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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

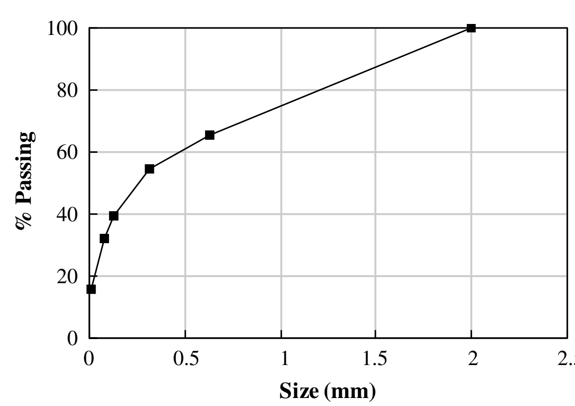

Fig. 1. Particle size distribution of flax by-product particles.

Table 1
Dissolved extractive components of flax particles

Component	Weight content (%)
Dissolved extractives	22.75
Lignin	22.00

Table 2
Composite mixture proportions

Weight content of flax particles (%)	Cement (kg/m^3)	Flax particles (kg/m^3)	w/c
0	858.00	0.00	0.30
2.5	703.75	18.00	0.36
5	591.85	31.15	0.42
7.5	506.90	41.10	0.48
10	440.25	48.90	0.55

Table 3
Properties of fresh and dry hardened composite without air-entraining agent [11]

Weight content of flax particles (%)	Entrapped air (%)	Fresh unit weight (kg/m^3)	Hardened unit weight (kg/m^3)	Elasticity dynamic modulus (GPa)	Compressive strength (MPa)	Flexural strength (MPa)
0	2.6	2125	2025	26.0	65	5.8
2.5	4.2	1942	1800	18.4	46	4.9
5	5.4	1820	1630	14.7	32	4.5
7.5	6.5	1735	1475	10.3	22	4.1
10	7.8	1650	1360	8.4	15	3.8

0.3 ml/g of cement and additional 2.26 ml/g of flax particles, based on experiment reported in previous study [10]. Control sample contained neat cement (Portland cement and water). Immediately after mixing, the sample was placed in a with-mouth insulated flask with a thermocouple wire (type K), and then covered with Styrofoam for insulation purposes. The flask was sealed with wrapping tape. The temperature rise of the mixture was recorded with a data acquisition system (HP 92804 C type) and plotted against the time. All the experiments were undertaken in a controlled room at 21 ± 2 °C and three replications were run for each composition. Different schemes have been proposed for evaluating the compatibility of wood with cement based on hydration test. Compatibility was assessed based on maximum hydration temperature, time taken to reach maximum temperature, hydration rate, and area under the hydration heating rate curve, relative to that of neat cement. In the study concerning the effects of combined pre-treatment on the compatibility of rattan cane particles with Portland cement, Olorunnisola [18] explored the possibility of developing an alternative cement-lignocellulosics compatibility classification method. The proposed compatibility index is based on the ratio of setting times of lignocellulosic-cement mixture and neat cement. In this study, the compatibility between flax particles and cement was evaluated by means the inhibitory index I (%), calculated using Eq. (1) [19],

$$I = 100 \cdot \left(\frac{T - T'}{T}\right)\left(\frac{t' - t}{t}\right)\left(\frac{S - S'}{S}\right) \quad (1)$$

where T and T' (°C) are the maximum hydration temperatures of neat cement and the mixture, respectively; t and t' (h) are the times to reach maximum hydration temperature of neat cement and the mixture; and S and S' (°C/h) are the maximum slopes of neat cement and the mixture, respectively.

