2nd Conference on Sustainability in Civil Engineering (CSCE'20)
Department of Civil Engineering
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DIFFERENT TECHNIQUES FOR ENHANCING DURABILITY OF NATURAL FIBERS IN CEMENTITIOUS COMPOSITES - AN OVERVIEW

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Abstract- Natural fibers in cementitious composites (NFCC) have been gaining popularity universal due to their application in low cost construction processes. In spite of the fact that there is wide scope of opening for natural fibers in cementitious composites, their long term durability performance under various exposure environmental conditions is still a question with unstable answer. Since several decades researchers have been working to dominate the durability issue by providing a correct technology for NFCC, actually possible product for different applications. This overview reveals a light on various durability mechanism of natural fibers and NFCC under several exposure environmental conditions, different techniques are accepted for enhancing the durability of natural fibers and NFCC. The durability improvement is encountered to be premier with the composites containing cementitious material than in plain fiber cement composites. Furthermore, incorporation/use of treated fibers in the treated matrix shows superior performance under durability testing. However, many studies necessity to be improved to confirm the existent improvement on durability of the natural fibers in cementitious composites.

Keywords- Different techniques, Enhancing durability, natural fibers in cementitious composites

1. INTRODUCTION

Measurement of aging durability of natural fibers in cementitious composites, specimens for flexure test were placed into hot water saturated with lime and kept at a constant temperature of 70 ± 2 Cº and tested according to ASTM C1560-03 [1]. Accelerated aging test was performed for Vegetable fibers in natural weathering, specimens were placed into water for 170 min at 20 ± 5 Cº, and then 10 min after they were dried for 170 min at 70 ± 5 Cº in an oven. Another cycle is started after 10 min, samples were immersed 200 accelerated aging cycles and test was recommended according EN 494 standard [2-3]. Water absorption test was performed at flax fiber, first sample was dried in a dehydrating oven at 40 Cº for three days, and then sample was immersed into distilled water at a room temperature. This test was stopped after 30 days, at each cycle, calculated weight of the fiber at dried and saturated conditions respectively. The related water absorption was calculated by (saturated weight minus dried weight) divided dried weight [4]. Jute fiber durability test was performed, first fiber was soaked in 100 Cº boiling water for 1h and then absorption moisture was evaporated for 2h at room temperature to fix specimens and then durability test was performed [5]. Environmental aging tests were performed by Bamboo fiber reinforced polymer and Bamboo Glass reinforced polymer, samples were immersed in water at 25 Cº and at 75 Cº for 6 months 3 months respectively. Tensile tests were performed at the end of 6 months and 3 months for samples which immersed at 25 Cº and 75 Cº respectively [6]. Durability tests of vegetable fibers mortar composites were performed on the basis of flexure properties before and after exposures to various environmental conditions. Samples were placed to three various environmental conditions, first set of samples were placed into water at 18 Cº temperature, second set of samples were placed into London natural weathering conditions started from December 1994, and third set of samples were placed into wetting and drying cycles. Samples were tested after 6 months. Wetting and drying period was 7 days, samples were placed into water for a day at 18 Cº, and 6 days for drying at 23 Cº and 40% relative humidity [7].

Natural fibers are used in cementitious composites to enhance the mechanical properties of the cementitious composites. Cementitious composites properties are reduced due to their durability problems, such as occur in aggressive and alkaline environments [31]. In durability conditions, mechanical properties of the NFCC were reduced like shear strength, flexural strength and flexural modulus [8]. Some natural fibers maintained their tensile strength when fully wetted at room temperature in humidity conditions, but others showed a significant decrease in tensile strength [9]. Sisal fiber has best mechanical properties with low density, however it has poor durability in alkaline environment, such as in cement matrix

