Vegetable Fibre Reinforced Concrete Composites: A Review

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Keywords: Reinforced concrete; vegetable; fibres; properties; durability

Abstract. The current manuscript deals with the subject of natural fiber reinforced concrete. It includes fiber characteristics, properties and the description of the treatments that improve their performance; it covers the compatibility between the fibers and the cement matrix and also how their presence influences cement properties like setting time or the interfacial transition zone. It also includes the properties and durability performance of concrete reinforced with natural fibers. Future research trends are also presented.

Introduction

Regular concrete is a brittle material which possesses a high compressive strength but on the other side has a low tensile strength. The combined use of regular concrete and steel reinforcing bars was able to overcome that disadvantage leading to a material with good compressive and tensile strengths but also with a long post-crack deformation (strain softening). Unfortunately reinforced concrete has a high permeability that allows water and other aggressive elements to enter, leading to carbonation and chloride ion attack resulting in corrosion problems. Steel rebar corrosion is in fact the main reason for infrastructure deterioration.

Gjorv mentioned a study of Norway OPC bridges indicating that 25 % of those built after 1970 presented corrosion problems [1]. Another author mentioned that 40% of the 600.000 bridges in the U.S. were affected by corrosion problems being estimated in 50 billion dollars the cost of the repairing operations [2]. Since world population is expected to grow more 2000 millions until the year 2030, much more reinforced concrete structures will be built and much more deterioration problems are expected to take place. Concrete durability is environmental related. Because if we were able to increase the life time of a concrete from 50 to 500 years, its environmental impact decreases 10 times [3].

On the other hand, reinforced steel is a high cost material, has high energy consumption and comes from non renewable resource. Natural fibers are a renewable resource and are available almost all over the world [4]. Therefore to promote the use of concrete reinforced with vegetable fibers could be a way to improve concrete durability and also sustainable construction. This chapter deals with the subject of natural fiber reinforced concrete. It includes fiber characteristics, properties and the description of the treatments that improve their performance; it covers the compatibility between the fibers and the cement matrix and also how their presence influences cement properties. It also includes the properties and durability performance of concrete reinforced with natural fibers.

Fibre characteristics and properties

Vegetable fibers are natural composites with a cellular structure. Different proportions of cellulose, hemicellulose and lignin constitute the different layers. Cellulose is a polymer containing glucose units. Hemicellulose is a polymer made of various polysaccharides. As for lignin it is an amorphous and heterogeneous mixture of aromatic polymers and phenylpropane monomers [5]. Although natural fibres possess a high tensile strength they have low modulus of elasticity (Table 1).

Table 1 - Properties of vegetable fibers [6]

Properties	Specific gravity [Kg/m^3]	Water absorption [%]	Tensile strength [MPa]	Modulus of elasticity [GPa]
Sisal	1370	110	347-378	15,2
Coconut	1177	93,8	95-118	2,8
Bamboo	1158	145	73-505	10-40
Hemp	1500	85-105	900	34
Caesarweed	1409	182	300-500	10-40
Banana	1031	407	384	20-51
Piassava palm	1054	34-108	143	5,6
Date palm [7]	1300-1450	60-84	70-170	2,5-4

One of the disadvantages of using natural fibers is that they have a high variation on their properties which could lead to unpredictable concrete properties [8,9]. Pre-treatment of natural fibers was found to increase concrete performance. Pulping is one of the fibre treatments that improve fiber adhesion to the cement matrix and also resistance to alkaline attack [10]. Pulping can be obtained by a chemical way (kraft) or a mechanical way. The latter have a lower cost (around half) and needs not effluent treatments [11].

Matrix characteristics

Savastano [12] mentioned that acid compounds released from natural fibres reduce setting time of cement matrix. Some authors reported that fiber sugar components, hemicellulose and lignin can contribute to prevent cement hydration [13, 14]. According to Sedan et al. (2008), fiber inclusion can reduce the delay of setting by 45 minutes. The explanation relies on the fact that pectin (a fiber component) can fix calcium preventing the formation of CSH structures.

Somme authors argue that the interfacial transition zone between concrete and natural fibers is porous, cracked and rich in calcium hydroxide crystal [15]. They reported a 200 μm thick at 180 days. Figure 1 shows a concrete sample were fiber imprints are visible as an example for low adhesion between cement matrix and natural fibers.

