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Effects of fiber surface treatments on mechanical properties of wood fiber–cement composites

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Abstract

The purpose of this research was to determine the effects of treated and untreated hardwood, kraft softwood, and newsprint wood fibers on the 7- and 28-day bending strength, compressive strength, and toughness values for wood fiber–cement composites. Untreated and acrylic- or alkylalkoxysilane-treated hardwood, kraft softwood, and newsprint wood fibers used in wood fiber–cement composites resulted in different bending and compression properties. Fiber characteristics along with different chemical treatments influenced the composite properties. Compressive strength decreased for all fiber types and chemical treatments compared to the neat cement controls. Bending strength values for all wood fiber composites were higher than the neat cement control specimens. Both the acrylic emulsion and alkylalkoxysilane treatments provided improvements in the bending strength values compared to the untreated wood fiber–cement composites. Toughness improved for all untreated and treated wood fiber–cement composites compared to the neat cement control specimens. The toughness value results for the alkylalkoxysilane-treated fibers were similar to the acrylic-treated fibers in that the longer kraft softwood fiber–cement composites had the highest toughness values compared to the other fiber groups.

Keywords: Composite; Fiber reinforcement; Fiber surface treatments; Organic materials; Compressive strength; Bending properties

1. Introduction

Secondary wood fibers from recycled paper and paper products have been used with cement to form wood fiber–cement composites. Chemically processed hardwood and softwood wood fibers used in paper manufacturing have most of the hemicelluloses and lignin removed from the cell wall [1,2]. The primary chemical constituent remaining in the cell wall is cellulose. The pulp yield (ovendry mass out/ovendry mass in × 100) after chemical pulping is around 50%. During the papermaking process the chemically pulped hollow wood cell wall collapses and the wood cells are hydrogen bonded together as they are randomly laid on top of each other. Newsprint is produced with a different process and the pulp yield is over 90%. This process leaves most of the hemicelluloses, lignin, and cellulose intact in the wood cell walls. During the manufacture of newsprint the wood cells do not collapse, resulting in a relatively weak paper product. Secondary wood fibers from paper manufactured with chemically pulped hardwoods and softwoods are different from hardwood and softwood secondary fibers from newsprint. Composites manufactured with wood fibers from different sources of paper will have some variation in properties related to each fiber type used in the composite [1].

Soroushian et al. [3] reported that the flexural strength and toughness values for wood fiber–cement composites were higher than the values for neat cement. They also reported that as the freeze–thaw cycles increased the dynamic modulus of elasticity remained relatively constant for wood fiber–cement composites while decreasing for neat cement specimens. Soroushian and Marikunte [4] reported that flexural strength decreased with increasing moisture contents in wood fiber–cement composites and that dry wood fiber–cement composites appeared to have lower toughness values than wet wood fiber–cement composites.

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Dispersion of wood fibers in the cement matrix is helped by first processing the secondary wood fibers into a fibrous form [5–10]. Mechanical properties have been enhanced by chemically modifying the wood fiber surface [6], using high shear mixing [7] and modifying the cement matrix [7].

Limited dimensional stability properties of wood fiber–cement composites have been reported by Lin et al. [6]. In another study, Blankenhorn et al. [10] reported on the moisture effects from wet–dry cycling on the dimensional properties of acrylic-treated hardwood and kraft softwood wood fiber–cement composites. The controls were Type III Portland cement without any wood fibers. The control specimens failed after 10 wet–dry cycles. Specimens made with Type III Portland cement and untreated kraft or hardwood fibers failed after 22 wet–dry cycles. Treating the wood fibers with 10% (by volume) aqueous acrylic or alkylalkoxysilane solution improved the durability of the wood fiber–cement composites compared to the controls and the untreated wood fiber–cement composites. The average number of wet–dry cycles at failure for the acrylic-treated kraft wood fiber–cement composites and the acrylic-treated hardwood fiber–cement composites increased to 29 and 44, respectively [10]. The alkylalkoxysilane-treated kraft and hardwood fiber–cement composites required 50 or more cycles before failing [10].

