

Impact of aggregate coating with a PEC elastomer on properties of lightweight flax shive concrete

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ABSTRACT

Lightweight concrete becomes an important subject of research because of its insulating properties. The main objective of this research is to present a process improving the flax shive behaviour in a cement matrix. Flax shives stem from flax culture. It is the major product (50% of biomass weight). To be used as aggregates, shives should have a hydrophobization treatment. The aim of this work is the treatment of shives with a biodegradable elastomer: poly(PEG-co-CA). This elastomer is synthesized by the polycondensation of polyethyleneglycol (PEG) and citric acid (CA). After their treatment with PEC elastomer, flax shives show a decrease in water absorption. Then, they are incorporated in a cement matrix. Mechanical properties, thermal properties and behaviour towards water (dimensional variations) of concrete are determined. The shive treatment shows an improvement in compressive and flexural strengths but an increase in thermal conductivity. The extreme dimensional variations (EDVs) and drying shrinkage (DS) decrease also with concrete prepared with treated shives compared to the standard. Overall the lightweight concrete obtained exhibits performances close to those of wood concrete.

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1. Introduction

Wood–cement composites are made from a mixture of lignocellulosic materials with cement to obtain a lightweight concrete. These lightweight concretes can be classified as bearing, bearing insulating or insulating according to their bulk density, compressive strength and thermal conductivity (RILEM Committee, 1978). Often made from vegetable products or byproducts, this kind of composite offers the opportunity to enhance the upgrading of lignocellulosic wastes (Jorge et al., 2004).

To increase the use of lightweight concrete it is necessary to decrease the setting delay and the dimensional variations, and to increase the mechanical strengths obtained with this kind of materials. The lignocellulosic aggregates can release water-soluble molecules responsible for a setting delay of the matrix (Bederina et al., 2007). Furthermore these vegetal aggregates exhibit an important water absorption capacity leading (i) to a competition for water between them and the cement (Coatanlem et al., 2006; Teo et al., 2007) and, consequently to an inhibition of cement matrix hydration, (ii) to important dimensional variations of the concrete in humid environment (Coatanlem et al., 2006). Moreover a setting delay and/or a cement hydration modification can involve poor mechanical strength development. Several treatment processes of aggregates have been designed to limit these drawbacks. Thermal

processes with high temperature and pressure, or high temperature and water are energy consuming (Kamdern et al., 2002; Jacobs et al., 2003; Nuopponen et al., 2004). Chemical processes can use not very environmentally friendly reagents (Rozman et al., 1997; Jahn et al., 2002; Van de Weyenberg et al., 2003; Tserki et al., 2005; Abdul Khalil et al., 2007). Mineral coating processes consume few energy but they can limit aggregate biodegradability at composite life end (Khazma et al., 2007; Bederina et al., 2009). Few works are relating to the use of organic coatings for lignocellulosic aggregates (Ledhem et al., 2000a,b; Khazma et al., 2008a).

The purpose of the process described below is to make possible the use of flax shives, a byproduct of flax culture, as aggregates in a cement matrix while remaining in the field of insulating concrete with acceptable mechanical properties. To increase the compatibility between shive aggregates and cement, an organic coating process is studied. The choice of the coating process is based on its low energy consumption. The choice of the coating substance is based on its biodegradability to obtain environmentally friendly aggregates and on its elastomeric character to permit reversible deformation.

In recent decades, research on biodegradable polymers has increased (Younes et al., 2004; Cohn and Hotovely-Salomon, 2005; Yang et al., 2006; Qiu et al., 2006; Lei et al., 2007; Tatai et al., 2007; Gerech et al., 2007). Polyglycolide (Yang et al., 1999), polylactide (Zhang et al., 2003) and other polymers have been developed. Few works have been conducted on elastomers until Wang and co-workers synthesized the poly(glycerol sebacate) (Wang et al., 2002, 2003): a biodegradable elastomer obtained by condensation

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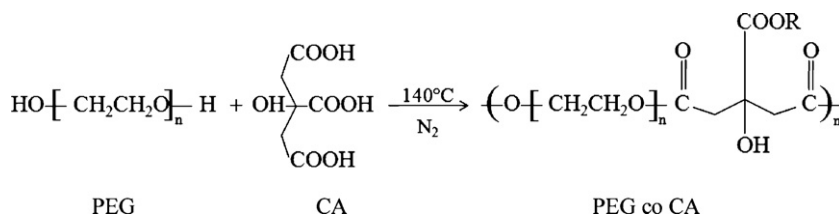


Fig. 1. Condensing reaction between PEG and CA (Ding et al., 2006).

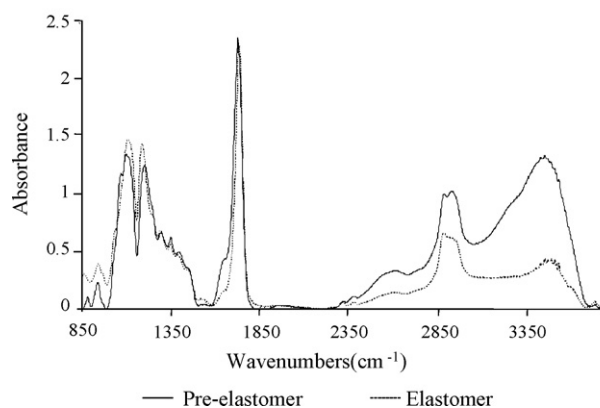


Fig. 2. FTIR spectra showing the two stages of polymerization.

