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# Wood fiber surface treatment level effects on selected mechanical properties of wood fiber–cement composites

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**Abstract**

The objective of this study was to determine the effects of sodium (N) silicate, potassium (K) silicate, and silane (Si) treatment levels on newspaper and unbleached kraft fibers for enhancing selected mechanical properties of wood fiber–cement composites compared to untreated wood fiber–cement composites. Both wood fiber types were treated with selected aqueous solution strengths, air dried, and mixed with water and cement. The bending and compression properties of the specimens were determined after 28 days of hydration. Results of this study indicated that the aqueous chemical treatments of the wood fibers enhanced some of the mechanical properties of wood fiber–cement composites compared to the untreated wood fiber–cement composites. The enhancement depended on chemical treatment and wood fiber type. All three chemical treatments of newspaper fiber enhanced the normalized toughness values compared to the untreated newspaper fiber–cement composites. In addition, higher treatment levels using N silicate with newspaper fiber improved the compressive strength and bending modulus of the composites compared to the untreated newspaper fiber–cement composites. Kraft fiber treated with all three chemicals enhanced the compressive strength, bending modulus and bending strength compared to the untreated kraft fiber–cement composites. However, only silane-treated kraft fiber improved the normalized toughness values compared to the untreated kraft fiber–cement composites. The results of the study indicated that certain chemical treatments react better with different wood fiber types resulting in selected mechanical property enhancements.


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

## 1. Introduction

Cement is an alkaline inorganic composite containing surface hydroxyl groups [1,2]. Wood, in general, inhibits the setting of cement with hardwood fibers being the most inhibitory [3,4]. In addition to hardwood fibers being found to inhibit cement setting, Weatherwax and Tarkow [3] also found that heartwood was highly inhibitory during curing of cement. Wood extractives were found to adversely affect the exothermic hydration characteristics of Portland cement, which in turn affects the wood cement compatibility [5].

There are many chemical constituents in wood fiber, but the main inhibiter of cement hydration are sugars [6]. Inhibition of cement hydration occurs when the calcium silicate hydrate nucleation sites on the originally positively charged surfaces are poisoned by the sugar-acid anions [6,7].

Weatherwax and Tarkow [8] reported that decayed wood and bark are also inhibitors of cement setting. It has also been found by Sandermann et al. [9], that along with sugars, starches and tannins can be inhibitory to cement setting. Other extractives that cause problems in cement wood compatibility are resins and fatty acids, terpenes and terpenoids, simple sugars and salts [10].

The wood fiber surface is probably the most likely place to find the inhibitory effects to hydration taking place. For example, terpenes, resins, and fats on the surface have been found to reduce fiber cement interaction as would simple sugars that naturally move to the wood surface during drying [10].

The use of wood fibers and recycled paper fibers in cement composites has many advantages [11,12]. Wood fiber reinforced composites are easy to cast or mold into a

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desired shape, resistant to fire, as well as being resistant to harmful effects of sunlight, rain, and insects [13]. These composites also have low thermal conductivity, a great degree of processing flexibility, in addition to helping eliminate environmental pollution by recycling wood fiber. Another reason for interest in this area is the need to find alternatives to organic adhesives for bonding wood [14].

Some of the advantages wood fibers bring to cement fiber composites are availability, high tensile strength, relatively high modulus of elasticity, and the well-developed technology to easily extract the fibers from wood for use in the composites [15]. The main disadvantage is their vulnerability to chemical decomposition of certain wood chemical constituents in the alkaline cement environment.

Soroushian et al. [16] found that wood fiber reinforced cement composites performed better under freeze–thaw conditions compared to plain cement matrices. A concern of wood fiber reinforced cement is the long-term durability of the fibers in the cement. This was investigated using accelerated wetting–drying and hot water soaking conditions [17]. The accelerated wetting–drying showed only slight improvements in flexural strength of the fiber cement composites and also a slight improvement of flexural strength in hot water soaking.

Lee and Hong [13] and Blankenhorn et al. [18] used compressive strength as an indicator of wood fiber–cement compatibility. Lee and Hong [13] showed compressive strength to be linearly proportional to the maximum hydration temperature, but independent of hydration time. Blankenhorn et al. [18] indicated that as hydration time increased, compressive strength increases. A study examining the effects of cement/wood ratios and wood storage conditions on hydration temperature, hydration time, and compressive strength of fiber cement mixes concluded that as hydration temperature was drastically reduced, hydration time was prolonged [19]. The same study also concluded that compressive strength was reduced as the cement/wood ratio was decreased.

