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Feasibility study of lightweight cement composite containing flax by-product particles: Physico-mechanical properties

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ABSTRACT

The purpose of this study was to investigate the potential utilisation of flax by-products in cementitious matrices, as aggregate additives, to develop lightweight construction materials that could be used for load-bearing walls. A material containing different amounts of flax particles, ranging from 0% to 10% as partial replacement of cement, was aerated by artificially entrapping air voids by means of a protein air-entraining agent. The composites were characterised by destructive and non-destructive testing. Analyses were made regarding the inhibitory effect of flax particles on hydration of cement, and the properties of the fresh and hardened composite. The results of hydration test have shown that an increase of flax particles in the cement matrix increases the inhibitory effect on cement hydration with a long setting time of the composite. For a specific mix with 10% of flax particles replacement, the corresponding inhibitory index-value of 57.5% classifies the mixture as being of "high inhibition". However, the use of calcium chloride reduced the inhibitory effect on cement hydration, resulting in a "low inhibition" classification. Results from tests performed on fresh composite have shown attractive properties such as improvements in workability and air-entrainment with increasing flax particles. Study of the hardened composite obtained from oven dried specimens has indicated a significant reduction in sample unit weight, along with compressive strengths compatible with the basic requirement of lightweight construction materials, corresponding to RILEM "class III" recommendations. The reduction in flexural strength was lower than that in compressive strength. The results have also shown a high reduction in the dynamic elastic modulus, which indicates a high level of sound insulation of the composite.

1. Introduction

Increased agricultural production and the development of agro-based industries have brought about the production of large quantities of agricultural wastes, most of which are not adequately managed and utilised. Agricultural wastes were generally used for fertiliser and fuel for energy production, but little work has been carried out to develop utilisation of these wastes in the production of building materials. However, the use of cement composites based on agricultural residues opens up a vast field of study, production and application in civil engineering. The application of these elements is interesting as regards the recycling of the residues, since these are easily available and renewable low-cost raw materials.

A large amount of agriculture wastes are generated every year from the northern region of France. The reuse of this waste as a raw material to substitute mineral aggregates, in cement matrix provides an interesting alternative to meet the challenge of disposal that would solve environmental problem. In this context, several studies have been conducted on various types of agriculture wastes modified Portland cement material [1–4]. These composites display lower density and have several potential applications such as acoustic and thermal insulation, fire resistance cladding…etc. Other natural fibres have also been studied, including hemp [5], rice husks [6], or other vegetable fibres [7]. Results have indicated that the mortar mixes containing these admixtures are already used for insulating or coating applications. However, the main disadvantage of these composites is their sensitivity to the water absorption and dimensional instability in the presence of change in relative humidity [8]. In addition to these, agricultural wastes such as wheat straw ash, and sugarcane bagasse ash are also being used as pozzolanic materials. The study carried out by Ganesan et al. [9] reported on the effects of bagasse ash (BA) content as partial replacement of cement on physico-mechanical properties of hardened concrete. The test-results have indicated that BA is an effective mineral admixture, with 20% as optimal replacement ratio of cement. However, although cement composite containing vegetable waste particles have all the above mentioned advantages they are not totally free of problems. Cellulose particles are highly polar materials and their compatibility with very apolar matrices is highly problematic. Furthermore, due to their polar nature they are hydrophilic materials, which also pose restrictions on their use in some applications. The viability of the use of vegetable residues in cement paste depends on the appropriate chemical treatment for each species. Usually, these residues are

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incompatible with Portland cement, inhibiting the cement composites adhesiveness and hardening. This incompatibility can be attributed to the amount of dissolved material extracts, which interfere in the cement hydration process, and hence, in the formation of the essential products that contribute to the strength of the composite. These extractives are generally composed of terpenes, fatty acids, cellulose, hemicellulose, lignin, sugars available, etc. [10].