The effects of temperature cycling (thaw–freeze–thaw) on the average compressive strength was reported for acrylic-treated kraft and acrylic-treated hardwood wood fiber–cement composites [10]. The statistical analysis of the Control Type III Portland cement (no wood fiber) specimen average compressive strength values indicated that the average compressive strength values from 36 to 144 cycles were significantly different from the values obtained between 180 and 252 cycles [10]. The average compressive strength values after 144 cycles were about half of the average compressive strength values prior to 144 cycles. However, a downward trend in the average compressive strength values was not evident in the Control cement data set. The statistical analysis of the acrylic-treated kraft fiber–cement composite average compressive strength values indicated that the average compressive strength value at 216 cycles was significantly different from all of the other average values. The statistical analysis of the acrylic-treated and alkylalkoxysilane-treated hardwood fiber–cement composites and alkylalkoxysilane-treated kraft fiber–cement composites indicated that the average compressive strength values were not significantly different at all temperature cycling intervals, indicating that the composite specimens did not deteriorate.

The data reported by Blankenhorn et al. [10] indicated that acrylic-treated and alkylalkoxysilane-treated kraft and hardwood fibers in wood fiber–cement composites improved the durability of the composite compared to nontreated wood fiber–cement composites. The treatment of the kraft and hardwood fibers improved the ability of the wood fiber–cement composites to withstand wet–dry cycling compared to the untreated wood fiber–cement composites and the controls (no wood fiber). The treated fibers also improved the ability of the composites to withstand temperature cycling compared to the controls.

The purpose of this research is to determine the effects of treated and untreated hardwood, kraft softwood, and newsprint wood fibers on the 7- and 28-day bending strength, compressive strength, and toughness values for wood fiber–cement composites. The wood fibers will be treated with selected solutions of acrylic and alkylalkoxysilane aqueous solutions prior to incorporation into the wood fiber–cement composites.

2. Experimental

2.1. Materials

Secondary wood fibers used in this study were bleached hardwood pulp, unbleached recycled kraft softwood paper bags, and recycled newsprint. Lehigh Portland Cement (Allentown, PA) provided the ASTM Type III Portland cement (Table 1) used in this study.

2.2. Preparation of fibers

The wood fibers were placed in deionized water at room temperature for more than 30 h at room temperature before mechanical beating in water using a Valley Beater. Vacuum filtration was used to remove the wood fibers from the slurry. The fibers were air dried and separated by milling so that the wood fibers passed through a 2-mm screen.

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

2.3. Wood fiber–cement specimen preparation

The untreated and treated wood fiber–cement composites used in this study were as follows:

Table 1
Chemical composition of the cement used in this study

Chemical	ASTM Type III Portland cement (oxide equivalent weight percent)
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. Controls = neat cement made with Type III Portland cement,
2. untreated hardwood fiber mixed with Type III Portland cement,
3. untreated kraft softwood fiber mixed with Type III Portland cement,
4. untreated newsprint mixed with Type III Portland cement,
5. acrylic-treated hardwood fiber = aqueous acrylic (Acryl-60, Thoro System Products, Miami, FL, USA) emulsion solution (1%, 10%, 30%, 60%, and 100% by volume) -treated hardwood fiber mixed with Type III Portland cement,
6. acrylic-treated kraft softwood fiber = aqueous acrylic (Acryl-60, Thoro System Products) emulsion solution (1%, 10%, 30%, 60%, and 100% by volume) -treated kraft softwood fiber mixed with Type III Portland cement,
7. acrylic-treated newsprint = aqueous acrylic (Acryl-60, Thoro System Products) emulsion solution (1%, 10%, 30%, 60%, and 100% by volume) -treated newsprint fiber mixed with Type III Portland cement,
8. alkylalkoxysilane-treated hardwood fiber = aqueous alkylalkoxysilane (Environseal 20, Hydrozo, Lincoln, NE, USA) solution (1%, 10%, 30%, 60%, and 100% by volume) -treated hardwood fiber mixed with Type III Portland cement,
9. alkylalkoxysilane-treated kraft softwood fiber = aqueous alkylalkoxysilane (Environseal 20, Hydrozo) solution (1%, 10%, 30%, 60%, and 100% by volume) -treated kraft softwood fiber mixed with Type III Portland cement, and
10. alkylalkoxysilane-treated newsprint fiber = aqueous alkylalkoxysilane (Environseal 20, Hydrozo) solution (1%, 10%, 30%, 60%, and 100% by volume) -treated newsprint fiber mixed with Type III Portland cement.

