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BOND OF NATURAL FIBERS WITH SURROUNDING CEMENTITIOUS MATRIX-A REVIEW

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Abstract-The need for sustainable material from renewable resources in the field of construction has become necessary due to large consumption of resources.Fibers obtained from plants are renewable.This literature study analyzes specifically; fiber used in various research, processing techniques, mechanical properties and their bonding mechanism in cement composites.Factors affecting the properties of concrete such as fiber types,fiber characteristics are also studied.It also presents the results obtained from pull-out tests conducted on embedded natural fibers in concrete mix.The purpose of this research is to investigate the effect of different treatment at the surfaces of natural fibers including their bonding in cement matrix. Four different treatments have been considered for this specific review. These treatment includes hybrid treatment using combination of horrification and polymer pigmentation, polymer pigmentation alone, horrification alone and alkali treatment using calcium hydroxide. A significant portion of this review is based on future trends related to the utilization of natural plant based fibers acting as curing agents and also as bond capacity improving material in cement composites.

Keywords- Bond strength, Natural fibers, Cementitious matrix.

1 INTRODUCTION

Construction industry is known as the most dynamic sectors throughout the world.Itcovers about 28% and 7% of employment both in skilled and unskilled areas, respectively. At the same time, construction sector is responsible for major depletion of large number of resources. The utilization of renewable resources in construction industry as a building material will facilitate to attain stable utilization pattern of resources. Concrete is the most used materialsin construction works because of its reliable compressive strength properties. Different fiber cement products are being produced which replaces mineral fiber by other fibers, i.e. PVA and polypropylene [1]. This shows a great change in field of construction to use plant based fiber cement material with properties same as synthetic fibers and are also cost effective as well as eco-friendly. Therefore, adding natural fibers in cement composites can be a better approach to attain sustainable construction. This study covers utilization of natural fibers in building material by reviewing past related publications.

Natural fibers consist of cellular structure. With various composition of cellulose, hemi-cellulosesas well as lignin comprise of various layers.Cellulose and hemi-celluloses are polymers made glucose units and various poly-saccharides, respectively. In case of lignin, it contains a mixture of heterogeneous and amorphous of aromatic polymers and also phenyl propane [2]. Fibers with difference in properties shows different behavior towards cement mix. Natural fibers show higher value of tensile strength and lower value of elasticity modulus; this shows a better performance when compared with synthetic fibers. One specific and significant draw backs of using natural fibers is their variation in properties due to which they show unpredictable variation in concrete properties [3, 4]. Performance of concrete can be enhanced by treating natural fibers using various methods and chemicals.

Cement composites along with aligned fibers shows tension-hardening behavior[5]. Researchers have used many models to predict the pull-out behavior of fiber based reinforced concrete. Naaman et al. proposed a method with bond–stress–slip relation of interface for fibers with smooth surfaces [6].

Naaman and Najm stated that fiber-matrix bond is influenced by four factors, (i) physical adhesion and chemical adhesion, (ii) mechanical component in bond, (iii) fiber interlocking, and (iv) friction [7]. Peled et al. studied that the friction stress for different matrices through pull-out behavior of natural fibers depending upon their mixture found to be 2.76MPA to 4.96MPA[8,9]. This can help to predict the bond shear stress versus slip curve, keeping in mind that method of back calculations can be applied in estimation of parameter by pull-out versus slip [10]. Naaman's presented a model of analyzing result of pull-out test, to verify bond properties in different fibers.
Therefore, due to demand of natural fibers for both structural and non-structural application in the field of civil engineering needs to be explored by latest use of technology like SEM,TGA. There is need to explore bond strength and pull out behaviour by the use of latest technology.