Moisture effects on flexural performance of wood fiber–cement composites showed, on a microstructural level, that high moisture contents tend to lower the fiber-to-matrix bond strength which leads to changes in failure mechanisms [20]. Moisture cycling reported by Blankenhorn et al. [21] showed treated wood fiber–cement composites were more resistant to deterioration than the neat cement samples. When adding wood fiber to a composite, extra water is needed to complete the mixing process; the need to find the proper amount of extra water to add is a key in developing a wood fiber–cement composite [18]. In 1986, Rowlands et al. [22] found that strength and stiffness are increased in both tension and flexure by adding fiber reinforcement.

The purposes of this study were to determine the ability of selected levels of aqueous inorganic compounds to enhance selected properties of wood fiber–cement composites made with treated recycled newspaper and kraft fibers and to compare those properties with the properties of composites made with untreated wood fibers. The compressive strength and bending properties were analyzed to determine the effects of the aqueous inorganic compound treatments.

## 2. Experimental

### 2.1. Materials

The two types of wood fibers used in this study were recycled newspaper and unbleached kraft softwood paper from recycled brown paper bags. The recycled newspaper is composed primarily of hardwood fibers with some softwood fibers. The kraft paper is composed of softwood fiber. Hardwood fibers are generally shorter in length and have a smaller diameter compared to softwood fibers [23].

Table 1 lists the chemical components in oxide equivalents of the ASTM Type III Portland cement [12] used for all mixes in this study. The oxide equivalent components of CaO, $SiO_2$, $Al_2O_3$, and $Fe_2O_3$ along with other minor chemical components react with water and go through hydration to form a rigid solid matrix composed of crystalline and amorphous hydrated compounds [11].

Neat cement specimens and untreated wood fiber–cement specimens were compared to treated wood fiber–cement specimens. The wood fiber treatment solution levels (percent by volume with 100% being the as received aqueous solution) were 0.25%, 0.50%, 0.75%, 1%, 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9%, and 10% for sodium (N) and potassium (K) silicate and 0.25%, 0.50%, 0.75%, 1%, 3%, 5%, 10%, 15%, 30%, 60%, and 100% for Silane 20 (Si).

Sodium (N) silicate, potassium (K) silicate, and Silane 20 (Si) aqueous inorganic compounds were used to modify the surface of the wood fibers. Sodium (N) and potassium (K) silicates in aqueous solutions (N and K silicate supplied by The PQ, Valley Forge, PA) have physical and chemical properties that are useful in bonding and coating applications. The silane was supplied by Harris Specialty Chemicals, Jacksonville, FL (now ChemRex, Shakopee, MN). The silane treatment is composed of alkylalkoxysilane, approximately 20%, in water and is not usually used as adhesives; rather they are used to modify gap-filling polymers to improve surface adhesion [24].

Table 1
Chemical composition of Portland Type III cement based on oxide equivalents [12]

| Chemical | Oxide equivalent weight (%) |
|---|---|
| CaO | 63.7 |
| $SiO_2$ | 20.7 |
| $Al_2O_3$ | 4.2 |
| MgO | 3.7 |
| $Fe_2O_3$ | 2.3 |
| $SO_3$ | 3.1 |
| $Na_2O$ equiv. | 0.57 |
| LOI | 2.0 |
| Insoluble residue | 0.2 |

The recycled wood fiber was prepared by soaking in deionized water at room temperature for more than 30 h before mechanical beating 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 they passed through a 2-mm screen.

Before the treatment of the fibers in the aqueous inorganic solutions, the fine wood particles were removed by placing the dry wood fiber in a cloth rag with openings comparable to a 200-mesh (0.053 mm) screen. Compressed air was forced into the cloth for 15 min to blow out the fines. After the fine wood particles were removed, the remaining fiber was weighed and used either as untreated or treated fiber.

Treatment of the wood fibers with the chemical aqueous solutions (percent of as-received aqueous solution by volume in deionized water with 100% being the as-received solution) was accomplished by placing the wood fibers in the diluted chemicals for 30 min. After chemically treating the wood fibers, they were air dried and milled so they passed a 2-mm screen.

