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Degradation mechanisms of natural fiber in the matrix of cement composites

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ABSTRACT

The degradation mechanisms of natural fiber in the alkaline and mineral-rich environment of cement matrix are investigated. Cement hydration is presented to be a crucial factor in understanding fiber degradation behavior by designing a contrast test to embed sisal fibers in pure and metakaolin modified cement matrices. In addition to durability of sisal fiber-reinforced cement composites determined by means of flexural properties, degradation degree of the embedded fibers is directly evaluated by proposing a novel separation approach. The results indicate that, by reducing alkalinity of pore solution, metakaolin effectively mitigates the deterioration of natural fiber. By combining results of thermogravimetric analysis and microstructure, the alkali degradation process of natural fiber, which consists of hydrolysis of lignin and hemicellulose, stripping of cellulose microfibrils and deterioration of amorphous regions in cellulose chains, is visually presented. Two new concepts of mineralization mechanism, calcium hydroxide (CH)-mineralization and self-mineralization, are also proposed and quantitatively characterized.

1. Introduction

The increasing environmental concern and awareness of industrial pollution have forced the construction and manufacturing industries to search for innovative materials that are reliable, sustainable and can replace conventional synthetic fibers as reinforcement of structural materials. Natural fibers, such as sisal, jute, cotton, flax, hemp, and kenaf, have already been considered as potential alternatives, given their environmental friendliness and ready availability in fibrous form and the fact that they can be extracted from plant leaves at low cost [1]. Natural fiber reinforced composites also offer environmental advantages such as reduced dependence on non-renewable energy/material sources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery, and biodegradability [2]. Cement and concrete products are notable for their weakness in tension and low toughness which gives rise to early cracking under impact loads or thermal shock, unless they are reinforced. Fiber reinforcement can be used to mitigate these issues [3]. Therefore, in the last two decades, considerable effort has been directed towards the use of various natural fibers, which are available in abundance in tropical and sub-tropical countries, as reinforcement of cement composites for producing cost-effective construction materials [4].

However, in spite of natural fibers' advantages, their usefulness in cement based materials is limited by the relatively low degradation resistance in alkaline environments, which means it loses strength when used as reinforcement of a cement matrix exposed to aggressive environmental conditions [5,6]. The low durability caused by degradation of natural fiber in cement's alkaline-mineral environment, which depletes the reinforcing effect of fiber, is often regarded as a challenge need be avoided. This has been the central issue that needs to be solved before promoting the widespread application of natural fiber in various composites.

Studies on the mechanical performance of natural fiber reinforced cement based composite [7–18], the durability of natural fiber-cement composite in different aging conditions [19–25], and treatment methods for improving its durability [3,26–29] have been performed in recent years. However, the investigation of the degradation mechanisms of natural fiber in the complex alkaline and mineral-rich environment of cement matrices, as characterized by hydration process, crystallization, setting and hardening, was reported rarely. Only a few publications addressed the failure of natural fiber in cement composites. Gram [30] and Filho [19] described the dissolution of lignin and hemicellulose in a cement pore solution and alkaline hydrolysis of cellulose molecules, which leads to the degradation of molecular chains and the reduction in the degree of polymerization and the tensile strength were the main aging mechanisms of natural fibers in cement based composites. Besides, the crystallization of lime in the lumen and middle lamellae also decreased the fiber's flexibility and strength [19,31]. Mohr et al. [21] proposed a three-part progressive degradation mechanism during wetting and drying cycles, the third part of which is the fiber embrittlement due to fiber cell wall mineralization, which was indicated by the lack of recovered toughness. Melo Filho et al. [32]

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investigated two fiber degradation mechanisms in Portland cement composites: fiber mineralization and degradation of cellulose, hemicellulose and lignin due to the existence of calcium hydroxide and adsorption of calcium and hydroxyl ions. However, the results obtained so far have been disappointing, primarily because the intrinsic degradation kinetics and mechanisms of natural fiber and its three