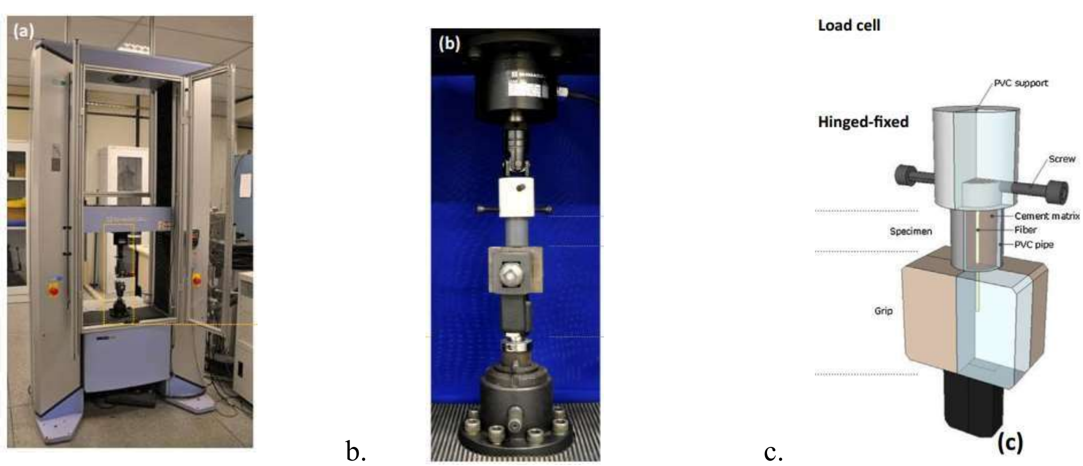
2 SURFACES OF NATURAL FIBERS

2.1 Surfaces of natural fibers for better bond.

The fiber amendment can be done based on three groups:1)physical treatments to improve their properties; 2) chemically treated fibers to increase interfacial bonding in fiber-matrix 3) both physical and chemical treatments of preserved good fibers.Physical treatments on the surfaces of natural fibers cause change in their properties and also in structure.This change in properties and structures of natural fibers (NF) effect their bond with composites. However, treating natural fibers with compatible chemicals leads to change in their properties and structure. Alkaline treatments affect fiber surface in two ways: 1) Increase in surface roughness, 2) Increase in number of cellulose exposed at fiber surface causing better interlocking between fiber cement matrixes. For composites with good physical as well as mechanical properties, increase in hydrophobic nature of natural fiber is the best solution ,which will improve the bond matrix.

2.2 Bond strength techniques.

Micro-mechanical testing (pull-out, micro-bond, disintegration, hornification) are of significant importancefor describing bond relation between fiber and matrix in cement composites.The processes that occur at the interface, one of the best techniques is the direct examination of interfacial failures through micro-mechanical failures. It helps to determine the time when cracks start occurring and also to check the already calculated values with actual process. Thus, interfacial de-bonding process can be differ from other processes. The method involving the direct observation of cracks beginning and spreading was developed and used in last few years, which caused significant improvement in data handling of micromechanical tests.



a. b. c.

Figure 1: Pull-out testing setup: (a) Testing machine, (b) Pull-out testingsetup (c) detailed sketch of pull-out testing setup [11]

2.3 Bond strength investigation.

In spite of all advantages of natural fibers, there are also some draw backs of using them, which limited their application with cement composites in construction industry.The inter-facial bond among natural fibers and that of cement composites is comparatively weak [19].

2.4 Bond strength.

Natural fibers treated with different techniques and chemical leads to an improvement in their pull-out testing behavior. Fibers behave as bridge agent to create" bridging effect" in fiber matrix to enhance bonding strength between them. Adding natural fibers in concrete mix cause slip hardening during the process of pull-out testing. Fibers after horrification when treated with polymers, increase bond adhesion, that cause fiber fracture which is helpful for studying embedment lengths. The difference in embedment length can lead to variation in pull-out mechanism. It can be noticed from the previously conducted studies that all treatments on NF results in improving their properties like, stiffness, adhesion and frictional bonding.

3 BONDING BEHAVIOR OF FRC AND ITS APPLICATIONS

Natural fibers obtained from raw materials of plants and vegetables are characterized by their compound micro-structure. But they offer great performance towards mechanical properties through tensile strength, which is commonly higher than the value of 200MPA [12-13]. Studies conducted on use of natural fibers shows their better properties and structure as compared to artificial and synthetic fibers. These studies describe that structure and properties of these fibers are somehow similar to those available in industry. While, to promote the use of natural fibers in construction industry as building material studies should be conducted on mechanism of bonding between natural fibers and cement composites.