Table 4
Inhibitory index used to classify the compatibility level [19]

Inhibitory index I (%)	Grade
$I < 10$	Low inhibition
$I = 10–50$	Moderate inhibition
$I = 50–100$	High inhibition
$I > 100$	Extreme inhibition

The effect of the inhibited cement was classified according to Table 4 [19]. The smaller the I-value the higher the compatibility between cement and particles addition. The setting time of the fresh composite was conducted using the Vicat apparatus, according to Standard NFP 15-431 [20]. The tests of the fresh sample included air-entrainment, measured using pressure method, according to the Standard NF P 18-353 [21]. A measurement of the workability was performed with "mortar maniabilimeter" described in French Standard NF P18-452 [22]. It is the measure of the time necessary for a defined quantity of mortar to cross a reference line while flowing under a specified vibration.

The 28-days properties tested on the hardened composite at dry state included unit weight, as determined by means geometrical measurement and weighting. The elasticity dynamic modulus was determined by applying longitudinal ultrasonic vibration, as specified in Standard NF P 18-418 [23]. The compressive and flexural tests were carried out in accordance with Standard EN 196-1 [24], using a universal testing machine. The rates of loading of compressive and flexural specimens were 45 and 3 kN/min. Three replications were used for each properties tested.

3. Results and discussion

3.1. Hydration test

Fig. 2 shows the variation of the hydration temperature vs. time for composite containing different levels of flax particles. The corresponding parameter-values of hydration test for all compositions are listed in Table 5. The addition of flax particles to cement clearly reduced maximum temperature attained and increased time to achieve the maximum temperature, as compared to the neat control cement. When no $CaCl_2$ was used, the initial setting time varied from 2.5 h, for neat cement, to 7.5 h and 16 h, for composite containing 5% and 10% of flax particles, respectively. The corresponding inhibitory index-values of 11.3% and 57.5% classified the mixture as being of "moderate inhibition" and "high inhibition", respectively. This inhibitory effect can be attributed to the

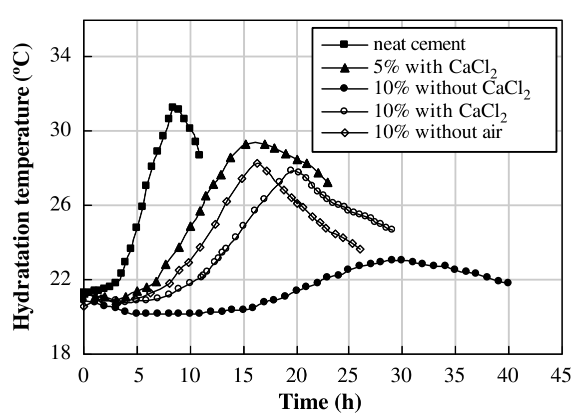

Fig. 2. Variation of the hydration temperature vs. time for neat cement and composite with 10% of flax particles.

Table 5
Parameter-values of cement hydration test for different flax particle ratios

Weight content of flax particles (%)	Hydration rate (°C/h)	Maximum temperature of cement hydration (°C)	Initial setting time (h)	Inhibitory index I (%)
0	2.07	31.3	2.5	–
5[a]	0.69	25.5	7.5	11.3
5[b]	0.97	29.2	4.0	3.1
5[c]	1.2	29.8	3.1	2.7
10[a]	0.21	23.0	16.0	57.5
10[b]	0.67	28.0	7.0	9.2
10[c]	0.86	28.4	5.4	5.0

[a] Mixture without CaCl2.
[b] Mixture with CaCl2.
[c] Mixture without protein agent.