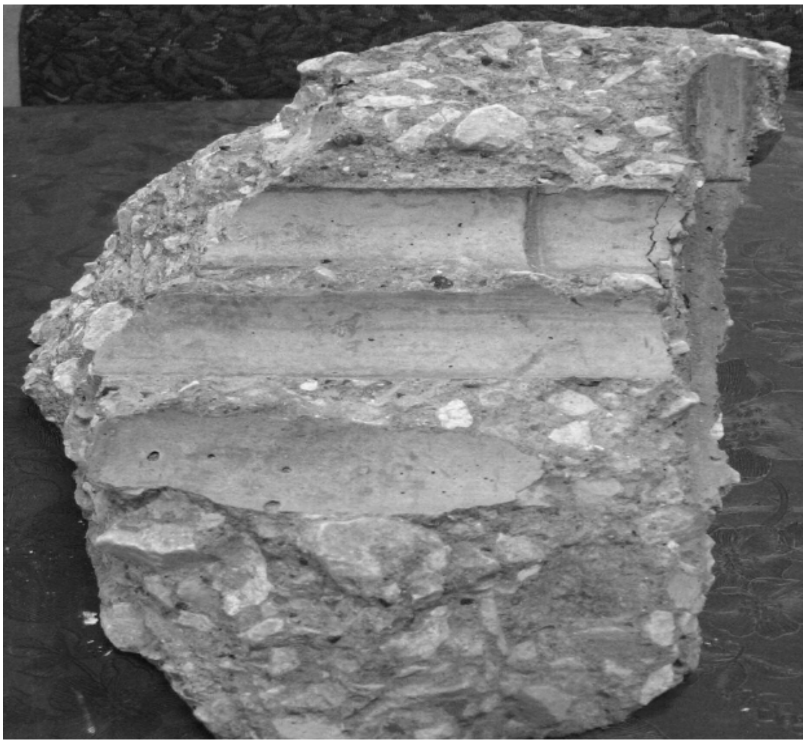

Figure 1 – Imprints of fiber reinforcement

On the contrary others reported that using vacuum dewatering and high pressure applied after molding lead to a dense ITZ [16]. The use of water-repellents also lead to a good bond between natural fibers and concrete [17]. The mechanical treatment of the fibers also improve the bonding between the fibre and cement [18]. According to some authors, alkaline treatment of fibers improve their strength and also fibre-matrix adhesion [19].

Properties

Filho et al. [20] found out that the use of 0,2% volume fraction of 25mm sisal fibres leads to free plastic shrinkage reduction. The combined use of coconut and sisal short fibers seem to delayed restrained plastic shrinkage controlling crack development at early ages.

As for the mechanical performance of natural fiber concrete Al-Oraimi & Seibi [21] reported that using a low percentage of natural fibres improved the mechanical properties and the impact resistance of concrete and had similar performance when compared to synthetic fibre concrete. Khare [22] tested several concrete beams and reported that bamboo has potential to be used as substitute for steel reinforcement (Figure 2).

