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Cement & Concrete Composites 27 (2005) 435–448
Cement & Concrete Composites
www.elsevier.com/locate/cemconcomp

Durability of kraft pulp fiber–cement composites to wet/dry cycling

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Received 26 June 2003; accepted 22 July 2004

Abstract

If pulp fiber–cement composites are to be used for exterior applications, the effect of cyclical wet/dry exposure must be known. In this research program the effects of three fiber treatments—beating, bleaching, and drying—were investigated to identify those that may minimize effects of environmental aging and degradation during wet/dry cycling. After 25 wet/dry cycles, all composites showed significant losses in first crack strength, peak strength, and post-cracking toughness. The majority of losses in mechanical properties occurred within the first 5 wet/dry cycles, though ductile fiber failure was still observed by scanning electron microscopy (SEM). A three-part progressive degradation mechanism during wet/dry cycling is proposed: (1) initial fiber–cement debonding, (2) reprecipitation of hydration products within the void space at the former fiber–cement interface, and (3) fiber embrittlement due to fiber cell wall mineralization. Unbeaten fiber–cement composites exhibited greater peak strength and post-cracking toughness, prior to cycling, while no significant differences were seen after 25 cycles. The effects of fiber beating varied prior to and after cycling. Unbleached fiber–cement composites exhibited the slowest progression of degradation during cycling. The initial drying state appeared to have no effect on composite performance after 25 wet/dry cycles.

Keywords: Fiber–cement; Durability; Wet/dry cycling; Pulp; Beating; Bleaching; Drying; Microscopy

1. Introduction

It is well known that fiber–cement composites exhibit improved toughness, ductility, flexural capacity, and crack resistance as compared to non-fiber-reinforced cement-based materials. Wood pulp fibers are a unique reinforcing material that offer numerous advantages. They are non-hazardous, renewable, and readily available at relatively low cost compared to other commercially available fibers [1]. As a result, pulp fiber–cement composites have found practical applications in recent decades in the commercial market as a replacement for hazardous asbestos fibers. Today, pulp fiber–cement composites can be found in products such as extruded non-pressure pipes and non-structural building materials, mainly thin-sheet products [2]. Fiber–cement siding has been called "tomorrow's growth product" [3] and as of the late 1990s, shares 7–10% of the North American siding market [4].

If such composites are to be used for applications where performance must be ensured after environmental exposure, the effects of cyclical wetting and drying on performance must be known. Using sisal fiber–mortar composites, Gram [5] found significant losses in post-cracking peak strength and toughness with wet/dry cycling. The majority of these losses occurred by 12 wet/dry cycles. On the other hand, Soroushian et al. [6] found that flexural strength of kraft pulp fiber–mortar composites increased with wet/dry cycling. Additionally, flexural toughness was found to significantly decrease,

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0958-9465/$ - see front matter
doi:10.1016/j.cemconcomp.2004.07.006

particularly by 20 wet/dry cycles. The differences between peak (flexural) strength trends with wet/dry cycling warrants further investigation of the influence of wet/dry cycling on mechanical performance, particularly flexural first crack and peak strength.

Marikunte and Soroushian [7] concluded that the mechanical properties of fiber–cement composite are adversely affected after 25 wet/dry cycles compared to control specimens (i.e., zero wet/dry cycles). However, it is unclear from the published data, if progressive damage occurs to fiber–cement composites with wet/dry cycling. That is, how do the mechanical properties, such as strength and toughness, differ after 25 wet/dry cycles as compared to a fiber–cement composite exposed to 5, 10, or 15 wet/dry cycles? It is important to examine the progression of degradation to understand and predict changes in performance with exposure.

To mitigate fiber–cement composite degradation due to wet/dry exposure, two approaches—fiber modification and matrix modification—have been investigated. Gram [5] produced encouraging results by modifying the cement matrix through the use of a high alumina cement. Prior to wet/dry cycling, high alumina cement composites exhibited lower peak strength and toughness compared to ordinary Portland cement composites. However, by 120 wet/dry cycles, the post-cracking peak strength of high alumina cement composite decreased by only 56.2% as compared to a 98.8% loss for the ordinary Portland cement composite.

