane, Kraft fibers treated with 10% (by volume) aqueous acrylic emulsion, and Kraft fibers treated with 10% (by volume) aqueous alkyalkoxysilane in a matrix of Type III Portland cement.

Table 3 lists a summary of the moisture-cycling data for the controls (neat cement) and the acrylic- and silane-treated Kraft and hardwood fiber-cement composites. Percent change in the length and volume along with the average number of wet-dry cycles at failure is given.

Analysis of variance statistical techniques were used to determine if the treatments had a significant effect on the average number of cycles at failure. The level of significance was set at 0.025. The data reported by Lin [8] for untreated newspaper, untreated Kraft, and untreated hardwood-cement composites were also included in the statistical analysis. The average number of cycles at failure for all of the treatments were significantly different from each other except for the untreated Kraft compared to the untreated hardwood-cement composites reported by Lin [8].

Comparing the average percent change in length at failure for both fiber treatments using the aqueous acrylic emulsion and the aqueous alkylalkoxysilane indicated that the dimensional properties of the wood fiber-cement composites improved relative to the untreated wood fiber-cement composites [8] and the controls. The average percent linear dimension change at failure was lower for the treated wood fibers at failure than the untreated wood fiber composites and the average control value. This indicated that the treated wood fibers stabilized the dimension changes in the wood fiber-cement composites.

The Kraft and hardwood fibers treated with aqueous acrylic emulsion produced similar average percent linear expansion data at failure to the untreated Kraft and hardwood fiber composite values reported by Lin [8]. However, the average number of cycles at failure increased from 22 for the untreated wood fiber composites to 34 and 44 for the aqueous acrylic emulsion-treated Kraft and hardwood fiber-cement composites, respectively. The acrylic treatment of the wood fibers enhanced the ability of the composite to withstand wet-dry cycling.

The aqueous alkylalkoxysilane treatment of the Kraft and hardwood fibers produced enhanced results over the untreated fiber [8] and the aqueous acrylic-treated fiber composites. The average percent length change at failure was lowest for the alkylalkoxysilane-treated Kraft and hardwood fiber-cement composites compared to the controls, untreated Kraft and hardwood fiber-cement composites [8], and the acrylic Kraft and hardwood-cement composites. In addition the average number of cycles at failure was the highest for the alkylalkoxysilane-treated fibers. This indicated that the

Table 3
Summary of moisture effects from wet-dry cycling on the dimensional properties of wood fiber-cement composites

Wood fiber-cement composites	Average number of wet-dry cycles at failure	Average percent change at failure			
		Dry cycle		Wet cycle	
		Length	Volume	Length	Volume
Controls[1]	10	0.88	1.87	0.93	2.71
UNT K[2]	22	0.41	NA[8]	0.69	NA
UNT H[3]	22	0.15	NA	0.39	NA
A60-K[4]	29	0.01	0.24	0.08	0.48
A60-H[5]	44	0.62	0.69	0.55	1.58
Si-K[6]	50	0.09	0.27	−0.13	−0.36
Si-H[7]	55	−0.07	−0.33	−0.17	−0.30

[1] Type III Portland cement controls, [2] UNT K is untreated Kraft fiber and Type III Portland cement, [3] UNT H is untreated hardwood fiber and Type III Portland cement, [4] A60-H is 10% (by volume) Acryl 60 (acrylic emulsion)-treated Kraft fiber and Type III Portland cement, [5] A60-H is 10% (by volume) Acryl 60 (acrylic emulsion)-treated hardwood fiber and Type III Portland cement, [6] Si-K is 10 (by volume) alkylalkoxysilane-treated Kraft fiber and Type III Portland cement, [7] Si-H is 10 (by volume) alkylalkoxysilane-treated hardwood fiber and Type III Portland cement, [8] NA means data not available.

Table 4
Summary of the average compressive strength values for wood-cement composites after thawing-freezing-thawing temperature cycling

	Average compressive strength (MPa)						
Wood fiber-cement specimens	36 cycles	72 cycles	108 cycles	144 cycles	180 cycles	216 cycles	252 cycles
Controls[1]	45.4	52.9	50.0	42.6	24.4	27.5	22.7
A60-K[2]	49.0	47.3	53.0	41.4	45.8	36.7	41.1
A60-H[3]	42.3	44.4	44.3	48.3	52.0	50.2	42.2
Si-K[4]	55.0	52.9	51.1	57.1	52.2	52.9	54.2
Si-H[5]	52.5	52.4	54.1	53.0	57.0	53.5	53.5

[1] Type III portland cement, [2] A60-K is an aqueous solution of 10% (by volume) Acryl 60 (acrylic emulsion)-treated Kraft fiber and Type III portland cement composites, [3] A60-H is an aqueous solution of 10% (by volume) Acryl 60 (acrylic emulsion)-treated hardwood fiber and Type III portland cement, [4] Si-K is an aqueous solution of 10% (by volume) alkylalkoxysilane-treated Kraft fiber and Type III portland cement, [5] Si-H is an aqueous solution of 10% (by volume) alkylalkoxysilane-treated hardwood fiber and Type III portland cement.

alkylalkoxysilane treatment was the most effective treatment used in this study for reinforcement of the cement matrix.