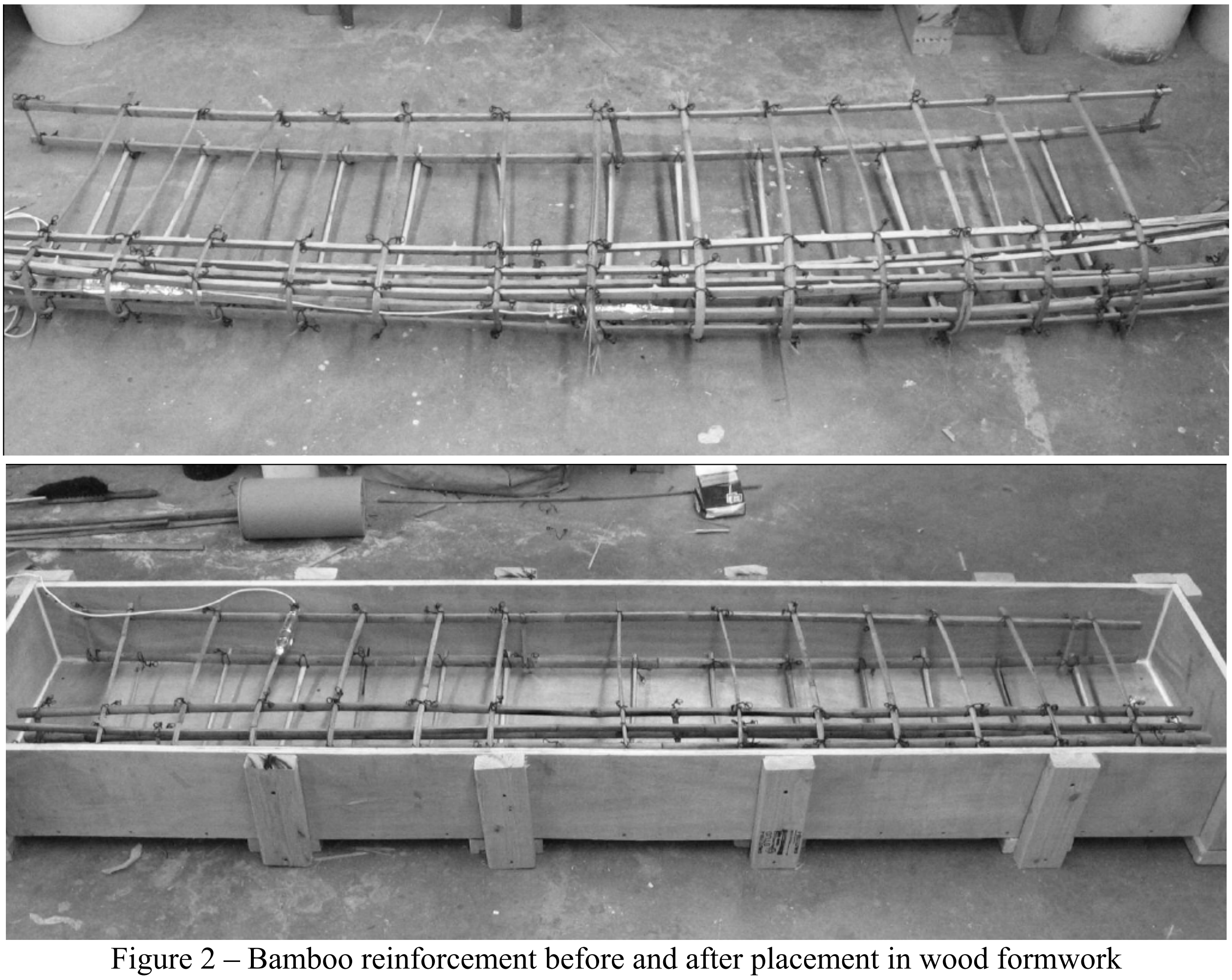

Figure 2 – Bamboo reinforcement before and after placement in wood formwork

Other authors reported that fiber inclusion increases impact resistance 3-18 times higher than when no fibers were used [23]. Reis [24] studies show that mechanical performance of fiber concrete depends on the typo of fiber. Being that coconut and sugar cane bagasse fiber increases concrete fracture toughness but banana pseudostem fiber does not. The use of coconut fibers shows even better flexural than synthetic fiber (glass and carbon) concrete.

Silva et al. [25] studied the addition of sisal fibers to concrete and reported that compressive strength was lower than concrete samples without the fibers. The explanation for that behaviour seems to be related to concrete workability.

Durability

Durability of vegetable fiber reinforced concrete is related to the ability to resist both external (temperature and humidity variations, sulfate or chloride attack etc) and internal damage (compatibility between fibers and cement matrix, volumetric changes etc).

The degradation of natural fibers immersed in portland cement is due to the high alkaline environment which dissolves the lignin and hemicellulose phases thus weakening the fiber structure [25]. Gram was the first author to study the durability of sisal and coir fiber reinforced concrete. The fiber degradation was evaluated by exposing them to alkaline solutions and then measuring the variations in tensile strength. This author reported a deleterious effect of Ca^{2+} elements on fiber degradation. He also stated that fibers were able to preserve their flexibility and strength in areas with carbonated concrete with a pH of 9 or less.