[10]. Flax fiber capability to moisture absorption, its durability resistance in humid environment is limited thus its application is restricted to semi-structural or non-structural interior products [11]. At moisture absorption of natural fibers bond in a polymeric matrix, the fibers hydro expansion can lead to reduction of the strength and stiffness, matrix cracking, over time associate losing of mass with water entrance [12]. Due to fiber mineralization and alkali attack in humidity environment is subjected to post-cracking strength and toughness reduction of the natural fiber reinforced composites [13]. Cellulose fiber reinforced cement composites gain strength and stiffness, but they are sensitive to moisture effects and they lost their durability with time [14]. Sisal and Coconut fibers reduced their strength when immersed in alkaline dilution, and date palm reinforced concrete had low durability performance when immersed in alkaline dilution [15]. In spite of vegetable natural fibers advantages, their production of cement base composites are limited due to their durability problems in environmental condition [16]. Sisal fiber durability problems are associated with increasing fibers fracture and decreasing in fiber pull out due to fibers attack by alkali, fiber mineralization, immigration of hydration products to lumens and fiber volume variation because of their superior water absorption [17, 32]. Fan palm fibers width were decreased when it were treated, using alkali treatment chemical method from 1 mm to a range between 0.6 and 0.9 mm [28]. The durability of natural fibers were related both external and internal environments, internal alkaline environment in cementitious matrixes were reduced the durability of natural fibers [30]. Short, discrete coconut fibers into high strength concrete reduced sulfate attacked on marine structures. Coconut fibers into high strength concrete retained crack propagation on marine structures, and it improved long term durability of marine structures compared to high-strength plain concrete, but degradation affected on fibers. To protect coconut fibers from degradation, treatment of the fibers is necessary [25].

Enhancing durability of NFCC were the modification of the matrix composites to remove or reduce the alkalinity of the composition [16]. Durability were improved of the natural fibers in cementitious composites by modified fiber surface by physical or chemical treatments to enhance their durability in cementitious composites [16]. Increasing durability of natural fibers in cementitious composites, a good solution is the replacement of Portland cement 30% and 20% by metakaolin and calcined crushed clay waste brick respectively [18]. Improving durability of sisal fiber composites by the help of matrix carbonation and soaking of the fibers in slurries silica fume [17]. Long term durability of natural fibers were enhanced by lower production of Calcium Hydroxide (only 50% normal Portland cement), reduced CO_2 transpiration, and a sustainable and economical approach [19]. To improve the durability efficiency of natural fibers in cementitious composites several investigation were done including fibers saturation with blocking agents and water-repulsive agents, matrix sealing, decreasing alkalinity of the matrix, and fibers and matrix modification [20]. Saturated vegetable fibers in mortar reinforced composites had better durability behavior than in those with unsaturated fibers, colophony was very effective in the reduction of fibers mineralization in exposure conditions for saturated and unsaturated fibers [21]. Enhancement of the durability of natural fibers in cementitious composites are the sealing dry composites or coating of the fibers to prevent the effect of the water basically alkalinity, and decreasing the alkalinity in matrix by improving low alkaline binders [21, 33]. Calcium-aluminate cement with 10% metakaolin content leaded to high durability of flax fiber reinforced composites materials [22]. Sisal fiber durability improved by treated of fiber by Acetic and Acetic Anhydride, and environmental condition had less effect on treated sisal fiber compared to untreated fiber [1]. Date palm fibers were treated by immersion in NaOH and $Ca(OH)_2$ solutions, and showed better tensile strength and stiffness compared to untreated fibers thus it improved the durability of mortar matrix [29].Different techniques are considered to enhance durability of natural fibers such as fibers surface modification and matrix modification, replacement of the part of Portland cement with silica fume, slag and metakaolin, and early water curing with rich CO_2 environment. This study will help to understand different techniques to enhance durability of natural fibers in cementitious composites.

