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Communication

Durability of thermomechanical pulp fiber-cement composites to wet/dry cycling

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Abstract

Previous research efforts on pulp fiber-cement composites have largely concentrated on kraft pulp fiber composites. In this research program, thermomechanical pulp (TMP) fibers were investigated as an economical alternative to kraft pulp fibers as reinforcement in fiber-cement composites. Prior to wet/dry cycling, TMP composites exhibited increased first crack strength, but lower peak strength and lower post-cracking toughness, as compared to unbleached and bleached kraft pulp composites at equivalent fiber volume fractions. It is believed that this behavior can be attributed to the lower tensile strength and shorter fiber length of TMP fibers as compared to kraft fibers. After 25 wet/dry cycles, TMP composites showed losses in first crack (peak) strength and post-cracking toughness. However, TMP composites exhibited a slower progression of degradation during wet/dry cycling than composites containing bleached or unbleached kraft fibers.

Keywords: Cement; Fiber reinforcement; Composite; Durability; TMP

1. Introduction

Traditionally, kraft pulp fibers have been used as reinforcement in cement-based materials containing pulp fibers. A potential lower-cost alternative to kraft pulp fibers is thermomechanical pulp (TMP) fibers. Typically, TMP fibers cost approximately 20% less than kraft fibers. Also, TMP fiber mass yield is about 90% versus 45% for kraft pulp fibers. The resulting mechanical pulp contains approximately 25–31% lignin by mass compared to 3–8% for unbleached kraft pulp and 0–1% for bleached kraft pulp [1]. Generally, however, pulp fibers with lower lignin and hemicellulose content, such as kraft pulp fibers, have been favored for use in cement-based composites, because of the potential for alkali degradation of these components [2]. Therefore, the durability of TMP fibers in a cement-based composite should be considered, as well as their relative mechanical performance and cost.

The mechanical properties of some TMP reinforced cement-based materials have been examined. Campbell and Coutts [3] found that thermomechanical pulp (TMP) fiber-cement composites exhibited lower flexural strength than kraft pulp fiber composites at moderate water-to-cement ratios (i.e., w/c of 0.33 to 0.45) and low fiber contents (i.e., mass fractions less than 5%). Additionally, Soroushian and Marikunte [4] have shown that the strength and toughness of composites reinforced with TMP were lower than respective fiber volumes of kraft pulp.

However, the anticipated durability of TMP fiber-cement composites to wet/dry exposure has been less extensively studied. Soroushian et al. [5] found that mechanical pulp composites exhibited a faster progression of composition degradation during wet/dry cycling. However, Mohr et al. [6] have shown that cement pastes reinforced with unbleached kraft fibers appear to exhibit a slower progression of composite degradation during wet/dry cycling, as compared to low-lignin bleached kraft fiber composites. This research [6] suggests that the fiber lignin content may play a role in slowing degradation during wet/dry exposure.

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Because, like unbleached kraft pulp, TMP fibers have a relatively higher lignin content than the bleached kraft fibers most commonly used for this application, further investigation of the effects of wet/dry cycling on TMP fiber-cement composites is warranted.

Because of the potential for improved composite durability, as well as the potential economic advantages associated with TMP fibers, the objective of this research is to evaluate thermomechanical pulp fiber-cement composite properties prior to and after wet/dry exposure. In order to minimize the effects of age (which is expected to increase matrix strength), all samples are tested at the same age (i.e., 78 days), regardless of the number of wet/dry cycles. The performance of the composites with increasing numbers of wet/dry cycles was assessed by center-point bending tests.

2. Experimental study

Fiber-cement beams were cast with a water-to-cement ratio of 0.60, using commercially available ASTM Type I Portland cement (oxide composition is reported in [6]) and deionized water (resistivity of 18.2 MΩ·m). ADVA Flow superplasticizer, obtained from Grace Construction Products, was used at a maximum dosage rate of 6.15 μL/g of cement to aid workability.

Both the TMP and kraft fibers were obtained from softwood species and were used at a 4% fiber volume fraction in cement paste. TMP southern Loblolly Pine fibers were obtained from Augusta Newsprint Company in Augusta, GA. The TMP fibers were collected from the secondary refiner. Bleached and unbleached kraft pulp fibers were southern Slash Pine and were obtained from Buckeye Technologies in Plant City, FL. A specific gravity of 0.5 was assumed for the TMP fibers, as compared to 1.5 for softwood kraft fibers. The specific gravity of TMP fibers is lower than that of kraft fibers since TMP fibers have an open lumen, whereas the kraft fiber lumen is collapsed. The kraft pulp fibers were treated by a process described in [7,8] to improve fiber dispersion. The TMP fibers did not require treatment to achieve good dispersion. The improved dispersion of the TMP fibers is likely due to their shorter length (~ 1–2 mm for TMP versus ~ 4–5 mm for kraft pulp of these species), which results from the mechanical action used during TMP pulping.