dissolved extractive components of flax particles, but the main inhibitors of cement hydration are sugars and lignin that severely delay the hydration process, and hence, inhibit the hardening of the composite [2]. Inhibition of cement occurs when the calcium silicate hydrate nucleation sites, on the originally positively charged surfaces, are poisoned by the sugar-acid anions and lignin component [10]. The results of the component extractives of flax particles measurement are shown in Table 1. There was a greater proportion of lignin and soluble extractives that inhibit cement hydration and act as set retarder. The use of calcium chloride enhanced the performances of the mixtures. The mixture with 20% of flax was graded as "low inhibition" (inhibitory index of 9.2%), due to the capacity of chemical accelerator to buffer or minimise the adverse effect of the dissolved extractives and also to accelerate the cement hardening and setting. The mixture containing $CaCl_2$ was associated with higher maximum hydration temperature achieved and hydration rate, as compared to the mixture without $CaCl_2$. The corresponding initial setting time was reduced from 16 h to 7 h, and the hydration rate was increased from 0.21 °C/h to 0.67 °C/h. These results suggest that particles of flax by-product are suitable for manufacturing cement composite. Fig. 2 also indicated that the aerating composite exhibits high setting time values, in comparison to the composite sample without air. As can be seen from Fig. 2 and Table 5, the peak value of hydration temperature, and the rate of hydration of aerated composite were lower than those of composite without protein agent. The retardation in achieving the maximum temperature and the lengthening of setting time by approximately 30%, are due to the generated air in the composite. Similar trends were observed by Jones and McCarthy [25] in the study that examined the temperature profiles that can develop in foamed concrete due to cement hydration and their effect on strength.

3.2. Physico-mechanical properties of cement composite

Test-results of fresh and 28-days dry hardened properties, with air-entraining agent, for all compositions are listed in Table 6. Each test result represents the average of three test values.

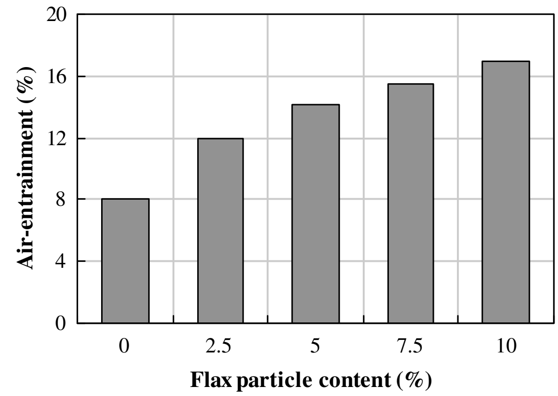

Fig. 3. Air-entrainment values of the composite containing different amount of flax particles.

3.2.1. Air-entrainment

The results of air-entrainment measurements of fresh composite, with respect to flax particle content, are displayed in Fig. 3. This figure clearly indicated that the addition of particles in cement matrix increases the level of air-entrainment. The value varied from 8%, for neat cement, to 17% for composite containing 10% of flax particles. When no protein agent was added, entrapped air varied from 2.6% to 7.8%. In fact, the packing of lightweight particles becomes difficult at high content and air voids are introduced into the product. When protein agent was added, the increase of air-entrainment with particle level is may be due to the capability of particles to entrap air in the matrix. Previous works have shown that the protein agent acts as an air-entraining promoter and the material gives rise to a foamed specimen. When mixing the ingredients, protein agent additive has foaming properties, improve the dispersion of cement grains and create air bubbles, which are well distributed in the whole matrix. It should be noted that the addition of protein agent increases the workability of the composite, due to both the generation of micros air bubbles and the plasticizer effect of the agent. This plasticizer effect has been already shown in previous work [26]. Reviewing paste literature on air-entrainment revealed that it is clearly an extremely complex process, which is affected by many factors, including the mixing process, material mixture proportioning, fine and coarse aggregates, physical and chemical properties of cement, water amount, dosage and properties of air-entraining agent and a range of other parameters [27].

3.2.2. Dry unit weight

The variation in dry unit weight of the composite vs. flax particle content is shown in Fig. 4. It should be noted that the addition of the flax particles reduces the dry unit weight of the composite. This behavior is due to the physical properties of flax, since it has lower density than cement paste. In addition, the air bubbles contribute to lightening the material. Fig. 5 shows the distribution of air bubbles in the matrix of hardened composite containing 10% of flax

Table 6
Properties of fresh and dry hardened composite with air-entraining agent

Weight content of flax particles (%)	Air-entrainment (%)	Fresh unit weight (kg/m^3)	Hardened unit weight (kg/m^3)	Elasticity dynamic modulus (GPa)	Compressive strength (MPa)	Flexural strength (MPa)	CLPA[a] (%)
0	8.0	1955	1560	16.5	32.0	4.0	6.3
2.5	12.0	1705	1285	10.8	21.0	3.4	4.5
5	14.2	1560	1160	8.2	15.6	3.1	3.6
7.5	15.5	1466	1070	6.4	11.3	2.6	3.1
10	17.0	1370	985	4.3	10.5	2.3	1.8

[a] Compressive strength loss per air-entrainment.