The figure-2 shown below gives a detailed review of natural fiber. Micro-structure of a NF consists of many fiber cells, joined together with many small lamellas. These lamellas contain hemi-celluloses and ligninas well. Every single fiber-cell in natural fiber micro-structure consists of further four major parts, which is primary wall of fiber cell, secondary wall with certain thickness, tertiary wall of fiber cell and lumen. Natural fibers are different due to factor, like;number and area of lumens, quantity and size of these fiber-cells,walls of secondary cell with thickness and the cross-section, but they show same morphology.

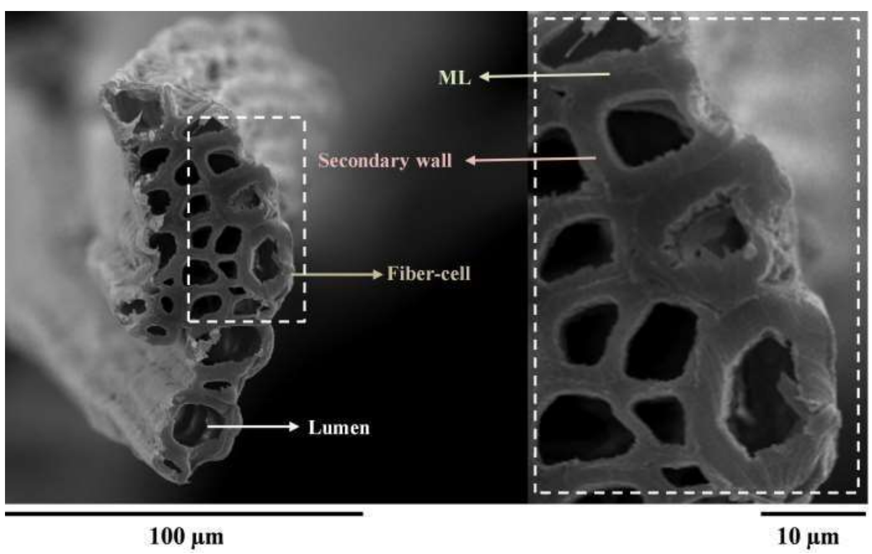


Figure 2: Microstructure of a natural fiber[14]

The factors such as lumen, fiber cells and secondary walls are reviewed for this specific study and few of these are presented(of specific fibers) in Table 1.. Example of fiber that consists of higher and lower lumen area are sisal, curaua and jute fiber. A single sisal fiber is made up of approximately 141 fiber cells with high lumen area value (about 5801 µm ^{2}). while, Curaua fiber contain high amount of fiber cells (about 305) and lowest lumen area (about 361 µm^{2}) with diameter of (about 0.81 µm).In case of jute fiber ,it is made of lowest quantity of fiber-cells (about 26), with lumen area of about 1000 µm^{2}[20, 22, 18]. It is a verification of the presence of hydrogen bridges hypothesis. Literature shows that the presence of hydroxyl group.