Paste samples were prepared as in [6]. A wet/dry cycle was defined for this research as 23 h and 30 min of drying in an oven at 65 ± 5 °C and 20 ± 5% RH, air drying at 22 ± 5 °C and 60 ± 5% RH for 30 min, 23 h and 30 min of soaking in water at 20 ± 2 °C, and air drying at 22 ± 5 °C and 60 ± 5% RH for 30 min. Air drying of samples was allowed between saturation and drying to avoid unrealistic thermal shock and subsequent microcracking. Samples were exposed to 0, 1, 2, 5, 10, 15, or 25 cycles prior to testing in order to determine how the mechanical properties of these fiber-cement composites are affected after various numbers of wet/dry cycles. Mechanical testing was performed after the 30 min at 22 ± 5 °C and 60 ± 5% RH preceded by 23 h and 30 min of soaking.

The 2.54 × 2.54 × 10.2 cm (1 × 1 × 4 inch) samples were tested according to ASTM C 348-97 and C 293-94 [9,10]. Again, it is important to note that all samples were tested at 78 days, regardless of the number of wet/dry cycles. Thus, any variations in measured properties should be attributable to wet/dry exposure, rather than a combination of exposure and prolonged cement hydration.

3. Results

3.1. Flexural performance prior to wet/dry cycling

Samples were tested in flexure at 78 days of age after 0, 1, 2, 5, 10, 15, or 25 wet/dry cycles. Typical load–deflection curves for each fiber composite after 0 cycles are illustrated in Fig. 1a. TMP composites initially (after 0 wet/dry cycles) exhibited higher first crack strength, but lower peak strength and lower toughness as compared to unbleached and bleached kraft pulp composites

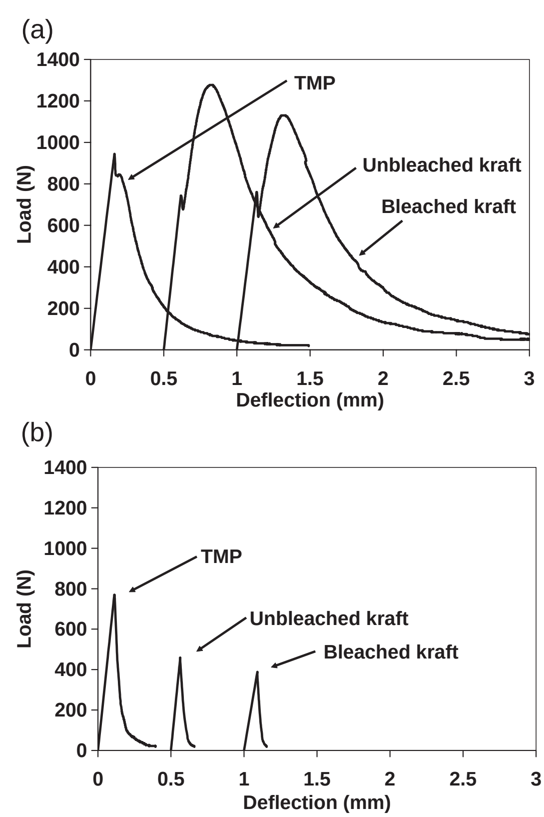

Fig. 1. Typical load–deflection curves (offset) for TMP, unbleached kraft, and bleached kraft composites with 4% fibers by volume. (a) After 0 wet/dry cycles. (b) After 25 wet/dry cycles.