The standard fiber weight used in the preparation of the test specimens was 0.20503 lb (93 g). A preliminary experiment established the treated fiber procedures. Wood fiber with the fines removed were used and weighed out to 0.2094 lb (95 g) and oven dried. The procedures consisted of weighing out 0.2094 lb (95 g) of untreated fiber and adding it to the aqueous inorganic chemical solution bath for the 30-min soak time. The fiber was then removed from the solution, drained, dried, and milled. The preliminary experiment was conducted using untreated fiber and 1%-, 5%-, and 10%-N-silicate-treated fiber. The untreated fibers were soaked in water for 30 min to simulate a treatment; this gave a true fiber weight without having to compensate for the added weight of the treatment for making the wood fiber composites. The wood fiber was air dried, weighed, and then oven dried and weighed again. At this point, the fiber was milled, after which it was weighed and oven dried. The fiber was scraped out of the mill to recover as much as possible. The preliminary experiment was repeated using three untreated controls and three different treatment levels. The result was an average loss of 0.0044 lb (2 g) of fiber during the treatment process. Hence, 0.2094 lb (95 g) of fiber was used during the aqueous chemical treatment process in order to obtain 0.2050 lb (93 g) for the test specimens.

The wet treated and untreated fiber batches were spread out on plastic sheets and air dried for about 24 h. At this point, the fiber was in hardened different size clumps and the fiber had to be separated for use in preparation of the samples. After separation, the fiber was placed directly into a sealable plastic bag for use when preparing the wood fiber–cement samples.

The samples were prepared following the steps in the ASTM C192/C 192M-98 standard. The neat cement mixes followed ASTM C192/C 192M-98 exactly while the fiber mixes altered the standard slightly since there are currently no provisions available for mixing fiber into cement. The formulations used for both the neat cement mixes and wood fiber mixes are in Table 2. Type III Portland cement (Capitol Cement, Martinsburg, WV) and Rheobuild 1000 plasticizer (Master Builders Technologies, Cleveland, OH) was used for all specimen formulations.

The composites were mixed in a paddle style mixer with the neat cement mix following ASTM C 305-94. In the fiber composite mix, the dry wood fiber and cement were mixed by hand in the plastic bag. The water and plasticizer were added to the mixing bowl. Then the cement/wood mixture was added to the bowl with the water/plasticizer mix and let soak for 30 s before mixing. The samples were then placed into molds in three layers with tamping of each layer forming three $50.76 \times 50.76$ mm ($2 \times 2$ in.) cubes and two $25.38 \times 25.38 \times 304.57$ mm ($1 \times 1 \times 12$ in.) bars. The molds and samples were placed in a humidity chamber at 126 °F (38 °C) for 24 h. At the end of the 24 h, the samples were demolded and placed in a limewater bath and continued to cure for an additional 27 days. The temperature range of the limewater bath was $73.4 + 3$ °F ($23 + 1.7$ °C) in accordance with ASTM C 192/C 192M-98. The samples were to be tested within 20 h of the mix time after 28 days of curing according to ASTM C 39, the specimens for this study were cured for 28 days and tested within 3 h of the initial mix time. The compression and bending properties were statistically analyzed to determine significant differences between untreated and treated wood fiber–cement composites.

### 2.2. Property measurements

Mechanical properties determined after 28 days curing were bending modulus (MOE) and strength (MOR), 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.

Table 2
Neat cement and fiber–cement, treated and untreated, specimen formulations

| Component | Neat cement | | Fiber cement composites | |
|---|---|---|---|---|
| | Weight (%) | Batch weight (lb) | Weight (%) | Batch weight (lb) |
| Type III Portland cement | 75.8 | 3.307 | 68.9 | 3.307 |
| Deionized water | 22.7 | 0.992 | 20.7 | 0.992 |
| Rheobuild 1000 plasticizer | 1.5 | 0.066 | 1.4 | 0.066 |
| Fiber | – | – | 4.3 | 0.205 |
| Extra water | – | | 4.7 | 0.227 |
| Total | 100.0 | 4.365 | 100.0 | 4.797 |

## 3. Discussion

Trends in the average mechanical property values between treatment levels were difficult to ascertain because of variation in the average values for each chemical treatment level. The variation was related to:

1. Wood fiber being a biological material had inherent variability in fiber length and properties;
2. Surface treatment of each wood fiber by aqueous chemicals was not uniform over the fiber surface; and
3. The properties at each treatment level had a statistical distribution with the test specimens being a small sample of each population distribution.

