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Influence of lignocellulosic aggregate coating with paraffin wax on flax shive and cement-shive composite properties

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HIGHLIGHTS

- Flax shives are used with cement for making lightweight composite.
- Uncoated and coated shives with paraffin wax are used as lightweight aggregates.
- Paraffin wax is able to protect shives from water and to inhibit swelling.
- Improvement in mechanical and hygral properties of the composite due to coated shives.
- Small increase in thermal conductivity and bulk density with coated shive use.

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ABSTRACT

Due to their low cost, lightweight and thermal insulation properties, lignocellulosic by-products received a particular attention, in the recent years, for manufacturing lightweight concretes. However these by-products are not fully compatible with cement matrix leading to setting delay, significant dimensional variations, and low mechanical strengths. To avoid such drawbacks, a coating process of flax shives using paraffin wax is proposed in this study. This will lead to reduction in shive water absorption. Compared to composites elaborated with raw shives, the composite obtained in this work exhibited significant improvements in hydrous behavior and mechanical strengths with moderate increase in apparent bulk density and thermal conductivity.

1. Introduction

Various lignocellulosic materials are available locally as wastes from the agro-forestry industries and cultivation (from wood and natural plants) in many parts of the world [1]. The disposal of the lignocellulosic wastes is a major environmental problem because of their huge quantity. Using these wastes as raw materials to substitute mineral aggregates in the field of civil engineering could reduce the magnitude of the problem. In cementitious composites, the main function of the lignocellulosic aggregate introduction is to reduce the density of the concrete composite and increase the thermal and acoustic insulating properties [1]. During the last four decades, several reports on the use of lignocellulosic materials to produce cement-bonded composites have been published. These include variety of wastes found in different countries [2–4]. Not all lignocellulosic materials are compatible with cement. Several factors influence the compatibility between lignocellulosic materials and cement such as particle size, extractive effects and quantity of lignocellulosic aggregates to the amount of cement [5]. An initial statement could be that every lignocellulosic resource has a very complex physical and chemical structure. It is mostly composed of four components: cellulose, hemicellulose, lignin, and pectin [6]. In their cell walls the lignocellulosic aggregates also contain various soluble organic compounds such as carbohydrates, glycosides and phenolic compounds [1,7]. These compounds exert a set-retarding effect depending on their concentration. Thus leading to a partial or complete inhibition of the cement hydration, resulting in a weakening of the ultimate mechanical strength of the composite [8]. The inhibition mechanism of the cement setting by these soluble organic compounds is complex. However, several researchers believe that the organic extractives are pulled into the cement solution where they make complexes with the metal ions present. This decreases the

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concentration of Ca^{2+} ions in the solution and possibly disturbs the equilibrium of the solution, which delays the start of nucleation of $Ca(OH)_2$ and Calcium–Silicate–Hydrate (C–S–H) gel [1].

Dimensional variation of the composite is another difficulty encountered when lignocellulosic aggregates swell with increasing moisture content and shrink as they lose moisture [9]. These variations are likely to create cracks within the composite materials at both the macroscopic and microscopic scales, due to the stresses developed. These cracks may allow aggressive agents to penetrate into the composite [10].

Several methods have been investigated (i) to reduce the tendency of the lignocellulosic materials to absorb water, (ii) to avoid the migration of the harmful organic soluble compounds from lignocellulosic materials toward cement matrix and (iii) to prevent the lignocellulosic material degradation by the mineral compounds in cement paste [11]. Water can penetrate the cellular structure of the lignocellulosic aggregate mainly by capillarity as liquid water, by vapor diffusion into cell lumena and as bound water within the cell wall [12].

Several authors have investigated the treatment of the lignocellulosic aggregates by coating [6], soaking [5], chemical [6] or thermal methods [13]. The principle of the coating methods is to cover the surface of the lignocellulosic aggregates to isolate the aggregates from the cementitious matrix. Low water permeable (or soluble) mineral substances [10], organic substances [4,14], or both [15] can be used. Another goal is to enhance the adhesion between the vegetable particles and the cement paste where there is a close relation between the adhesion and the mechanical properties of the composites [16].

France is the world leader in flax cultivation, where its production of flax fiber and tow in 2013 was 83,100 T [17]. This is equivalent to about 194,000 T of flax shives [18]. Traditionally, flax shive is considered a waste product (26 €/T) [19] or used in low-value applications such as fiberboard, animal bedding, mulching and fuel for thermal energy [4]. The aim herein is to improve the compatibility between the flax shives and the cementitious matrix, and also to propose a recovery method for a local by-product.

This paper presents the results of an investigation carried out on a coating process using paraffin wax and its effects on the flax shives and the cement-shive composites elaborated. It discusses the hydrous, mechanical, thermal and microstructural properties of the cement-bonded composites made with the flax shives aggregates, their advantages, limitations, and possible applications in construction. Paraffin wax has been selected due to its physical and chemical properties. It is mostly found as a white, lightweight, odorless, and hydrophobic solid. It is also characterized by chemical inertness and stability [20].