2. FACTS ABOUT REDUCING DURABILITY OF NATURAL FIBERS IN CEMENTITIOUS COMPOSITES

2.1 Specification

Measuring aging durability of natural fibers in cementitous composites, two set of specimens were tested under bending. Treated and untreated specimens were prepared from 77.2% of Portland cement type CPV-ARI, 12.8% of ground carbonated material industrialized from agricultural application, and 10% unrefined unbleached eucalyptus cellulosic pulp. Fibers were treated by slurry dewatering technique. Specimens were cured in two different conditions, Non-carbonated curing (NCC), and Accelerated carbonation curing (ACC). NCC specimens for first two days were kept in pertaining to weather chamber at 60 C° temperature and 90% relative humidity, and then kept under 25 C° in saturated curing until 28 days. ACC specimens were kept for two initial days in pertaining to weather chamber at 60 C° temperature and 90% relative humidity, and then applied accelerated carbonation by releasing CO_2 cycles into the chamber until the saturation of the total environment. These cycles were performed until the absorption of the carbonation, and then specimens were kept under 25 C° in saturated curing until 28 days. All specimens were kept for 1 year in two different environmental conditions, natural weathering condition of the State of Sao Paulo, Brazil and soaking and drying cycles in laboratory. At soaking and drying cycles, specimens were placed into water for 170 min at 20 ± 5 C°, and then 10 min after they were dried for 170 min at 70 ± 5 C° in an oven. Another cycle was started after 10 min, samples were placed 200 and 400 soaking and drying cycles respectively and then were tested according EN 494 standard [2, 3].

Table 1: Natural weathering condition of the Sao Paulo Brazil, and Soaking and drying conditions for test specimens

Set/Time	natural weathering, and soaking and drying conditions	
	28 days	1 year
Natural weathering Condition	First 2 days water curing at 60 C° and 90% RH; Reaming water curing Until 28 days at 25 C°	State of Sao Paulo, Brazil Annual RH = 84%; Annual temperature = 21.4 C° Annual rainfall = 2310 mm
Soaking and drying Condition	First 2 days water curing at 60 C° and 90% RH; Reaming water curing Until 28 days at 25 C°	Soaking at 20 ± 5 C° for 170 min Drying at 70 ± 5 C° for 170 min 200 soaking and drying cycles, and 400 soaking and drying cycles

2.2 Technology Involve

Universal Testing Machine Emic DL - 30000 was used to perform the bending test. It has two spans upper and lower. Upper span and lower span lengths were 45 mm and 135 mm respectively. For the determination of the mechanical properties the deflection rate was 1.5 mm/min. A deflectometer was used in the middle of span to collect deflection during the test [2, 20].

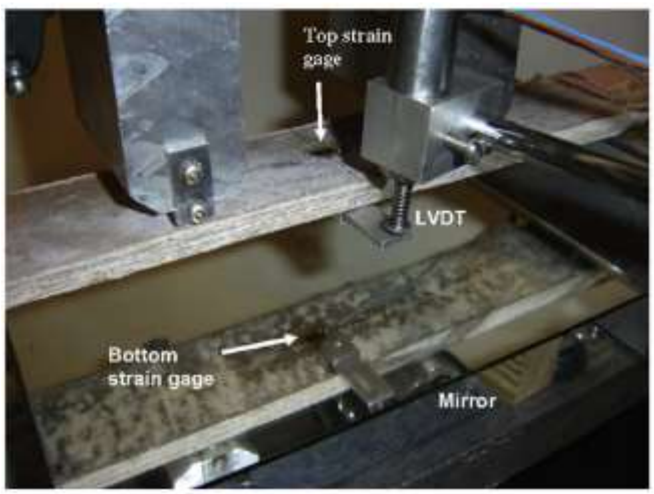

Fig. 1. Four point bending test [19].