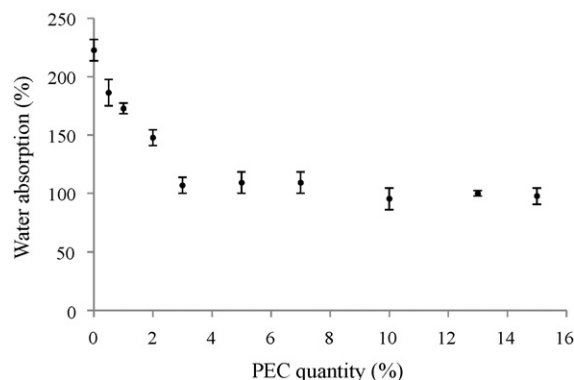


Fig. 3. Water absorption evolution with PEC quantity.

of glycerol with sebacic acid. However, this elastomer presents a low and slow biodegradability. Ding et al. (2006) have manufactured a new biodegradable elastomer exhibiting a weight loss greater than 60% after 96 h incubation at 37 °C in a phosphate buffer saline. This is the poly(polyethyleneglycol-co-citric acid) (PEG reagent-co-CA called PEC) summarized by a condensation reaction of polyethylene glycol (PEG reagent) and citric acid (CA reagent) under atmospheric pressure without any catalyst.

After the synthesis according to the method proposed by Ding et al. (2006), this elastomer is used for flax shive treatment. Shives are characterized by scanning electron microscopy (SEM), their real bulk density is determined, as well as their water absorption capacity before their incorporation into the cement matrix. The effects of this process on the cement composites are evaluated by conducting mechanical, hydrous and thermal tests.

2. Experimental program

2.1. Raw materials

Flax shives are supplied by CALIRA (Cooperative Agricole Linière de la Région d'Abbeville, France). These wood particles, 4–8 mm length and 0.6–1.3 mm width, are washed with distilled water to eliminate impurities and dried at 50 °C for 3 days until constant weight before their use.

The cement used was Portland cement CPA CEM I 52.5 supplied by Calcia, according to EN 197-1 (2001) standard. Clinker is the main component ($\geq 95\%$) of this cement, so result dispersion is avoided. No fillers and no sand particles were applied in this study.

Chemical materials are polyethyleneglycol (PEG 200) produced by Panreac, with 1.25–1.28 of density and citric acid (CA) produced by Fluka, 192.43 g/mol as molecular weight and 99.5% of purity.

2.2. Composite elaboration

The lightweight concrete is prepared with a shives to cement (S/C) volume ratio of 4 and water to cement (W/C) mass ratio of 0.50. These ratios arise from a preliminary study conducted in

order to obtain a composite containing the more lignocellulosic aggregates without being friable. W/C mass ratio is maintained constant for all composites with coated and not coated flax shives. Flax shives are not saturated in water prior their mix with cement. Different concrete constituents are mixed using a standard mixing machine (according to EN 196-1, 1995). For each mix, three 4 cm × 4 cm × 16 cm prismatic specimens were made. The mixture was introduced into the mould in two layers. Between each addition, the mould was placed on a shock table for 60 hits. After mixture levelling the samples were allowed to cure for 24 h, then demoulded and cured during 28 days at a temperature of $20 \pm 2^\circ\text{C}$ and 95% relative humidity inside a controlled room. After curing, concrete samples were dried in a 50 °C oven for 7 days (until constant weight).

2.3. Elastomer synthesis

The elastomer is synthesized according to the method proposed by Ding et al. (2006). The process starts with a pre-elastomer synthesis and then this pre-elastomer is reacted to generate the elastomer. For the pre-elastomer synthesis, the PEG and citric acid (molar ratio 10:9) are mixed in a flask well closed and equipped with a nitrogen flow. The mix is dissolved under nitrogen flow at a temperature of 150–155 °C in oil bath. After dissolution, the mixture is left for 7 h under atmospheric pressure. For the PEC elastomer synthesis, the pre-elastomer is post-polymerized under atmospheric flow for a period of 24 h. This elastomer is colourless, odourless and has a high viscous aspect. The reaction is characterized using a Fourier transformed infrared spectrometer (FTIR): IR-Prestige 21 provided by Shimadzu. The data processing software is the IR-solution.

The reaction presented in Fig. 1 shows the ester bond formation between PEG and CA. PEG takes the position of a functional monomer that can control the density of elastomer molecule. A decrease in peak at 3450 cm^{-1} with post-polymerization, related to “-OH linked” groups and an intense C=O stretch at 1720 cm^{-1} indicating ester bond formation have been observed on FTIR spectra of the pre-elastomer and elastomer (Fig. 2). Ding et al. (2006) have also observed this decrease at 3460 cm^{-1} after post-polymerization.

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