2. Materials and methods

2.1. Raw materials

Flax shives were supplied by CALIRA (Coopérative Agricole Linière de la Région d'Abbeville, France). These lignocellulosic particles are 7.39 ± 4.41 mm length and 1.14 ± 0.46 mm width. The size distribution of the bulk flax shives (before and after treatment) was studied using image analysis. The incremental and cumulated distributions of the untreated shive lengths and widths are presented in Fig. 1(A). This figure shows that 95% of the shives have a length between 1 and 16 mm and a width between 0.2 and 2 mm. However, 70% of this shives exhibit a length in the range between 3 and 9 mm and a width between 0.7 and 1.4 mm. The flax shives were dried at 50 °C until constant weight before their use. The cement used was Portland cement CPA CEM I 52.5 supplied by Calcia (France), according to the EN 197-1 standard [21]. Water and Ordinary Portland Cement (OPC) were the only components of the cementitious matrix. The chemical coating substance was commercial paraffin wax purchased from Sigma Aldrich (grade 68–70) with 66–70 °C as melting point, 900 kg m^{-3} as density at 20 °C and 430 g mol^{-1} as average molar mass. It exhibited a light appearance and was odorless.

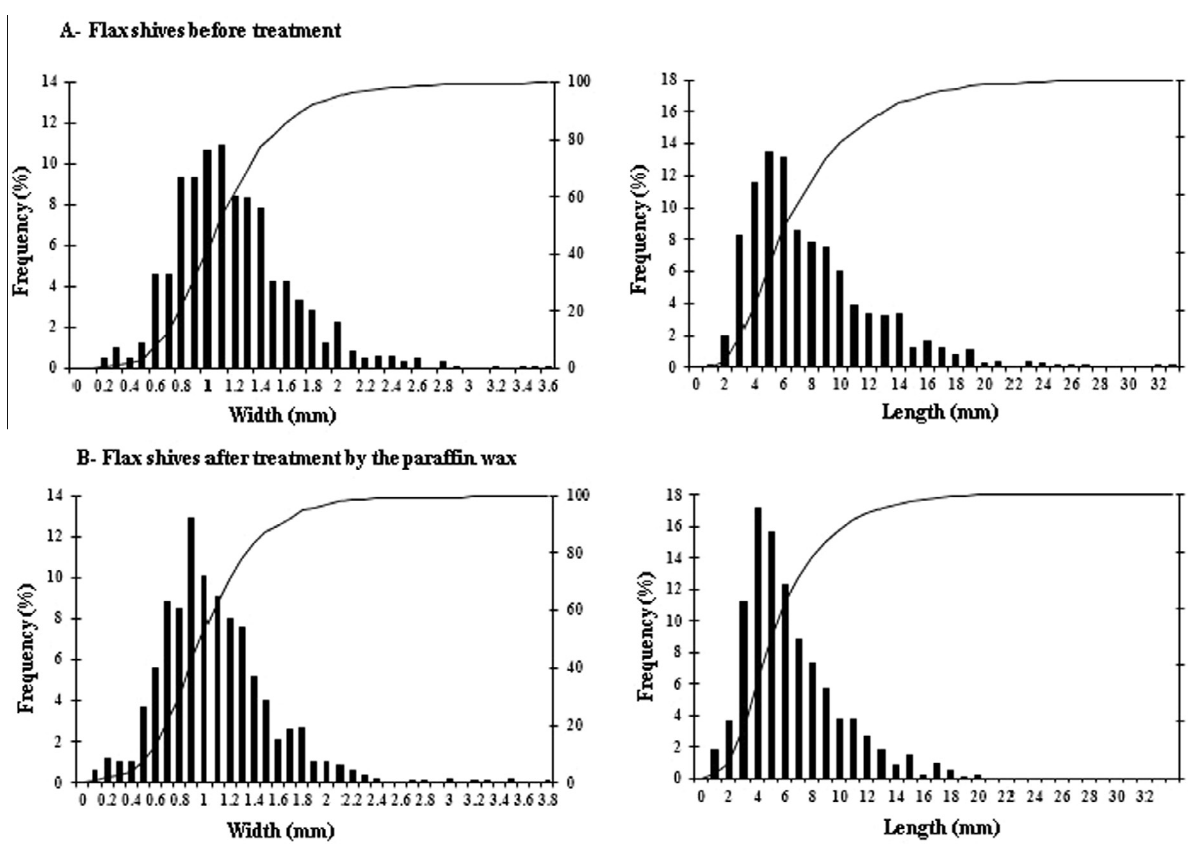

Fig. 1. Incremental (—) and cumulated (—) distributions of flax shive width (right) and length (left) before treatment (A) and after treatment by paraffin (B).