2.3 Method implementation

For determination of mechanical properties, (1)-(3) equations were used as described by Tonoli et al in detail [26, 27].

$$MOR = \frac{p_{max} . L_v}{b . h^2} \quad (1)$$

$$LOP = \frac{P_{lop} . L_v}{b . h^2} \quad (2)$$

$$MOE = \frac{276. L_v^{\ 3}}{1296. b. h^3} m \tag{3}$$

Where *MOR* is the modulus of rupture, *LOP* is the limit of proportionality, *MOE* is the modulus of elasticity, P_{max} is the maximum load value, L_v is major span, P_{lop} is the load at the upper point of the linear portion of the load-deflection curve, *m* is the tangent of the slope angle of the load vs deflection curve during elastic deformation, and *b* and *h* are the specimen width and depth respectively.
For the determination of the specific energy as the total absorbed energy during the test divided the cross sectional area of the specimen. Absorbed energy was calculated by load-deflection curve integration up to the point in which 30% reduction of the maximum load occurring in a load currying capacity [2].

3. DURABILITY METHOD IN CEMENTITIOUS COMPOSITES

Evaluation of the durability performance of the natural fibers in cementitious composites, laminates were created and tested under flexural subjected to before and after an accelerated aging. Each sample was prepared from 5 layers nonwoven flax fibers saturated in paste matrix, and piled after the immersion in a drilled and subjected to a vacuum in an absorption chamber. Then samples were compressed under 3.5 MPa and cured at 20 ± 1 C° and 90 relative humidity for 28 day, this principle for the lamination of 12 mm thickness (Fig. 2). Two plates were prepared of 300 x 300 mm^2 per sample composition. Half of the specimens were tested after 28 days curing and remaining half were tested after the process of accelerated aging after the curing of 28 days. Accelerated aging had 250 wetting and drying cycles performed in an automatic chamber (CCI Calidad, Span). Every cycle was started with specimens immersion into water for 3 h at 20 C° and then dried for 3 h at 20% relative humidity and 60 C°. Flexural test was performed with an Incotecnic Universal Testing Machine, equipped with a 3 kN load cell and a 4-point bending device with 270 mm and 90 mm support span and load span respectively. Test was performed at rate of 5 mm/min and mechanical properties were determined from the curves [22].

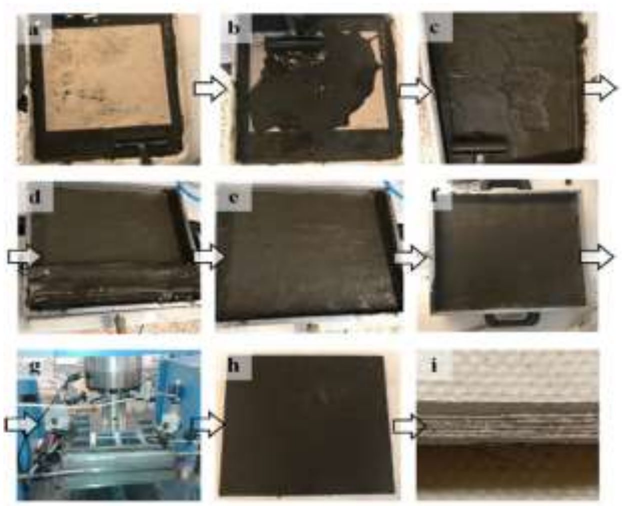

Fig. 2: composite samples preparation. (a)-(c) nonwoven fabric immersion process in cement paste. (d)- (f) For the elimination of excess water vacuum is applied, after the placing of reinforcement into the mold. (g) 5 layers of cement-nonwoven-cement layer are prepared up to reach into the required thickness, and then under a higher pressure the compaction is currying. (h) Before curing composite specimens. (i) Cutting of the samples showing nonwoven layers [22}.