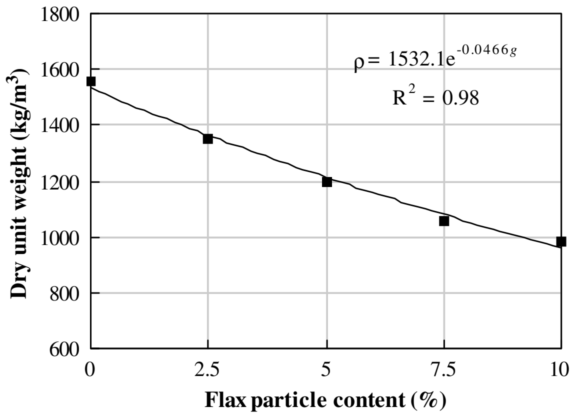

Fig. 4. Variation of dry unit weight of composite vs. flax particle content.

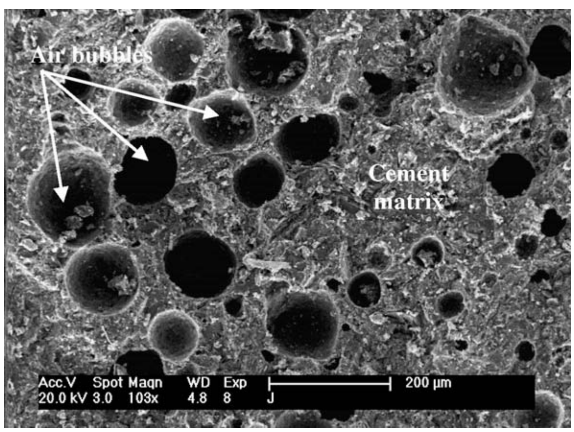

Fig. 5. SEM micrographs of hardened composite, showing the distribution of air bubbles in the matrix.

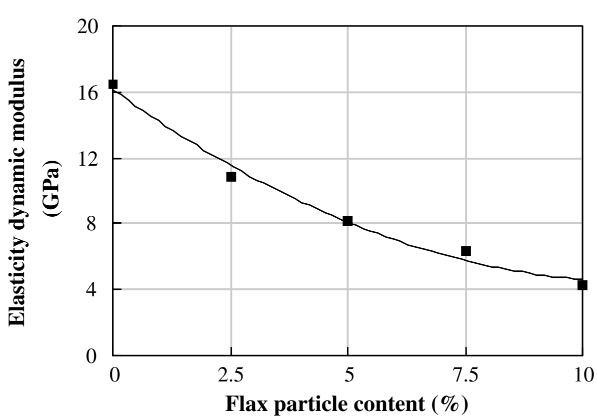

Fig. 6. Variation of elasticity dynamic modulus of composite vs. flax particle content.

particles. Dry unit weight-value decreases from 1560 kg/m^3, for neat cement, to 985 kg/m^3 for composite containing 10% of flax particles. These values correspond to reduction of up to approximately 37%. As compared to the composite without protein agent, aerating composite reduces the dry unit weigh by 38%. The following empirical relationship has been proposed: $\rho = 1532.1\exp(-0.0466g)$ (which yields a correlation coefficient of $R^2 = 0.98$), where ρ (kg/m^3) and g (%) are the unit weight and the flax particle content, respectively. The variation in dry unit weigh is not linear due to the increase in the level of air-entrainment with flax particles addition, which contributes to lightening the material.