Combining treatment levels produced a data set that allowed an examination of apparent trends in the average mechanical property values. The N silicate (Table 3) and K silicate (Table 4) treatments levels were combined into three data sets: (1) 0.25%, 0.50%, and 0.75% treatment levels into 0.25–0.75%; (2) 1%, 2%, 3%, 4%, and 5% treatment levels into 1–5%; and, (3) 6%, 7%, 8%, 9%, and 10% treatment levels into 6–10%. The silane (Table 5) treatment levels were combined into four data sets: (1a) 0.25%, 0.5%, and 0.75% treatment levels into 0.25–0.75%; (2a) 1%, 3%, 5%, and 10% treatment levels into 1–10%; (3a) 15%, 30%, and 60% treatment levels into 15–60%; and (4a) 100% treatment remained a single level.

### 3.1. Newspaper fiber–cement composites

The three chemical treatments of newspaper fiber (Table 3) produced average compression strength values that generally increased with increasing treatment level. The highest average compressive strength values for the untreated and all three chemically treated newspaper fiber–cement composites were for the 6–10% N silicate treatment group. The average MOE values were slightly higher for the N silicate treatment 1–5% and 6–10% level groups than the untreated and 0.25–0.75%-N-silicate-treated newspaper fiber–cement composites. All of the N silicate treatment levels produced lower average MOR values than the untreated newspaper fiber–cement composites. The normalized average toughness values were similar for all levels of N silicate treatment newspaper fiber–cement composites and higher than the neat cement and untreated newspaper fiber–cement composites.

The average compressive strength, MOE and MOR values for the untreated newspaper fiber–cement composites were higher than all levels of K-silicate-treated newspaper fiber–cement composites (Table 4). Results for the average normalized toughness values for the K silicate treatment level groups were similar to the N silicate treatment groups in that all treatment levels produced normalized average toughness values that were higher than the neat and untreated newspaper fiber cement specimens.

Silane-treated newspaper fiber–cement composites (Table 5) had average compressive strength, MOE and MOR values lower than the neat or untreated newspaper fiber–cement specimens. The average normalized toughness values for the silane-treated newspaper fiber–cement composites were somewhat similar or higher than the values for the neat and untreated newspaper fiber–cement composites. It is interesting to note that the 100% silane-treatment level had average strength values for compression and bending that were the lowest values compared to all chemical treatment levels for both wood fiber types.

### 3.2. Kraft fiber–cement composites

The average compressive strength, MOE and MOR values for all N silicate and K silicate treatment kraft fiber groups were higher than the untreated kraft fiber–cement composites. The untreated kraft fiber–cement composites had a slightly higher average normalized toughness value compared to the N-silicate- and K-silicate-treated kraft fiber–cement composites. However, the untreated, N-silicate- and K-silicate-treated kraft fiber–cement composite had average normalized toughness values greater than the neat cement specimens.

The silane-treated kraft fiber produced similar results to the N-silicate- and K-silicate-treated kraft fiber–cement composites, except for the average normalized toughness values. The average normalized toughness value for the 15–60% silane treatment level group was the only kraft fiber treatment group for all three chemicals that produced a value higher than the untreated kraft fiber–cement composite values.

Table 3
N-silicate-treated newspaper and kraft fiber–cement composite mechanical properties

| N silicate treatment (%) | Newspaper fiber | | | | Kraft fiber | | | |
|---|---|---|---|---|---|---|---|---|
| | Compression (psi) | Bending properties | | | Compression (psi) | Bending properties | | |
| | | MOE × $10^5$ (psi) | MOR (psi) | Normalized toughness | | MOE × $10^5$ (psi) | MOR (psi) | Normalized toughness |
| Neat | 8850 | 3.19 | 1930 | 1.00 | 7600 | 2.25 | 1380 | 1.00 |
| Untreated | 5130 | 2.37 | 1490 | 1.30 | 4750 | 1.32 | 1250 | 2.29 |
| 0.25–0.75 | 4920 | 2.27 | 1380 | 1.36 | 6690 | 2.42 | 1450 | 2.10 |
| 1–5 | 5840 | 2.55 | 1450 | 1.35 | 5940 | 2.00 | 1420 | 2.07 |
| 6–10 | 6150 | 2.47 | 1390 | 1.37 | 6790 | 2.19 | 1370 | 2.13 |

