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Effect of saccharides on the hydration of ordinary Portland cement

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HIGHLIGHTS

- The influence of saccharides on OPC was investigated.
- HPAEC and GC were used to characterised monomeric sugars and uronic acids.
- The influence of the fibre leachates on ordinary Portland cement was characterised.
- The pH of the leachates was correlated with the GAA and GLA acid concentration.

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ABSTRACT

Recently, the use of natural fibres as a sustainable alternative for reinforcements in cement-based materials has increased significantly. However, these lignocellulose fibres containing saccharides can have important retarding effects on cement hydration. The objective of this study is to characterise the effect of different organic compounds present in lignocellulose fibres on the cement hydration reactions. For a better understanding of this process, sugars such as fructose, glucose and sucrose, lignin and cellulose have been added to a cement paste as well as leachates of fibres. Experimental results show that glucose, mannose and xylose in fibre leachates had a significant impact on the cement hydration, slowing down the hydration for up to 2 days.

1. Introduction

For many years, wood fibres, in various forms, have been mixed with cement to make composite materials such as wood wool cement boards (WWCB) and wood cement bonded boards (WCBB), collectively referred as cement wood composites. WWCB are manufactured with wood fibres, binder and additives: The wood is stored for 6–12 months in order to minimise the influence of sugars before it is cut to wood wool. Thereafter, wood is wetted, mixed with cement, placed into a mould, compressed and dried [1]. Two types of woods from regional forestry are very common to manufacture WWCB, which are spruce and poplar wood [2]. The binder is generally ordinary Portland cement, but magnesia cement, also known as *Sorell cement,* can be used as a binder as well [1]. WWCB shows a good resistance to decay and insects, a low density as well as good acoustical and thermal insulating properties [3]. The uses have focused primarily on these advantages of these composites. They are mostly used in parking decks, basement ceilings, floor units, loft conversion or timber frame construction as sound barriers for acoustic absorption [1].

The use of a cellulosic material as filler or reinforcement in these composite materials has significantly increased over the past decade thanks to important the improvements in process technology, better economic incentives and increased sustainability concerns such as renewability and recycling of wood materials [4–8]. Nowadays, a large amount of inorganic and organic waste is generated with a huge environmental impact (waste dumps, pollution, etc.) [9,10]. These waste resources can be used to develop sustainable construction materials, for instance, cement fibre composites, where wood can be replaced by organic waste fibres like coir, hemp or oil palm fibres [11].

However, the development of cement wood composites has been slowed down by a lack of understanding of the mechanism involved in the reaction between cement and organic fibres [12]. Previous researchers have shown that not all wood types are compatible with cement, because generally, there is a retardation of cement hydration lowering the strength of the composite material below the requirements or even causing the disintegration of WWCB boards after compression [13–15]. The cause is saccharides contained in wood and the alternative fibres. [16]. Natural fibres

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contain different saccharides with different solubility in water due to the different structures of the saccharides and the fibres themselves. Those that can be dissolved create leachates, that can be analysed explaining how much and which saccharides, particularly monomeric sugars, are leaching from the fibres and how they could have an impact on the cement-fibre composite. The quantity and type of leached saccharides depend on the type of fibres and their growing conditions. However, not all types of sugar have the same inhibitory effect. In 2014, Na et al. [16] reported that glucose and sucrose have a greater retarding effect than others sugars.

The effect of saccharides on cement hydration can be explained by different phenomena. Firstly, the calcium binding capacity is important to consider, because general studies about organic retarders have shown that they have strong Ca^{-} chelating groups which can prevent C-S-H gel formation [16–24]. Another effect is that sugars act through nucleation poisoning/surface adsorption forming semipermeable layers on the cement grains. They can also interact with different clinker minerals differently, for example, sucrose reacts with C_3S but does not react directly with C_3A and also accelerate ettringite formation, which it shows at early stages [17]. Another aspect to consider is the instability of some saccharides in a highly alkaline environment such as cement paste (pH $\sim$ 13). The degradation products were more efficient than the original wood extractives at inhibiting cement hydration [16]. By-products such as sugar acid anions or calcium sucrate cations appear to be more effective retarders than the sugars themselves [18]. In 2009, Simatupang [25] characterised other degradation products of saccharides mixed with cement as dihydroxy-butyric acid, gluco-saccharine acid, gluco-meta saccharine acid, lactic acid and mannose. Organic acids like uronic acids can suppress cement hydration and damage cement hydration products [26,27]. Several studies have investigated the effect of sucrose and glucose on cement hydration by using calorimetry, showing that sucrose had a strong retarding effect on cement hydration for up to several months [19,20,22].