Investigation was done on sisal and coconut fibers reinforced mortars. Control specimen was preferred from ordinary Portland cement mortar matrix, specimens were reinforced with short 25 mm sisal or coconut untreated distributed fibers and long 375 mm sisal untreated aligned fibers. Fiber friction was 3%, 2% short fibers and 1% long fibers were used in investigation. For the better incorporation of the fibers in matrix long fibers were immersed for 10 min in slurry silica fume and then dried for 15 min in air. Four different types of treated specimens were preferred, one set of specimens were preferred from (0.6OPC+0.4slag) 40% ordinary Portland cement (OPC) replaced with slag, another set of specimens were preferred form (0.9OPC+0.1silica fume) 10% OPC replaced with silica fume. Third set of specimens were preferred from (0.6OPC+0.4slag) and fibers were immersed in slurry silica fume, fourth set of specimens were preferred from

(0.9OPC+0.1silica fume) and fibers were immersed in slurry silica fume. Test specimens, each measuring was 400 x 100 x 15 mm, and tested under bending after 28, 109, and 365 days respectively. The durability of the vegetable fiber reinforced mortar composites were measured before and after exposured to different environments on the basis of flexural properties. Results were indicated that increasing early water curing period decreasing the carbonation depth. Fibers were treated in slurry silica fume to create around the fiber low PH value to reduce or avoid alkaline attack and for the transportation of calcium products to the fibers. OPC was replaced 40% and 10% with slag and silica fume respectively, for the treatment of the matrix to reduce alkalinity and improved the durability of the matrix. Early cure of vegetable fiber reinforced mortar composites in a rich CO_2 environment is another way to improve the durability of the matrix with aging. The durability of the matrix was improved by the decreasing the alkalinity of the matrix [7]. The mechanical properties of the matrix were increased with treatment of the fibers by silica fume and slag. Table 2 showed that post-crack flexural strength of the matrixes were enhanced by the replacement of the ordinary Portland cement with slag and silica fume, and also it enhanced by the immersion (treatment) of the fibers in slurry silica fume.

Table 2: Comparison of post-crack flexural strength for different specimens

Mix	Mix proportions of mortar (By weight) (Cement: sand: water)	Treatment applied	Fiber types	Volume Friction V_f %	Condition: 46 wet-dry Cycles, post-crack Flexural strength (MPa) After 322 days
M1S2S1	1:1:0.4	Non-treated	Sisal	S2S1=3	3.06
M1C2S1	1:1:0.4	Non-treated	Coconut + Sisal	C2S1=3	3.79
M1slagS2S1	(605 OPC+40% slag):1:0.4	Replace 40% OPC With slag	Sisal	S2S1=3	2.9
M1msS2S1	(90% OPC+10% MS):1:0.46	Replace 10% OPC With silica fume	Sisal	S2S1=3	4.44
M1S2S1i	1:1:0.4	Aligned immersion of fiber In slurry silica fume	Sisal	S2S1=3	5.06
M1slagS2S1i	(60% OPC+40% slag):1:0.4	Replace 40% OPC with Slag + fiber immersion In slurry silica fume	Sisal	S2S1=3	5.12
M1S2S1cab	1:1:0.4	109 days carbonation	Sisal	S2S1=3	6.39
M1C2S1cab	1:1:0.4	109 days carbonation	Coconut + Sisal	C2S1=3	5.39

4. LESSON LEARNT

Result showed that composites which were made from non-dried flax fibers and resin were low sensitivity to moisture compared to those composites which were made form dried flax fibers [34]. Non-dried flax fibers composites were enhanced the flexural strength and modulus of elasticity compared to dried flax fibers composites [34]. Replacement 15% cement with silica fume and 8% cellulose fibers content were improved the mechanical strength and durability of the cement paste composites for bore well [35]. Cellulose fibers were enhanced the mechanical strength of the matrix, and replacement of the cement with silica fume enhanced the durability of cement paste composites [35]. Palmyra natural fibers were treated by 4% stearic acid to improve the durability. Experiment showed that treatment of the fibers by stearic acid lead to reduce moisture diffusivity and enhanced the durability of the Palmyra natural fiber composites under different wet environment and temperature [36]. Investigation was done on three different flax fiber reinforced composites, untreated, pre-treated, and treated by zirconium dioxide coating. Fibers were embedded in cement paste and tested after 90 days, untreated and pre-treated fibers retained 41% and 31% their initial strength respectively, while zirconium dioxide treated fibers retained 96% initial strength. Fibers treated by zirconium dioxide improved their durability in cementitious composites [37]. Treated and untreated jute fibers were investigated, fibers were treated combined alkali modified (0.5% NaOH, 24 h) and polymer modified (0.125% carboxylated styrene butadiene rubber) successfully. Treated fibers had more tensile strength compared to untreated fibers in different exposure conditions [23].