The test specimen composite formulations used in this study are given in Table 2. The wood fiber–cement composites were mixed using a paddle wheel mixer. The treated and untreated dry wood fibers and cement with superplasticizer (Borem 100 HMP, Boremco Specialty Chemicals, Fall River, ME) were first mixed in a plastic bag and placed in a bowl containing the measured amount of water for 0.5 min. The paste was mixed at a 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.

Specimens were molded into 25.4 × 25.4 × 127-mm bars for flexural testing and 50.8-mm cubes for compression testing. The specimens were demolded after 1 day of curing and continuously cured (~ 100% relative humidity, ambient pressure and 25°C temperature for 7 or 28 days prior to mechanical property testing.

Table 2
Basic specimen formulations

	Weight percent of components			
Sample	Cement	Deionized water	Fibers	Superplasticizer
Control[a]	75.99	21.25	0.00	2.76
WFRC[b]	67.38	25.13	4.24	3.25

[a] W/C = 0.28.
[b] W/C = 0.37.

2.4. Property measurements

Mechanical properties determined after 7 and 28 days curing were bending strength, toughness, and compressive strength. Flexural and compressive tests followed the procedures in ASTM C-78 and C-109, respectively. Three replications were used for each property and treatment level tested. All specimens were tested in the saturated condition immediately after being removed from the curing chamber. The level of significance was set at .05 for the statistical tests.

3. Discussion

3.1. Effects of the acrylic emulsion treatments

The average bending strength values for the controls, untreated, and acrylic-treated wood fiber–cement composites are listed in Table 3. After both 7 and 28 days curing, all the average bending strength values for the untreated and acrylic-treated hardwood and kraft softwood–cement composite specimens were higher than the control specimen values. The newsprint–cement composite specimens average bending strength values were higher than the controls except for the 100% (as-received) acrylic treatments. Untreated and acrylic-treated hardwood and untreated kraft softwood fibers produced specimens with the highest average bending strength values. The increased bending strength values for the wood fiber–cement specimens support the results reported by Soroushian et al. [3].

All of the untreated wood fiber–cement composites average bending strength values were significantly different from the controls for both the 7- and 28-day curing cycles. Acrylic-treated fibers had significantly different average bending strength values compared to the controls for both curing cycles, particularly at the lower acrylic treatment levels. The lower acrylic treatment levels up to 30% produced the highest average bending strength values. As the acrylic treatment levels approach the 100% solution (as-received), the average bending strength values were comparable to the controls. Acrylic treatment did not enhance the average bending strength values compared to the untreated fibers for all the wood fibers and both curing cycles.

Table 3
Summary of the average bending strength values[a] for wood fiber–cement composites

	Average bending strength (MPa)					
	Hardwood		Kraft softwood		Newsprint	
Specimens	7 days	28 days	7 days	28 days	7 days	28 days
Controls[b]	4.3	3.0	4.3	3.0	4.3	3.0
UNT[c]	10.1 A	11.3 A	10.0 A	11.5 A	9.0 A	9.6 A
Acrylic treatment[d]						
1%	10.9 A	10.3 A	8.2 Aa	9.5 A	8.3 A	10.3 A
10%	10.0 A	11.2 A	10.8 A	9.6 A	8.9 A	9.1 A
30%	9.4 A	10.2 A	9.1 A	9.1 A	8.5 A	8.1 Aa
60%	8.5 A	9.4 A	9.0 A	7.3 Aa	6.2	6.6 Aa
100%	4.8 a	5.6 Aa	5.7 a	6.7 Aa	3.6	3.8 a
Alkylalkoxysilane treatment[e]						
1%	9.3 A	10.9 A	10.0 A	11.3 A	8.0 A	10.0 A
10%	10.8 A	12.5 A	9.6 A	10.9 A	8.9 A	9.2 A
30%	9.8 A	10.3 A	10.3 A	10.0 A	8.5 A	10.0 A
60%	9.6 A	10.0 A	9.3 A	10.0 A	8.3 A	8.3 A
100%	9.9 A	9.6 Aa	8.5 A	10.0 A	7.8 A	6.9 Aa

[a] Average of three specimens. A capital letter "A" indicates significant difference between controls and untreated or treated fiber–cement composites. A lower case letter "a" indicates significant difference between untreated and treated fiber–cement composites.