These investigations show that hydration of cement in the presence of fibres is far more complex than the sum of hydration reactions of the individual minerals with saccharides. This study focuses on the influence of different little investigated natural fibres on cement hydration. Using leachates is a novel way to investigate this interaction. The studied fibres are bagasse, coconut husk fibres (coir), hemp, empty fruit bunches from oil palm trees and water hyacinth as well as spruce wood. Spruce wood is taken as a reference since it is commonly used for the production of cement fibres composites and is known to have relatively little influence on cement hydration [28]. The influence of saccharides on OPC hydration is investigated by adding pure fructose, glucose, sucrose, lignin or cellulose to cement pastes. Chemical characterization of the leachates is performed in order to explain the interaction between OPC and fibres. The most problematic leached organics are monomeric sugars (arabinose, galactose, glucose, mannose, xylose) and galacturonic and glucuronic acids [29–32]. The monomeric sugars and the organic acids concentration are characterised by high performance anion exchange chromatography (HPAEC). The concentration of uronic acids is measured by gas chromatography (GC). The chemical composition of natural fibres is determined by HPAEC following the Tappi standards. Cement hydration was studied by calorimetry to determine the most dominant factor affecting the hydration of cement. The aim of this article is to compare saccharides with leachates of fibres and explain differences of various saccharides and leachates on cement hydration.

2. Materials and methods

2.1. Materials

Fructose (purity of 99.0%), glucose (purity of 99.5%), sucrose (purity of 99.5%), lignin were provided by Sigma-Aldrich and microcrystalline cellulose (20–160 μm particle size) was produced by Merck KGaA, Germany. Six types of organic fibres were studied (Fig. 1). Bagasse, coir, hemp, oil palm – empty fruit bunch and water hyacinth were provided by Wageningen Food & Biobased Research, the Netherlands, and spruce wood was provided by Knauf Insulation, the Netherlands. Their general chemical composition measured in this study, and comparison values from literature, are shown in Table 1. The chemical composition of natural fibres was determined by Tappi T222, Tappi UM250, Tappi T264 and HPAEC. Measurements were done two times. Spruce wood and natural fibres samples were stored in plastic bags at room temperature until use. CEM I 52.5R (OPC) from ENCI, the Netherlands, was used in this study as a binder. The chemical composition of the OPC is given in Table 2.

2.2. Leachate preparation

Fibres were dried at 60 °C to constant mass and soaked for 2 h at 80 °C in distilled water (water/fibres ratio of 5:1). Filtrate and fibres were separated with filter paper. The pH of the fibre leachates was determined by a pH Meter (Metrohm 780) after the leachates were cooled down to room temperature. Then, cement was mixed with the fibre leachate instead of water. The leachates were compared with cement mixtures with additionally added saccharides. Plain OPC mixed with water is used as a reference.

2.3. Calorimetry measurements

Calorimetry was performed with a TAM Air Isothermal calorimeter at a constant temperature of 20 °C. All sugars, lignin, cellulose and fibre leachates were mixed with OPC and water. The percentage of sugars and lignin mixed with OPC were chosen as follows: 1.0, 0.5 and 0.2 wt%, the amount of cellulose was 1.0 wt% (all based on cement). For glucose, weight fractions of 0.1, 0.05, 0.02 and 0.01 wt% were also

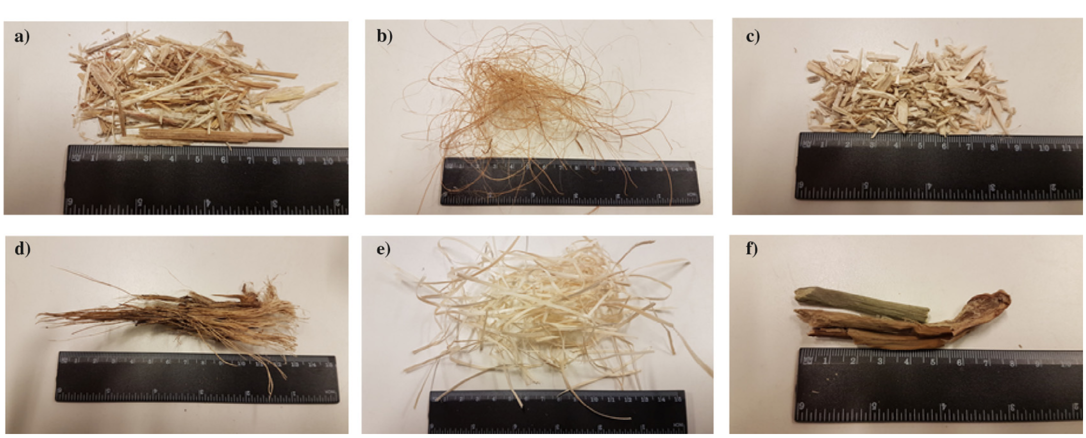

Fig. 1. Natural organic fibres: a) Bagasse; b) Coir; c) Hemp; d) Oil palm; e) Spruce; f) Water hyacinth.