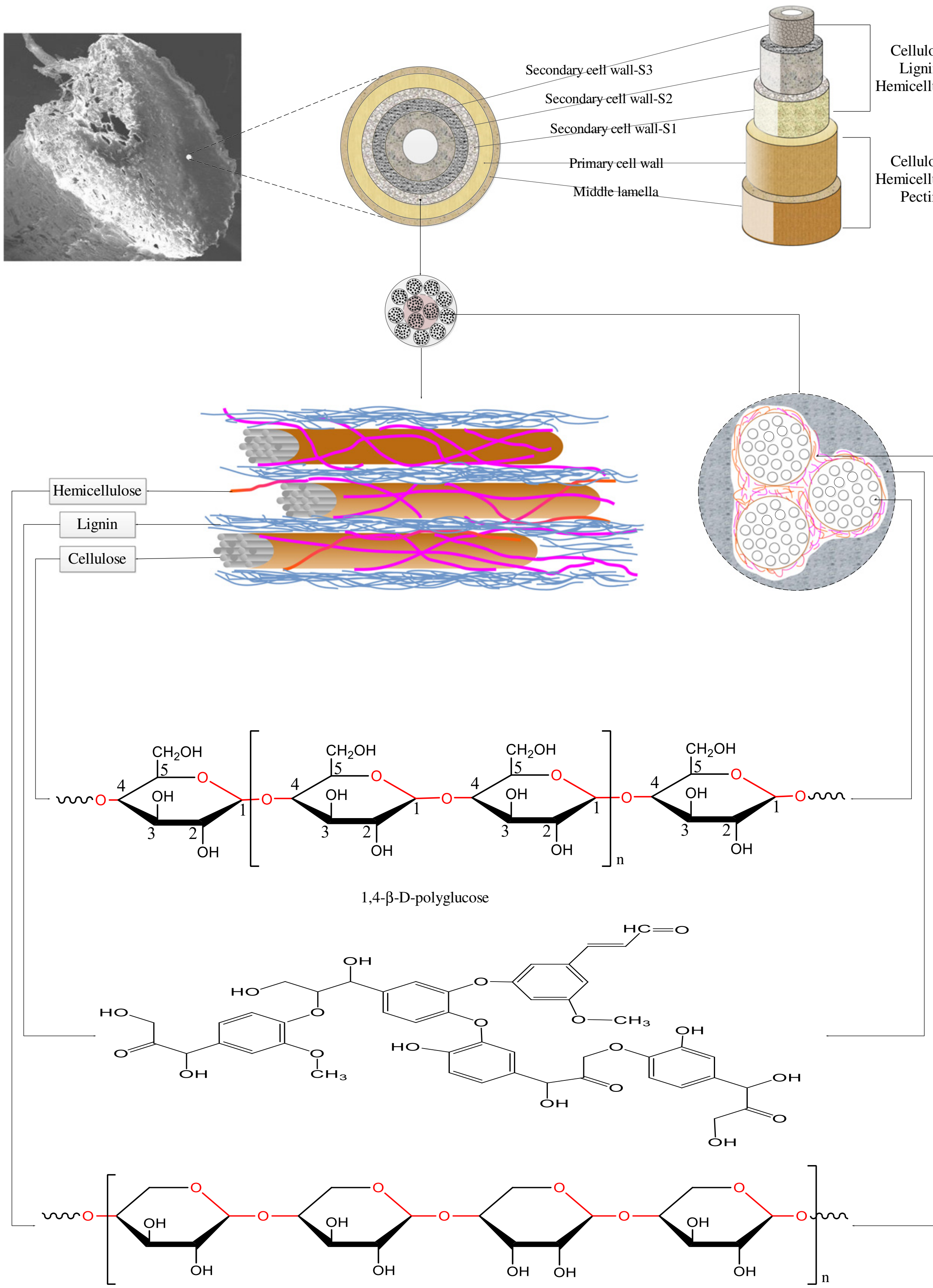

Fig. 1. Microstructure, schematic diagram and molecular structures of natural fiber cell wall.