2.2. Effects of temperature cycling

The effects of temperature cycling through freezing and thawing are presented in Table 4. The purpose of this part of the study was to determine, within the relative confines of the test procedures, the effects that the treated wood fibers had on the compressive strength retention of the composites. The treated wood fibers were used because results from the moisture-cycling study indicated that the treated fibers produced more durable composites than the untreated wood fibers.

Table 4 listed the average compressive strength values for the controls (neat cement) and the aqueous acrylic- and silane-treated Kraft and hardwood fiber-cement composites. The average compressive strength values for three specimens tested after intervals of 36 temperature cycles are listed in Table 4 for the specimen groups.

Analysis of variance statistical tests were used to determine any significant differences within a specimen treatment group for each 36 temperature-cycling interval and for comparing treatments at each 36-cycle interval. The level of significance was set at 0.025.

The average compressive strength values for the neat cement specimens were not significantly different after 36, 72, 108, and 144 cycles and after 180, 216, and 252 cycles. However, the average compressive strength values for the neat cement specimens after 36, 72 108, and 144 cycles were significantly different from the average compressive strength values after 180, 216, and 252 cycles. The Type III portland cement controls average compressive strength values decreased at 180 cycles. At the end of 252 cycles the average compressive strength values were about half of the average compressive strength values prior to 144 cycles. These results indicated that considerable deterioration occurred in the microstructure of the cement, possibly associated with the development of microcracks and associated extension of these cracks due to the freeze-thaw cycling.

The statistical analysis of the acrylic-treated Kraft cement specimen average compressive strength values indicated that the average compressive strength value at 216 cycles was significantly different from all the other means. The average compressive strength was lower at 216 cycles than at all the other test intervals. However, the average compressive strength value at 252 cycles was not significantly different from all the other intervals, except at 216 cycles. The lack of a lower average compressive strength value at 252 cycles negates any definition of a deterioration trend in the data set. In addition, the average compressive strength value at 216 cycles was only about 11% lower than at 252 cycles.

Statistical analysis of the acrylic-treated hardwood fiber-cement specimens indicated that the average compressive strength values were not significantly different at all intervals. This indicated that the specimens did not deteriorate.

The alkylalkoxysilane-treated Kraft and hardwood fiber specimens had higher average compressive strength value at all cycles compared to the acrylic-treated Kraft and hardwood-cement specimens. Statistical analysis indicated that there were no significant differences at all intervals for the alkylalkoxysilane-treated Kraft and hardwood fiber-cement specimens.

Statistical analysis of the average compressive strength values for each of the treatments at each interval indicated that the neat specimen values were not significantly different from the other treatments at 36, 72, 108, and 144 intervals. At 180, 216, and 252 intervals the average compressive strength values were significantly different from the means for the treated fiber specimens. Additional significant differences among treatments were identified in some of the intervals, but there were no consistent trends with any treated wood fiber-cement composites across all intervals.

Soroushian and colleagues [1] reported that the flexural strength of wood fiber-cement composites deteriorated slower than the neat cement specimens after repeated wet-dry cycling. They also reported that the relative dynamic modulus of elasticity of the wood fiber-cement specimens resisted deterioration better than the neat cement specimens after repeated freezing and thawing [1]. Their results support the findings reported here for the effects of temperature cycling on compressive strength.

Comparing the treated hardwood fiber-cement composite results with the treated Kraft fiber-cement composite results indicated that the treated hardwood fibers might be better at retarding microcrack growth than the treated Kraft softwood fibers.

Kraft and hardwood-fiber weights were constant for each test specimen. One possible reason for the hardwood fibers being more effective is that the number of hardwood fibers per unit weight is greater than the number of Kraft softwood fibers for the same unit weight. This is related to the fact that softwood fibers are longer than hardwood fibers [9]. Hence, more hardwood fibers were available to bridge microcracks and retard crack extension than Kraft softwood fibers in the wood fiber-cement composites.

3. Conclusion

Moisture-cycling effects on the dimensional stability of wood fiber-cement composites were investigated. Lin [8] reported that untreated newspaper, untreated Kraft, and untreated hardwood-cement composites resisted moisture cycling more than neat cement composites. This study used Kraft and hardwood fibers treated with an aqueous acrylic emulsion or aqueous alkylalkoxysilane prior to manufacturing the wood fiber-cement composites. The treated fiber-cement composites were more resistant to moisture-cycling deterioration than the neat cement and the untreated fiber-cement composites reported by Lin [8]. The alkylalkoxysilane-treated fibers were more resistant to moisture-cycling deterioration than the acrylic emulsion-treated fiber-cement composites. The treated hardwood fibers had more moisture resistance than the treated Kraft fiber composites within each treatment.

The effects of temperature cycling on the average compressive strength values produced somewhat similar results to the moisture cycling. The acrylic emulsion and the alkylalkoxysilane-treated fiber composites resisted deterioration compared to the neat cement specimens. The alkylalkoxysilane-treated fibers had higher average compressive strength values compared to the neat and acrylic emulsion-treated specimens.

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