Table 4
K-silicate-treated newspaper and kraft fiber–cement composite mechanical properties

| K silicate treatment (%) | Newspaper fiber | | | | Kraft fiber | | | |
|---|---|---|---|---|---|---|---|---|
| | Compression (psi) | Bending properties | | | Compression (psi) | Bending properties | | |
| | | MOE × $10^5$ (psi) | MOR (psi) | Normalized toughness | | MOE × $10^5$ (psi) | MOR (psi) | Normalized toughness |
| Neat | 8850 | 3.19 | 1930 | 1.00 | 7600 | 2.25 | 1380 | 1.00 |
| Untreated | 5130 | 2.37 | 1490 | 1.30 | 4750 | 1.32 | 1250 | 2.29 |
| 0.25–0.75 | 4860 | 2.13 | 1400 | 1.36 | 6620 | 2.20 | 1440 | 2.02 |
| 1–5 | 5210 | 1.77 | 1380 | 1.47 | 6920 | 1.94 | 1440 | 1.94 |
| 6–10 | 5000 | 2.18 | 1300 | 1.44 | 6930 | 2.32 | 1460 | 2.02 |

### 3.3. Comparison of neat cement and treated wood fiber–cement composites

Comparing the neat cement with the untreated and treated fiber–cement composite mechanical properties produced some interesting results. The neat cement average compressive strength values were higher than the average compressive strength values for untreated and all treated wood fiber–cement composites. All treated newspaper fiber–cement composite average normalized toughness values were higher than the neat and untreated newspaper fiber–cement specimen values. All treated kraft fiber–cement composite normalized toughness values were higher than the neat cement values, but only the 15–60%-silane-treated kraft fiber–cement composites had an average normalized toughness value higher than the untreated kraft fiber–cement composite. The treated kraft fiber–cement composites had average MOR values comparable to or better than the neat cement and untreated kraft fiber–cement composite values. All of the treated newspaper fiber–cement average MOR values were lower than the neat cement and untreated newspaper fiber–cement composite values. All of the treated and untreated fiber average MOE values were lower than the neat cement value except for the 0.25–0.75%-N-silicate-treated and 6–10%-K-silicate-treated kraft fiber–cement composites.

For most of the properties measured, lower percent treatments were the best treatment levels for kraft fiber–cement composites, while newspaper fiber cement composites had higher average values at higher percent treatment levels.

### 3.4. Comparison of treated wood fiber–cement composites

The average compressive strength values for kraft fiber–cement composites, regardless of chemical treatment level, had higher average compressive strength values than the treated newspaper fiber–cement composites. The average MOE values for the newspaper fiber–cement composites were similar to kraft fiber–cement composite values. Kraft fibers produced similar average MOR values to newspaper fiber–cement composites but much higher average toughness values than newspaper for all three chemical treatments.

At the interface between the wood fiber and cement matrix, stress is being transferred between the wood fiber and cement and the interface increases the fracture energy by deflecting and delocalizing stress at the crack tip [1,25]. A strong or weak interfacial bond influences the mechanical behavior of the composite [1]. If a strong bond exists, the result is a brittle material that has high strength and a weak bond results in a tough material lacking high strength [2]. Wood fiber–cement composites usually fail by fiber fracture or fiber pullout [1].

The bond between the wood fiber and cement may be chemical, physical, or a combination of the two. Chemical bonds are thought to be hydrogen bonds and/or hydroxide bridges [2]. The hydrogen bonds could form between fibers or between fibers and the cement matrix [25]. Physically, the bonding could occur during the hydration of cement when the crystals form and interlock with each other. A three-stage process, as described in Hachmi and Campbell [10], combines chemical and physical interaction. The first stage

Table 5
Silane (Si)-treated newspaper and kraft fiber–cement composite mechanical properties

| Silane treatment (%) | Newspaper fiber | | | | Kraft fiber | | | |
|---|---|---|---|---|---|---|---|---|
| | Compression (psi) | Bending properties | | | Compression (psi) | Bending properties | | |
| | | MOE × $10^5$ (psi) | MOR (psi) | Normalized toughness | | MOE × $10^5$ (psi) | MOR (psi) | Normalized toughness |
| Neat | 8850 | 3.19 | 1930 | 1.00 | 7600 | 2.25 | 1380 | 1.00 |
| Untreated | 5130 | 2.37 | 1490 | 1.30 | 4750 | 1.32 | 1250 | 2.29 |
| 0.25–0.75 | 4210 | 2.17 | 1340 | 1.40 | 6770 | 2.13 | 1590 | 1.97 |
| 1–10 | 4590 | 2.00 | 1390 | 1.37 | 6340 | 1.91 | 1450 | 2.17 |
| 15–60 | 4980 | 2.15 | 1240 | 1.42 | 5790 | 2.04 | 1320 | 2.49 |
| 100 | 3810 | 1.78 | 1110 | 1.51 | 5700 | 2.03 | 1350 | 2.28 |

is said to be chemical which corresponds to early wood fiber–cement hydration reactions. The second stage is chemical and physical when the cement begins to crystallize and form a matrix around the wood, and the final stage is physical which could continue for many years.