The use of pozzolanic materials as a partial weight replacement of cement has also been investigated in order to reduce the alkalinity of the cement matrix as well as refining the pore structure of the matrix. Silica fume, used at relatively large amounts (i.e., 30% or greater replacement of cement by weight) appears to significantly minimize composite degradation due to wet/dry cycling [5,8,9]. Silica fume replacements of 17% and 33% of cement by weight reduced the pore water pH from 13.2 to 12.9 and 12.0, respectively [5]. Partial replacement of Portland cement with 40% slag by weight by Tolêdo Filho et al. [8] did not significantly improve the durability of sisal fiber–mortar composites after 46 wet/dry cycles. Gram [5] has also shown that replacement of cement with 70% slag by weight reduced the pore solution pH from only 13.2 to 13.0 and did not improve the durability of sisal fiber–mortar composites after 120 wet/dry cycles. Similar results were obtained using fly ash as a partial weight replacement of Portland cement. Using rice-husk ash, Ziraba et al. [10] concluded that 45% replacement of Portland cement by weight minimized composite degradation due to wet/dry cycling by reducing the pore solution pH by 15–20%.

Ziraba et al. [10] also investigated methods of sealing the matrix pore structure of sisal fiber–mortar composites by infiltrating specimens with molten asphalt or molten plasticized sulfur. Asphalt infiltration did not offer any protection against composite degradation. However, plasticized sulfur infiltration did minimize the effects of wet/dry cycling. Additional mortar matrix additives—colophony, tannin, and montan wax—were used by Canovas et al. [11] to seal the pore structure of sisal fiber–mortar composites. Though all additives significantly reduced the porosity and subsequent water adsorption of composite specimens, only colophony appeared to be effective in reducing composite degradation due to wet/dry cycling.

Another approach to reduce composite degradation due to wet/dry cycling has been to modify the fibers by coating or impregnating the fibers with water-repelling or blocking agents. By reducing the moisture movement around and within the fibers, it is presumed that the progression of fiber mineralization will be slowed or prevented. Gram [5] impregnated sisal fibers with formine and stearic acid, potassium nitrate and stearic acid, sodium chromate and fluorine–carbon–hydrogen–stearate, and borax and chromium stearate. The use of these impregnation agents slightly improved the durability of the mortar composites during wet/dry cycling, compared to unimpregnated fiber composites. However, impregnated sisal fiber composites exhibited peak strengths about half that of unimpregnated fiber composites prior to cycling. Attempts to reduce composite degradation by Ziraba et al. [10] using fiber coatings of asphalt, epoxy, and linseed oil were not effective in mitigating the effects of wet/dry exposure and decreased the strength of the composite prior to wet/dry cycling.

The main objective of this research is to investigate how variations in pulp fiber treatments influence fiber–cement composite properties prior to and after wet/dry exposure. The treatment processes investigated include refining (or beating), bleaching, and drying. Some research [7,12–15] has shown that the strength of fiber–cement composites may experience no change or actually improves with wet/dry cycling. However, in this previous research, it is difficult to separate increases in matrix strength due to continued cement hydration with time from the changes in mechanical properties of the composite due to wet/dry cycling. Therefore, in this research, to eliminate the effects of age on matrix strength, all samples are tested at the same age (i.e., 78 days), regardless of the number of wet/dry cycles. That is, all samples remained in a curing environment for at least 28 days prior to testing, with those subjected to fewer or no wet/dry cycles remaining in the curing tank for longer periods until wet/dry cycling or mechanical testing. The performance of the composites with increasing numbers of wet/dry cycles is assessed by center-point bending tests. Further characterization of the composite and the failure mode is accomplished by scanning electron microscopy (SEM) of the composite fracture surfaces.