[b] Type III Portland cement controls without wood fiber.

[c] Untreated wood fiber and Type III Portland cement.

[d] Wood fibers treated with selected Acryl 60 acrylic aqueous solutions (percent by volume) prior to composite preparation. As-received aqueous solution is listed as 100%.

[e] As-received solution is about 20% alkylalkoxysilane and is listed in this table as 100% treated. Wood fibers treated with selected alkylalkoxysilane aqueous solutions (percent by volume) prior to composite preparation. As-received aqueous solution is listed as 100%.

Average toughness value (Table 4) trends after acrylic treatment were different from the average bending strength trends. All of the untreated and acrylic-treated wood fiber–cement composites were significantly different and had a higher, in some specimen groups more than two times higher, average toughness value compared to the neat cement control values. Newsprint treated with 60% acrylic solution was the only acrylic-treated wood fiber that was significantly different from the untreated fibers after 28 days curing. The average toughness for the 60% acrylic-treated newsprint was 28% higher than the average toughness for the untreated newsprint fiber–cement composites. In general, the highest average toughness values were associated with acrylic treatments above 30%. As previously stated, the average bending strength values were higher for acrylic treatments up to 30% compared to bending strength values for wood fibers treated with higher concentrations of acrylic emulsion. The data indicated that average toughness values increased with acrylic treatments of wood fibers at higher concentrations while the average bending strength values decreased. It must be pointed out that even though the average bending strength values decreased for acrylic treatments at the highest concentrations, the average bending strength values were still generally greater than the values for the neat cement control specimens. The untreated and acrylic-treated kraft softwood fiber–cement composites had the highest average toughness values compared to the other wood fiber composites.

All of the untreated and acrylic-treated wood fiber–cement composites were significantly different and had lower average compressive strength values (Table 5) compared to the neat cement control specimens. Acrylic treatment of the wood fibers improved the average compressive strength values compared to the untreated wood fiber–cement composites, particularly the newsprint composites. After 7 and 28 days curing, the acrylic-treated hardwood and newsprint fibers up to 60% by volume produced similar average compressive strength values compared to the untreated wood fiber specimens. The acrylic-treated kraft softwood fibers produced similar average compressive strength values compared to the untreated kraft softwood fiber–cement composites up to 30% treatment levels. Above the 30% treatment level the average compressive strength values decreased compared to the untreated values. The as-received acrylic emulsion, used as the 100% treatment level, resulted in lowest average compressive strength values for all three types of treated and untreated wood fibers.

A unit weight of kraft softwood fibers has a lower number of fibers than hardwood and newsprint fibers because the average fiber length is larger than the hard-

Table 4
Summary of the average toughness[a] (normalized) for wood fiber–cement composites

	Average toughness (normalized)					
	Hardwood		Kraft softwood		Newsprint	
Specimens	7 days	28 days	7 days	28 days	7 days	28 days
Controls[b]	1.00	1.00	1.00	1.00	1.00	1.00
UNT[c]	1.75 A	1.87 A	2.16 A	2.40 A	1.79 A	1.48 A
Acrylic treatment[d]						
1%	1.60 A	1.90 A	2.26 A	2.64 A	1.40 Aa	1.14
10%	1.92 A	1.73 A	1.86 Aa	1.88 A	2.71 Aa	1.24 A
30%	1.88 A	1.62 A	2.02 A	2.41 A	1.42 Aa	1.42 A
60%	1.95 A	2.02 A	2.55 Aa	2.03 A	1.89 A	1.89 Aa
100%	2.08 A	2.08 A	2.62 Aa	2.20 A	2.49 Aa	1.79 A
Alkylalkoxysilane treatment[e]						
1%	1.96 A	1.64 A	1.75 Aa	1.84 A	1.45 Aa	1.11 a
10%	1.79 A	1.57 Aa	2.02 A	1.82 A	1.42 Aa	1.10 a
30%	1.91 A	1.72 A	2.52 A	2.64 A	1.39 Aa	1.13 a
60%	1.76 A	1.84 A	2.36 A	2.29 A	1.79 A	1.58 A
100%	2.02 A	1.60 A	2.49 A	1.96 A	1.71 A	1.61 A