Ahn and Moslemi [14] concluded that during hydration, the crystals interlocked with wood surfaces within the cell lumens and in other openings and when the crystals grow against the wood they grow into whatever cavities are present. If the crystals come against a flat location the crystals may form flat ends. Lin et al. [12] showed that the bond between the wood fiber and cement increases as the cement matrix gets stronger, but the fibers may become more brittle.

The strength of the bond between wood fiber and cement determines the composite properties and depends on the wood species, treatment of the fiber, and additives in the mixture [13]. Some major parameters that affect fiber interaction with the matrix are the matrix composition (cracked or uncracked), fiber geometry, fiber type, surface characteristics of the fiber, fiber orientation, fiber volume, and the overall durability of the composite [15].

Each composite specimen in this study had the same weight of fibers for each fiber type and chemical treatment. However, newspaper fibers are shorter than kraft fibers so there were more individual newspaper fibers per unit weight. More fibers may lead to an increase in void space per unit weight due to cell lumens in the fibers. This fiber characteristic could explain why kraft fibers had better compressive strength values than newspaper fibers. Kraft fibers are larger and longer than newspaper fibers. This may have contributed to the increased toughness values for the kraft fiber composites compared to the newspaper composites because each kraft fiber had more surface area enabling the kraft fiber to resist fiber pullout and more effectively bridge microcracks within the composite.

## 4. Summary

Treated wood fiber was better than the untreated wood fiber for certain chemical treatments and wood fiber–cement combinations. N silicate treatments of both wood fibers produced higher average properties than untreated fiber–cement composites except for newspaper fiber–cement composite average MOR values and kraft fiber–cement composite average normalized toughness values. Silane- and K-silicate-treated newspaper fiber had lower average compression strength, MOE and MOR values and higher average normalized toughness values compared to untreated newspaper fiber–cement composites. All of the K-silicate- and silane-treated kraft fiber composites had higher average mechanical property values than the untreated kraft fiber–cement composites.

Comparing the neat cement with the untreated and treated fiber–cement composite mechanical properties produced mixed results. The neat cement average compressive strength values were higher than the average compressive strength values for untreated and all treated wood fiber–cement composites. All treated newspaper fiber–cement composite average normalized toughness values were higher than the neat and untreated newspaper fiber–cement specimen values. All treated kraft fiber–cement composite normalized toughness values were higher than the neat cement values, but only the 15–60%-silane-treated kraft fiber–cement composites had an average normalized toughness value higher than the untreated kraft fiber–cement composite. The treated kraft fiber–cement composites had average MOR values comparable to or better than the neat cement and untreated kraft fiber–cement composite values. All of the treated newspaper fiber–cement average MOR values were lower than the neat cement and untreated newspaper fiber–cement composite values. All of the treated and untreated fiber average MOE values were lower than the neat cement value except for the 0.25–0.75%-N-silicate-treated and 6–10%-K-silicate-treated kraft fiber–cement composites.

In all the treatments used in newspaper fiber–cement composites, the N silicate treatment had the highest or comparable average compressive strength, MOE, and MOR values for all three chemicals. Silane and K silicate treatments had generally higher average normalized toughness values than N-silicate-treated newspaper fiber–cement composites. However, kraft fiber had different results than the newspaper fiber with only the silane treatments achieving the highest average values in normalized toughness. These results indicated that of these chemical treatments, certain treatments react better with different wood fiber types resulting in selected mechanical property enhancements.

Kraft fiber had the highest average values in compressive strength and normalized toughness compared to newspaper fiber within each chemical treatment. Treatment levels of 0.25–0.75% silane had the highest MOR values for the untreated and treated kraft fiber–cement specimens. Treated newspaper fiber–cement composites had the highest average values in MOE for the N silicate treatments compared to the K-silicate- and silane-treated newspaper fiber–cement composites. Treated kraft fiber–cement composites averaged over all treatment levels within a chemical treatment had comparable average values in compressive strength for all three chemical treatments. The highest average normalized toughness values for both fibers and all chemical treatments were associated with the silane-treated kraft fiber. Newspaper fiber treated with N silicate generally had the highest average MOE values.

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