Vegetable fibers durability performance in cementitious composites can be increased with curing conditions. Investigation showed that increasing initial water curing period, decreasing the carbonation depth in vegetable fiber composites matrix. Thus increasing early water curing period in a rich CO_2 environment can be improved the durability of vegetable fibers in cementitious composites with aging. The durability of natural fibers cementitious composites were enhanced with treatment of the fibers by slurry silica fume. Another way to improve the durability of natural fibers in cementitious composites is the replacement of the ordinary Portland cement 40% and 10% with slag and silica fume respectively. Slag and silica fume reduce the PH value of the matrix, thus it reduce the alkalinity of the matrix and improve the durability in different environmental conditions. Vegetable fibers durability were enhanced in reinforced cement mortar with saturation of the fibers, because colophony was effective in the reduction of the fibers mineralization in exposure conditions. Coating of the vegetable fibers with different chemical material also enhanced the durability of the natural fibers in cementitious composites.

A good solution to enhance the durability of natural fibers in cementitious composites is the replacement of Portland cement 30% and 20% by metakaolin and calcined crushed clay waste brick respectively. Durability of the natural fibers were enhanced with surface modification of the fibers and matrix modification. Fibers surface modification was done with saturating of the fibers by slurry silica, stearic acid, silane, natural resins, bariumnitrate, formine, etc. and matrix modification was done by replacement of partially ordinary Portland cement with pozzaolanic materials such as fly ash, slag, metakaolin, silica fume, etc. Alkaline treatment of the fibers showed better performance in reduction of water absorption capacity, and modified surface of the fibers. Usually alkali treatments of the fibers are done with immersion of the fibers in NaOH, KOH, Ca(OH)2 etc. solutions. One of the investigation showed that treatment of the hemp fibers in NaOH solution enhanced the flexural strength 39% compared to those hemp fibers which were untreated. Durability of the natural fibers can be enhanced with beating and bleaching of the fibers, beating and bleaching is a type of mechanical surface treatment of the fibers. Treatment of the wood fibers with silane contents had better durability performance with aging, and also this type treatment improved the compressive strength and compressive toughness compared to untreated wood fibers. Pulping of the natural fibers is another technique to enhance the durability of the matrixes. Pulping removes the lignin (a material causing degradation effect) in greater extent and provides better durability and mechanical behavior for the composites.

5. CONCLUSION

Various types of natural fibers such as sisal, coir, banana, hemp, jute, kenaf, rice husk, human hair, horse hair, etc are widely used in low cast construction. Different unwell effects associated with natural fibers due to water connectivity and degradation under alkaline solutions. These ill effects cause the natural fibers to be little used for long service life under different climatic conditions. There are several techniques to improve the durability of natural fibers in cementitious composites.

- One of a good solution to enhance the durability of natural fibers in cementitious composites is the replacement of a part of Portland cement with metakaolin and calcined crushed clay brick.
- Durability of the natural fibers can be enhanced with surface modification of the fibers and matrix modification.
- Fibers alkaline treatment modify fibers surface, reduce fibers water absorption capacity, and improve fibers durability in matrix.
- Early curing in a rich CO_2 environment can be improved durability of the vegetable fibers in cementitious composites.

This study demonstrates different techniques to enhance durability of natural fibers in cementitious composites. It shows, that natural fiber cementitious production will have been found better options for enhancing durability for different civil engineering applications.

6. Acknowledgment

The author is would like to thank for his gratefully acknowledge Dr. Engr. Majid Ali for his guidance and help in this an overview study.

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