[a] Average of three specimens. A capital letter "A" indicates significant difference between controls and untreated or treated fiber–cement composites. A lower case letter "a" indicates significant difference between untreated and treated fiber–cement composites.

[b] Type III Portland cement controls without wood fiber.

[c] Untreated wood fiber and Type III Portland cement.

[d] Wood fibers treated with selected Acryl 60 acrylic aqueous solutions (percent by volume) prior to composite preparation. As-received aqueous solution is listed as 100%.

[e] As-received solution is about 20% alkylalkoxysilane and is listed in this table as 100% treated. Wood fibers treated with selected alkylalkoxysilane aqueous solutions (percent by volume) prior to composite preparation. As-received aqueous solution is listed as 100%.

Table 5
Summary of the average compressive strength values[a] for wood fiber–cement composites

	Average compressive strength (MPa)					
	Hardwood		Kraft softwood		Newsprint	
Specimens	7 days	28 days	7 days	28 days	7 days	28 days
Controls[b]	91.2	95.5	91.2	95.5	91.2	95.5
UNT[c]	40.8 A	49.3 A	38.6 A	51.7 A	36.3 A	43.3 A
Acrylic treatment[d]						
1%	46.3 Aa	55.5 A	33.7 A	51.0 A	40.3 A	44.0 A
10%	40.6 A	51.5 A	39.9 A	49.2 A	42.2 A	51.2 Aa
30%	46.5 Aa	54.3 A	39.4 A	49.9 A	41.2 A	47.8 Aa
60%	39.9 A	52.3 A	34.9 Aa	42.2 Aa	37.4 A	47.7 Aa
100%	25.2 Aa	34.5 Aa	26.5 Aa	28.6 Aa	22.5 Aa	23.1 Aa
Alkylalkoxysilane treatment[e]						
1%	44.8 Aa	49.8 A	39.5 A	53.3 A	38.5 A	45.4 A
10%	40.3 A	51.6 A	43.6 Aa	55.8 Aa	39.1 A	51.6 Aa
30%	46.7 Aa	54.0 A	37.6 A	54.7 Aa	35.2 A	49.0 Aa
60%	42.9 Aa	53.2 A	38.2 A	46.6 Aa	40.9 A	36.6 A
100%	42.8 Aa	47.3 A	43.6 Aa	46.3 Aa	38.8 A	43.3 A

[a] Average of three specimens. A capital letter "A" indicates significant difference between controls and untreated or treated fiber–cement composites. A lower case letter "a" indicates significant difference between untreated and treated fiber–cement composites.

[b] Type III Portland cement controls without wood fiber.

[c] Untreated wood fiber and Type III Portland cement.

[d] Wood fibers treated with selected Acryl 60 acrylic aqueous solutions (percent by volume) prior to composite preparation. As-received aqueous solution is listed as 100%.

[e] As-received solution is about 20% alkylalkoxysilane and is listed in this table as 100% treated. Wood fibers treated with selected alkylalkoxysilane aqueous solutions (percent by volume) prior to composite preparation. As-received aqueous solution is listed as 100%.

wood and newsprint fibers [1,2]. This resulted in fewer kraft softwood wood fibers available to enhance the compressive strength compared to the hardwood and newsprint fibers. Kraft softwood fibers being longer may have contributed more to increasing the toughness values because each fiber has more surface area in contact with the cement matrix than each of the shorter hardwood and newsprint fibers. On the other hand, the shorter hardwood fibers have a higher number of fibers per unit weight or volume available to bridge the developing microcracks inside the composite matrix and may have contributed to increasing the bending strength compared to the kraft softwood fiber–cement composite. The larger number of shorter hardwood and newsprint fibers per unit weight may also have contributed to improving the compressive strength values for up to 60% acrylic treatment solutions compared to the untreated hardwood and newsprint wood fiber–cement composites, respectively.