Filho et al [27] also investigated the durability of sisal and coconut fibers when immersed in alkaline solutions. Sisal and coconut fibers conditioned in a sodium hydroxide solution retained respectively 72,7% and 60,9% of their initial strength after 420 days. As for the immersion of the fibers in a calcium hydroxide solution, it was noticed that original strength was completely lost after 300 days. According to those authors the explanation for the higher attack by $Ca(OH)_2$ can be related to a crystallization of lime in the fibers pores.

Ramakrishna & Sundararajan [28] also reported degradation of natural fiber when exposed to alkaline medium. Other authors studied date palm reinforced concrete reporting low durability performance which is related to fiber degradation when immersed in alkaline solutions [29]. Ghavami [30] reported the case of a bamboo reinforced concrete beam with 15 years old and without deterioration signs. Lima et al. [31] studied the variations of tensile strength and Young´s modulus of bamboo fiber reinforced concrete expose to wetting and drying cycles, reporting insignificant changes, thus confirming its durability.

The capacity of natural fibers to absorb water is another path to decrease the durability of fiber reinforced concrete. Water absorption leads to volume changes that can induce concrete cracks [31, 32]. In order to improve the durability of fiber reinforced concrete the two following paths could be used:

a) Matrix modification.
Using low alkaline concrete adding pozzolanic by-products such as rice husk ash, blast furnace slag, or fly ashes to portland cement [32 -34]

Results show that the use of ternary blends containing slag/metakaolin and silica fume are effective in preventing degradation [35]. But in some cases the low alkalinity is not enough to prevent lignin from being decomposed [5]. Other authors reported that fast carbonation can induce lower alkalinity [32].

b) Fiber modification.
Coating natural fibers to avoid water absorption and free alkalis. Use water repellent agents or fibre impregnation with sodium silicate, sodium sulphite, or magnesium sulphate. Ghavami [17] reported the use of a water-repellent in bamboo fibers allowed only 4% water absorption.

The use of organic compounds like vegetable oils reduced the embrittlement process, but not completely [36]. Recent findings report that silane coating of fibers is a good way to improve the durability of natural fiber reinforced concrete [37]. Other authors mentioned that using pulped fibers can improve durability performance [38]. Some even reported that fiber extraction process can prevent durability reductions [39].

Future research trends

Further investigations about natural reinforced concrete are needed in order to clarify several aspects that current knowledge does not.

The available literature data is mostly related to the mechanical behaviour of natural fibre reinforced concrete. For instance only recently has the delaying effect of fibre inclusion received the proper attention. Since the main reason for fibre degradation relates to alkaline degradation, much more research is needed about the chemical interactions between the cement matrix and the natural fibers.

The right treatments to improve fiber and cement matrix compatibility are still to be found. The same could be said about the variation on fiber properties thus control quality methods are needed in order to ensure minimal variations on the properties of natural fibers. Durability related issues also deserve more research efforts.

References

[1] Gjorv, O.: ACI Concrete International, (1994), p.35-39

[2] Ferreira, Rui M.: Tests For Evaluation Of Concrete Durability. Master Thesis, (2000), University of Minho.

[3] Mora, E.: Building And Environment Vol. 42 (2007), p.1329-1334.

[4] Brandt, A.:Composite Structures Vol. 86 (2008), p.3-9.

[5] John, V.; Cincotto, M.; Sjotrom, C.; Agopyan, V.; Oliveira, C.: Cement & Concrete Composites Vol.27 (2005), p.565-574.

[6] Savastano, H.; Warden, P.;Coutts, R. : Cement & Concrete Composites Vol. 22 (2000), p.379-384.

[7] Kriker, A.; Debicki, G.; Bali, A.; Khenfer, M.; Chabannet, M.: Cement & Concrete Composites Vol. 27 (2005), p.554-648.

[8] Swamy, R., in: Proceedings Of The 2nd International Symposium On Vegetable Plants And Their Fibres As Building Materials. Rilem Proceedings 7. Chapman And Hall, (1990), p.3-8.

[9] Li, Z.; Wang, X.; Wang, L.: Composites: Part A Vol. 37 (2006), p.497-505.

[10] Savastano, H.; Warden, P.;Coutts, R.: Cement & Concrete Composites Vol. 25 (2003), p.311-319.