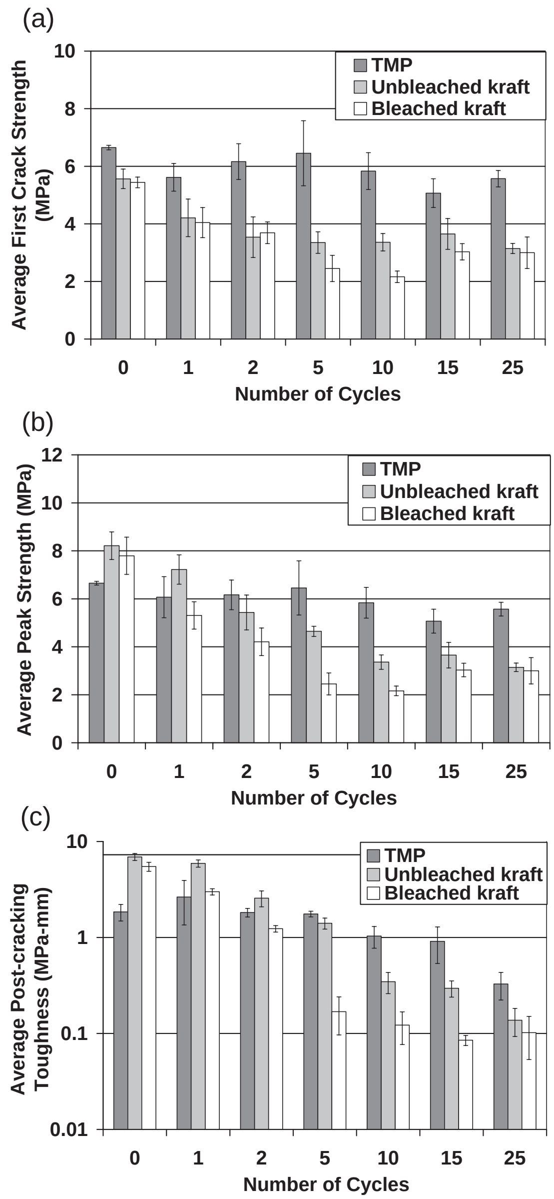

Fig. 2. Flexural testing results. (a) Average first crack strength (MPa) versus number of cycles. (b) Average peak strength (MPa) versus number of cycles. (c) Average post-cracking toughness (MPa–mm) versus number of cycles. Note: First crack and peak strength are the same for TMP samples. Also, the kraft pulp composite data are from [6].

(Fig. 2), in general agreement with the findings reported in [3,4].

Differences in first crack strength and post-crack behavior when comparing the kraft and TMP fiber composites are apparent. The higher first crack strength for the TMP composites may result from the shorter length of TMP fibers. The variation in fiber length is due to the differences in the TMP and kraft pulping operations. As more shorter (i.e., TMP) fibers are present in a sample for a given fiber volume fraction, micro-crack bridging may be improved, resulting in a higher first crack strength. In the post-cracking region, peak strength and toughness are decreased with TMP fibers. It is proposed that this is due to lower tensile strengths and shorter fiber pull-out lengths (also due to a shorter fiber length), as compared to the higher strength, longer kraft fibers. Since TMP fibers typically contain less cellulose by mass (40–45%) than kraft fibers (65–80%), TMP fiber tensile strength is approximately 50–70% that of kraft fibers [11,12].

3.2. Flexural behavior after wet/dry cycling

With wet/dry cycling, all composites, regardless of fiber type, showed some degradation in mechanical properties. However, the relative losses for the TMP fiber composites were less than for the bleached or unbleached kraft fiber composites. Typical load–deflection curves after 25 wet/dry cycles can be seen in Fig. 1b. These curves show that the composites exhibited lower strength and post-crack toughening than samples prior to cycling. As seen in Fig. 2, TMP fiber-cement composites exhibited a 16.3% and 82.2% loss in first crack (peak) strength and post-cracking toughness, respectively, after 25 cycles compared to TMP specimens of the same age which were not subjected to cycling. For comparison, after 25 cycles, unbleached kraft pulp composites showed a 43.5% decrease in first crack strength, a 64.4% decrease in peak strength, and a 98.0% decrease in post-cracking toughness, as originally reported in [6]. Similarly, bleached kraft pulp composites lost 44.9% of first crack strength, 61.5% of peak strength, and 98.1% of post-cracking toughness after 25 wet/dry cycles [6].

However, as clearly seen in Fig. 2, TMP composites generally exhibited a slower progression of degradation, as measured by mechanical performance, than both bleached and unbleached kraft fiber composites. That is, losses of 50% or more in post-cracking toughness, compared to that prior to cycling, were observed after 1 and 2 cycles for the bleached and unbleached kraft pulp composites, respectively. However, the TMP composites exhibited toughness losses of more than 50% after 15 wet/dry cycles. Similarly, bleached and unbleached kraft pulp composites exhibited losses of more than 25% in peak strength after 1 and 2 cycles, respectively, while TMP composites did not exhibit strength losses greater than 25% over the range of wet/dry cycles investigated here.

Comparing the data after 25 wet/dry cycles, TMP composite strength and toughness exceeded that of the kraft pulp composites. Relative to unbleached and bleached kraft composites, TMP composite first crack (peak) strength was 77.1% and 85.7% greater, respectively, and toughness was 138.6% and 221.7% greater, respectively, after 25 cycles [6]. These results suggest that TMP fibers may afford enhanced durability as compared to kraft pulp fiber-cement composites.

Further research is ongoing to establish the mechanism(s) underlying the improved performance of the TMP composites during wet/dry cycling. However, it is proposed that the lignin in TMP and unbleached kraft fibers may slow the progression of composite degradation due to wet/dry cycling.

4. Conclusions

Flexural testing of specimens was conducted after 0, 1, 2, 5, 10, 15, and 25 wet/dry cycles. Prior to cycling, the shorter fiber length of TMP fibers, as compared to kraft fibers, is believed to lead to higher first crack strength, but lower peak strength and post-cracking toughness. After 25 cycles, TMP composites exhibited higher strength and toughness than kraft pulp composites. In general, losses in mechanical properties (i.e., peak strength, post-cracking toughness) progressed more slowly in TMP composites than for bleached or unbleached kraft pulp composites.

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