3.2. *Effects of alkylalkoxysilane treatments*

All the untreated and alkylalkoxysilane-treated wood fiber–cement composites specimens were significantly different and had higher average bending strength values (Table 3) after 7 and 28 days curing than the neat cement control specimens. The data presented here supports the higher bending strength values for wood fiber–cement composites reported by Soroushian et al. [3]. The alkylalkoxysilane-treated hardwood, kraft softwood, and newsprint wood fibers had bending strength values that were not significantly different and were comparable to the untreated wood fiber–cement composites within each fiber group up to about the 60% alkylalkoxysilane treatment level. Wood fibers treated with the as-received alkylalkoxysilane solution, 100% treatment level, had the lowest bending strength values within each fiber group after 28 days of curing. However, the bending strength values for the 100% alkylalkoxysilane-treated hardwood, kraft softwood, and newsprint fiber–cement composites were between two and three times higher than the neat cement controls after 28 days of curing. Comparison of the acrylic-treated and alkylalkoxysilane-treated fibers indicated that the alkylalkoxysilane-treated fibers produced slightly higher bending strength values within more of the treatment levels used with each fiber type.

The average toughness values (Table 4) were significantly different for all the untreated and alkylalkoxysilane-treated hardwood, kraft softwood, and newsprint fiber–cement composites and were higher than the values for the neat cement controls. Treated and untreated kraft softwood fiber–cement composites had the highest toughness values of all the specimen groups. Toughness values for the 7-day cured specimens were similar or slightly lower than the 28-day cured specimens within each alkylalkoxysilane treatment group. The toughness value results for the alkylalkoxysilane-treated fibers were similar to the acrylic-treated fibers in that the longer kraft softwood fiber–cement composites had the highest toughness values compared to the other fiber groups.

All of the wood fiber–cement composites had significantly different values and had lower average compressive strength values (Table 5) than the neat cement control specimens. In addition, the alkylalkoxysilane treatments had somewhat higher average compressive strength values compared to the untreated wood fiber–cement specimens. After 7 and 28 days of curing the untreated and alkylalkoxysilane-treated hardwood and kraft softwood specimens had slightly higher compressive strength values than the newsprint specimens. Within each fiber type and treatment level, the alkylalkoxysilane-treated fibers had slightly higher compressive strength values than the acrylic-treated fibers. The wood fibers treated with the as-received (100%) alkylalkoxysilane solution after 28 days curing had average compressive strength values that were 5%, 13%, and 5% lower than the 1% treated hardwood, kraft softwood, and newsprint fibers, respectively. The acrylic treatment produced more drastic results. After 28 days of curing as-received (100%) acrylic treatment had average compressive strength values that were 38%, 44%, and 47% lower than the 1% treated hardwood, kraft softwood, and newsprint fibers, respectively. This result indicated that the compressive strength reduction observed for the as-received acrylic-treated wood fibers was somewhat negated using alkylalkoxysilane as the treatment solution.

The influence of fiber length for the alkylalkoxysilane-treated fibers on the properties measured was only apparent in toughness. Kraft softwood fibers, with the longest average fibers, treated with alkylalkoxysilane had the highest toughness values of all the wood fiber–cement composites. Fiber length appeared to have little influence on the bending and compressive strength values. However, alkylalkoxysilane-treated hardwood and kraft softwood fiber–cement composites had slightly higher average bending strength values compared to the alkylalkoxysilane-treated newsprint fiber–cement composites. The major difference between the hardwood and kraft softwood fibers and the newsprint fibers was that the hardwood and kraft softwood fibers were comprised primarily of cellulose while the newsprint contains cellulose, hemicelluloses, and lignin. The implication being that alkylalkoxysilane is more compatible with cellulose than hemicellulose or lignin.