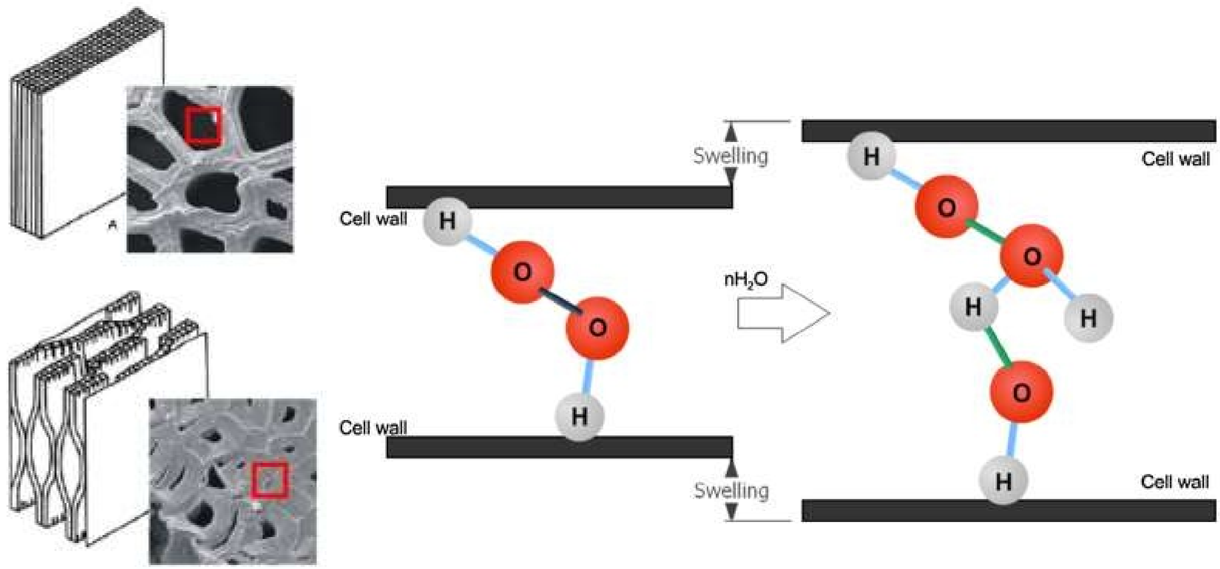


Figure 3: Schematic diagram showing swelling mechanism in wall of affecting bonding [15]

in cellulose, hemi-celluloses and in lignin develop a great number of the hydrogen bonding among macro-molecules found inthe fiber cell of walls.

Breakage of hydrogen bonds takes place because of humidity, which are again developed by hydroxyl group when come in contact with water. This process of breaking down and again developing bond provoke swelling, as shown with a sketch in Fig. 3. Breaking down these bonds requires a high amount of energy. The number of cycles applied on fiber increase hydrogen bond, cause structural variation in walls of fiber and also increase the amount of AOH bonds. Increase in this specific group cause an increase in hydrophobicity of lignin. The carboxyl groupswhen connect with new hydrogen bonds comes up with an increase in lignin macromolecule network [16].The process develops an improved bond among lignin, cellulose and hemicelluloses, giving stronger material, excellent stiffness and good strain capacity. Literature also shows that the presence of covalent bond between lignin and that of hemi-celluloses is same as present in inhabitant wood [17]. These lignins are covalently bound to hemicelluloses and these are bound to the cellulose with broad hydrogen nbonds.

Table 1: Nano-clay platelets with respective physical properties [21]

Color	Off-white
Density value(g/cm3)	1.99
d-Spacingvalue (001)(nm)	1.89
Aspect ratio value	220-1000
Surfacearea value(m2/g)	751
Size of Mean particle(lm)	6.1

Natural fiber starts absorbing a major amount of water after some specific time. Under normal conditions natural fibers have capacity to absorb approximately 200% of theirrespective weight [18].

The presence of hemi-celluloses,cellulose and lignin in plant fibers are responsible for absorbing high amount of moisture. Ligno celluloses fiber keeps on absorbing moisture until it gets saturated with water. This water covers the available spaces present between fibrils. Thus moisture absorption capacity is being reduced by various treatments. It can be noticed from literature that hornified technique cause reduction in moisture content by 15%, while, alkali treated, polymer treated and hybrid treated fibers reduce moisture content by 17.5%, 25% and 50%, accordingly.

Decrease in capacity of water absorption can be related with minor losses of hemi-celluloses and that of lignin, shown as TG analysis and the changes occur between chemical bonds making fibers further hydrophilic. In hornified treatment of fiber, moisture absorption capacity decreases after many cycles of wetting and drying . This process of wetting and drying increase the packing of fiber cells, while decreasing lumen. This result in minimizing moisture absorption capacity of fibers. For alkali treatment method, the mechanism is related to the removal of the lignin and that of hemi-celluloses, because of which it absorbs high quantity of water. Using polymer promotes for a coating layer, which specifically decreases its capacity to absorb water. In combination with hornification technique, it seems to be an effective method for high hydro-phobicity performance. It is believed that polymers penetrate in fiber cells ,this reduce the moisture absorption capacity of fibers.