The literature about the use of flax by-product wastes, as aggregates, to produce cement composite is poor. In this study, the particles were used as cement replacement in order to ensure a good contact between flax particle and cement paste. It's possible that the presence of sand and/or gravel reduces the contact zone between flax particle and cement paste. This also leads to mitigate the decrease of the mechanical strengths of the composite, which is also due to the defect bond between cement paste and flax particles. The suitability of utilising flax by-product materials for lightweight cement composites has been already examined [11]. Results of the chemical compatibility-test between flax particles and cement have shown that the particles inhibit cement hydration to such an extent as to make unsuitable for cement composite development. For mixture containing 20% of flax particles, it was even impossible for cement to set for time less than 36 h. In addition, the use of $CaCl_2$ chemical accelerator has not sufficiently reduced the inhibition effect of flax particles. To overcome this problem, other chemical treatments of the particles made evident to be necessary in order to improve the cement-flax particles compatibility. The selected treatments used were: hot water, NaOH solution, $Ca(OH)_2$, and $[(Na_2SiO_3)/(Al_2(SO_4)_3–18H_2O)]$ mixture solution of sodium metasilicate and aluminium sulphate. Results have indicated that the most effective treatment is $[(Na_2SiO_3)/(Al_2(SO_4)_3–18H_2O)]$ solution, which reduces the corresponding inhibitory index from 97.3%, for untreated particles, to 8.3%. Consequently, the initial setting time was reduced from 20 h to 6 h. The investigation of the composite properties has shown that the treatment of the particles also increases the mechanical strengths [12]. However, lightweight cement composite containing 20% of flax particles, that conforms to RILEM "class II" recommendations [13], has been developed (compressive strength is above 6.5 MPa and the apparent dry unit weight is less than 1300 kg/m^3). Nevertheless, the higher cost of chemical treatments would make the composite development questionable. This research is aimed at determining the technical feasibility of using flax by-product particles to develop lightweight cement composite. An additional objective was to minimise detrimental effect of the flax particles on the cement hydration, without using the various treatments. However, the idea consists to reduce the flax particle content in cement matrix and then to artificially entrap air void in the fresh composite by means of air-entraining agent. However, simple $CaCl_2$ chemical accelerator was used. In this paper, we report the test-results of the flax particles to cement compatibility and the influence of $CaCl_2$. An experimental test program was conducted mainly to investigate the properties of fresh composite included air-entrainment. The tested properties of hardened composite at dry state were unit weight, elastic dynamic modulus, and compressive and flexural strengths, all of them measured at 28 days. The flax particles were used as partial replacement of cement in mixture at different levels: 0% (neat control cement), 2.5%, 5%, 7.5% and 10% by weight.

2. Materials and experimental testing

2.1. Materials

The flax waste particles used in this study are generated from the mechanical processing of flax fibres in the stripping process. The flax materials are composed of different particle types and sizes. The materials, which contain a mixture of flax particles, steam fragments, lint, and wood shaves from the stripping process of linen manufacturers, are recovered within the dust extractors (exhauster hoods). This combination as waste particles in their natural form was sieved to having 2 mm maximum size and to remove the elongated particles. The bulk density of the materials is 130 kg/m^3 and their gradation curve is shown in Fig. 1.

The dissolved extractive components and the lignin content of flax particles were evaluated by using hot water treatment and Klason method [14], respectively. The test-results are shown in Table 1.

The air-entraining agent used is the powdered protein, received as a result of industrial processing of pig's and cow's blood. The main component of the substance is the atomized and thermally stabilized red blood cells. Powdered protein is manufactured by "Vapran Company". As a result of aerated cement composite containing rubber wastes study and preliminary research [15], the content of the powdered protein in test samples was at the levels of 1% by weight of cement. The bulk density of the entraining agent is 80 kg/m^3.

The cement used was ordinary Portland cement CPA CEM 1 52.5, in accordance with Standard NF P15-301 [16]. Both the flax particles and cement were initially dry-mixed in a planetary mixer. The particles were added as a partial replacement of the cement at four levels: 0% (neat control cement), 2.5%, 5%, 7.5% and 10% by weight. Total mixing water had been adjusted for all composites to achieve the same workability as the mortar with mixture proportions of 1:3:0.5 by weight for cement, sand, and water, respectively. $CaCl_2$ chemical accelerator, as 2% by weight of cement, was diluted in mixing water and then the total mixture was mixed for 3 min. The composite mixture proportions are shown in Table 2. Up until obtaining a uniform mixture, the required amount of protein air-entraining agent, as 1% by weight of cement, was added and the mixture was mixed for another 1 min. For measurement of the hardened properties, three prism samples of $40 \times 40 \times 160$ mm in size were prepared and moist-cured for 28 days at 20 ± 2 °C and 98% relative humidity. The hardened properties reported were obtained from the oven dried specimens. Before testing, all the specimens were dried in a drying oven at 70 ± 2 °C. The properties of the samples without air-entraining agent are listed in Table 3 [12].

2.2. Test procedures

The hydration test was carried out to determine compatibility between flax particles and cement. It was conducted under the methodology described in previous studies [17]. The test was performed with the addition of flax particles ranged from 2.5% to 10% by weight to the 200 g of cement. The amount of water added was

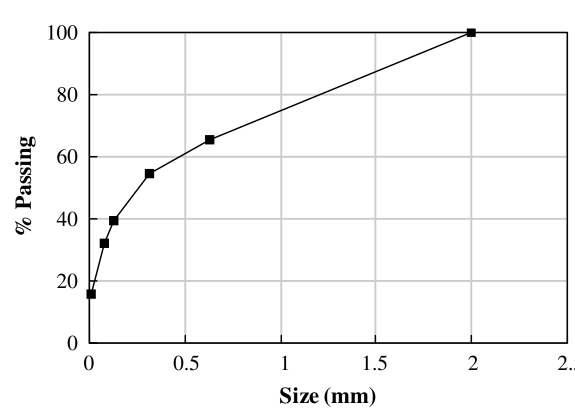

Fig. 1. Particle size distribution of flax by-product particles.