[11] Savastano, H.; Warden, P.;Coutts, R., in : Proceedings Of The CIB World Building Congress (2001 a), Wellington, New Zealand, p.11.

[12] Savastano, H.; Warden, P.;Coutts, R. : Cement & Concrete Composites Vol.22 (2000), p.379-384.

[13] Bilba, K.; Arsene, M.; Ouensanga, A. : Cement & Concrete Composites Vol.25 (2003), p.91-96.

[14] Stancato, A.; Burke, A.; Beraldo, A.: Cement & Concrete Composites Vol.27 (2005), p.599-603.

[15] Savastano, H.; Agopyan, V. : Cement & Concrete Composites Vol.21 (1999), p.49-57.

[16] Savastano, H.; Warden, P.; Coutts: Construction and Building Materials Vol.27 (2005), p.583-592.

[17] Ghavami, K. : Cement & Concrete Composites Vol.17 (1995), p.281-288.

[18] Coutts, R. : Cement & Concrete Composites Vol.27 (2005), p.518-526.

[19] Sedan, D. ; Pagnoux, C. ; Smith, A. ; Chotard, T.: Journal of European Ceramics Vol.21 (2008), p.183-192.

[20] Filho, R. ; Ghavami, K. ; Sanjuan, M. ; England, G. : Cement & Concrete Composites Vol.27 (2005), p.537-546.

[21] Al-Oraimi, S. ; Seibi, A. : Composites StructuresVol.32 (1995), p.165-171.

[22] Kare, L.: *Performance Evaluation of Bamboo Reinforced Concrete Beams* (2005), Master of Science in Civil Engineering, University of Texas.

[23] Ramakrishna, G. ; Sundararajan, T. : Cement & Concrete Composites Vol.27 (2005), p.547-553.

[24] Reis, J. : Construction and Building Materials Vol.20 (2006), p.673-678.

[25] Silva, J.; Rodrigues, D. : *Compressive Strength Of Low Resistance Concrete Manufactured With Sisal Fiber.* 51º Brazilian Congress of Ceramics (2007), Salvador, Brazil.

[26] Savastano, H.; Agopyan, V. : *Durability of Natural Fibres in Concrete.* Swedish Cement and Concrete Research Institute (1983), Stockolm.

[27] Filho, R.; Scrivener, K.; England, G.; Ghavami, K. : Cement & Concrete Composites Vol.22 (2000), p.127-143.

[28] Ramakrishna, G. ; Sundararajan, T. : Cement & Concrete Composites Vol.27 (2005a), p.575-582.

[29] Kriker, A. ; Bali, A. ; Debicki, G. ; Bouziane, M.; Chabannet, M. : Cement & Concrete Composites Vol.30 (2008), p.639-648.

[30] Ghavami, K. : Cement & Concrete Composites Vol.27 (2005), p.637-649.

[31] Lima, H. ; Willrich, F. ; Barbosa, N. ; Rosa, M. ; Cunha, B. : Materials and Structures Vol.41 (2008), p.981-989..

[32] Agopyan, V.; Savastano, H.; John, V.; Cincotto, M.: Cement & Concrete Composites Vol.27 (2005), p.527-536.

[33] Gutiérrez, R.; Diaz, L.; Delvasto, S.: Cement & Concrete Composites Vol.27 (2005), p.593-598.

[34] Savastano, H.; Warden, P.; Coutts: Construction and Building Materials Vol.25 (2005a), p.585-592..

[35] Mohr, B. ; Biernacki, J. ; Kurkis, K.: Cement and Concrete Research Vol.37 (2007), p.1531-1543.

[36] Filho, R.; Ghavami, K.; England, G.; Scrivener, K.: Cement & Concrete Composites Vol.25 (2003), p.185-196.

[37] Bilba, K. ; Arsene, M. : Composites Part A Vol.39 (2008), p.1488-1495.

[38] Savastano, H.; Warden, P.;Coutts, R.: Cement & Concrete Composites Vol. 23 (2001), p.389-397.

[39] Juárez, C. ; Durán, A. ; Valdez, P. ; Fajardo, G.: Building and Environment Vol.42 (2007), p.1151-1157.