4 DISCUSSION

The use of natural fibers as building material in cement matrix has gained so much importance because of its ability to enhance weaknesses in mortars. Fibers present in concrete mix develop bridging effect along the cracks, which reduce cracking propagation. Therefore, natural fiber reinforced cement concrete (NFRCC) are referred because of their high tensile, flexural strength also due their ductile behavior and ductility resulted from cracks reduction. The factors controlling the post-cracking behavior in fiber reinforced cement concrete(FRCC)may effect the design criteria for FRCC members. The factors that control the post cracking behavior includes; fiber proportion, fiber structure, their distribution and position in cement matrix, their properties and their chemical bond with matrix.

Micro-mechanical single fiber test can provide significant information related to strength of inter-facial bonding through the direct observation of cracks at their intiation and propagation. The inter-facial factors such as, interfacial shear strength (IFSS) and that of critical energy provide more reliable data than other conventional values. The values thus calculated had three independent micro-mechanical methods. The applied load to observe the distribution of shear stress experimentally along the interface of the produced cracks length shows the single shear lag produced due to applied load being function of internal failure. The stress and energy-based local failure criteria in similar way characterize the variations of interfacial bond quality upon fiber sizing for all systems investigated. By varying the size of natural fibers changes in IFSS are observed rather than aramid fibers because of various internal failure modes. The strength of natural fibers and those macro composites with sized as well as un-sized natural fibers correlates very well with bond strength investingated with the help of micro-mechanical testing such as pull-out testing etc. shown Figure3 below.

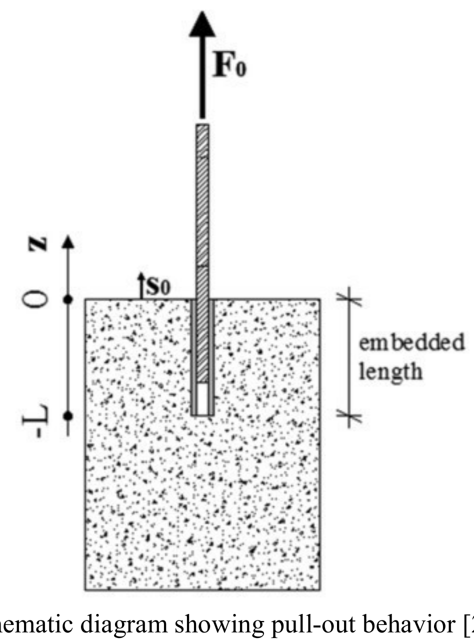


Figure 3: Schematic diagram showing pull-out behavior [23]

By increasing surface roughness, significant amendments can be done by above mention treatment as it results in disruption of hydrogen bonds in present network structure. It may develop a broad network of hydroxyl bond because of change in molecular hydrogen bonding.

5 CONCLUSION

Present research work presents all researches'conducted in recent past years regarding use of natural fibers in cement-based composites, depending upon their preparation techniques, properties, their methods to improve bonding between fiber-matrix and proportions. Keeping in mind all the facts, following conclusions can be made:

- Increase in embedment length cause an increase in pull-out force, however, no progress occurs in shear strength of bond after increase in embedded length from 10mm-40mm.
- The hornification method of treatment seems to be the simplest solution to enhance mechanical properties as well as bond to cement system. These properties can also be improved during the process of wetting and drying.
- Properties of NF depend on their origin, structures,their age and also on their experimental condition (i.e. diameter of fiber, length of gauge, temperature). These properties can be improved by removal of impurities present on the surface of natural fibers which reduce water absorption and enhance properties related to fiber-matrix.
- Removing impurities from the surface of the NF can facilitate the mechanical inter-locking also bond reaction that occur because of hydroxyl group's disclosure in chemicals for example resins and dyes.
- The bond between fiber composites and that of concrete mix can be strengthened by adding a calculated proportion of fine sand into water epoxy coating.
- In case of polymer treatment, high fiber-matrix bond can be achieved with better frictional mechanism and slip hardening.
- Boiled fibers with thickness ranging from 0.30-0.35mm show more tensile strength than those with thin surfaces dried and treated with chemicals.
- Change in embedment length can affect the bond strength of fiber and matrix. It has the highest embedded length value of 30mm.

The results obtained from conducted research will pave path for detailed study and understanding of mechanical behavior of natural fibers in cement matrix. Above all, the study will look for structural application of NFRC members through their mode of response.

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