4. Conclusion

Untreated and acrylic- or alkylalkoxysilane-treated hardwood, kraft softwood, and newsprint wood fibers used in wood fiber–cement composites resulted in different bending and compression properties. Fiber characteristics along with the different chemical treatments influenced the composite properties.

Bending strength values for all wood fiber composites were higher than the neat cement control specimens. Both the acrylic emulsion and alkylalkoxysilane treatments provided improvements in the bending strength values compared to the untreated wood fiber–cement composites. The acrylic-treated fibers had average bending strength values comparable to those of the untreated fibers within each fiber type up to about the 30% acrylic treatment level. After 28 days of curing the acrylic treatment did not appear to enhance the average bending strength values compared to the untreated wood fiber–cement specimens within each fiber group. The data also indicated that acrylic treatment above the 30% level decreased the average bending strength values compared to the untreated fiber specimens. On the other hand, the shorter hardwood fibers treated with the acrylic emulsion have a higher number of fibers per unit weight or volume, compared to kraft softwood fibers, available to bridge the developing microcracks inside the composite matrix. This may have contributed to slightly higher bending strength values for the hardwood fiber–cement composites compared to the acrylic-treated kraft softwood fiber–cement composite.

Fiber length appeared to have little influence on the bending strength values for the alkylalkoxysilane-treated fibers. The alkylalkoxysilane-treated hardwood, kraft softwood, and newsprint wood fibers had bending strength values that were comparable to the untreated wood fiber–cement composites within each fiber group up to about the 60% alkylalkoxysilane treatment level. Wood fibers treated with the as-received alkylalkoxysilane solution, 100% treatment level, had the lowest bending strength values within each fiber group after 28 days of curing. However, alkylalkoxysilane-treated hardwood and kraft softwood fiber–cement composites had slightly higher average bending strength values compared to the alkylalkoxysilane-treated newsprint fiber–cement composites. Comparison of the acrylic-treated and alkylalkoxysilane-treated fibers indicated that the alkylalkoxysilane-treated fibers produced slightly higher bending strength values within a higher number of the treatment levels used with each fiber type than the acrylic treatments.

Toughness improved for all untreated and treated wood fiber–cement composites compared to the neat cement control specimens. In contrast to the bending strength results, acrylic emulsion and alkylalkoxysilane fiber treatments improved the toughness values compared to the untreated wood fiber–cement specimens. Kraft softwood fibers, with the longest average fiber length of the three fiber types, untreated and treated with alkylalkoxysilane had the highest toughness values of all the wood fiber–cement composites. The toughness value results for the alkylalkoxysilane-treated fibers were similar to the acrylic-treated fibers in that the longer kraft softwood fiber–cement composites had the highest toughness values compared to the other fiber groups. In general, the highest average toughness values were associated with acrylic treatments above 30% while the average bending strength values decreased.

Compressive strength decreased for all fiber types and chemical treatments compared to the neat cement controls. Fiber length appeared to have little influence on the compressive strength values for the alkylalkoxysilane-treated wood fiber–cement composites. However, the alkylalkoxysilane treatments produced slightly higher 28-day compressive strength values than the untreated fibers up to 30% treatment level. The acrylic treatments produced somewhat different results. Acrylic treatment of the wood fibers did not produce significantly different average compressive strength values compared to the untreated wood fiber–cement composites at treatments up to 30%, particularly for the hardwood and kraft fiber–cement composites. The shorter hardwood fibers have a higher number of fibers per unit weight or volume, compared to the longer kraft softwood fibers, available to bridge the developing microcracks inside the composite matrix contributing to increasing the bending strength compared to the kraft softwood fiber–cement composites. Newsprint fibers improved the compressive strength values for up to 60% acrylic treatment solutions compared to the untreated newsprint wood fiber–cement composites, respectively. However, wood fibers treated with the as-received (100%) alkylalkoxysilane solution after 28 days curing had average compressive strength values that were higher than the as-received acrylic emulsion-treated hardwood, kraft softwood, and newsprint fiber–cement composites, respectively. This result indicated that the compressive strength reduction observed for the as-received acrylic-treated wood fibers was somewhat negated using alkylalkoxysilane as the treatment solution.

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