3.2.3. Elastic dynamic modulus

Results of elastic dynamic modulus measurements vs. flax particle content are shown in Fig. 6. For a composite containing 10% of flax content, the dynamic modulus of elasticity decreased from 8.4 to 4.3 GPa. It corresponds to reduction of 49%. Flax particles, however, favour the absorption of ultrasonic waves due to their cellular structure. The observation of the surface of flax particle by using an electronic scanning microscope revealed a high internal porosity (Fig. 7); this has the effect of improving the insulation properties of the composite. The constriction of the dynamic modulus is also due to the presence of air bubbles in the matrix. However, the composite reveals the ability to both reduce sound intensity and dampens vibrations, which serve to provide a high level of sound insulation.

3.2.4. Compressive strength

The 28-days compressive strength of the composite with respect to the flax particle content is presented in Fig. 8. The results showed that the increase of the particle content serves to considerably reduce compressive strength of the composite. Value decreases from 32 MPa, for neat cement, to 10.5 MPa for composite containing 10% of flax particles. It corresponds to reduction of 67%. When no protein agent was used, the reduction in compressive strength is about 77%. The decrease in the compressive strength is attributed to the physical properties of the flax particles, since they are less stiff than the surrounding cement paste. Under loading, cracks are initiated around the particles, which accelerate the failure in the matrix. It is assumed that mechanical strength of the composite is opposite to its unit weight. In addition, the decrease in compressive strength is related to air-entrainment. The more the air voids ratio, the lighter the specimen and the lower its mechanical strength. Fig. 9 shows the variation in compressive strength σ (MPa) vs. dry unit weight. The following relationship has been proposed: $\sigma = 1.44\exp(0.002\rho)$ (yielding correlation coefficient of $R^2 = 0.997$). The variation obtained is similar to that reported in previous work conducted on lightweight wood-concretes [8]. Although the strength was reduced, the composite satisfies the basic requirement of lightweight construction materials and corresponds to RILEM "class III" recommendations: compressive strength is above 4.5 MPa and the apparent dry unit weight is less than 1000 kg/m^3 [13]. The composite could be used for load-bearing wall.

The effect of adding air-entraining agent on the mechanical behavior of the composite has been investigated by evaluating the compressive strength loss per air-entrainment (CLPA). The

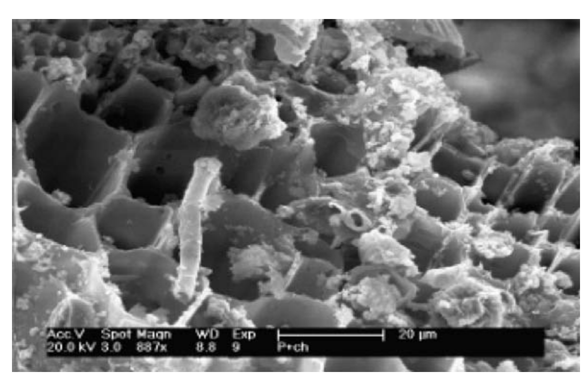

Fig. 7. SEM micrographs of flax particle, showing the internal porosity.

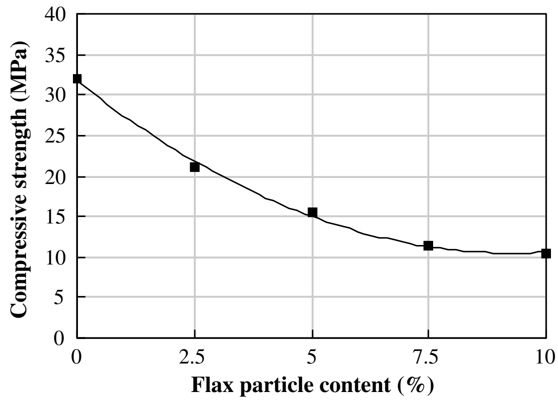

Fig. 8. Variation of the compressive strength of composite vs. flax particle content.

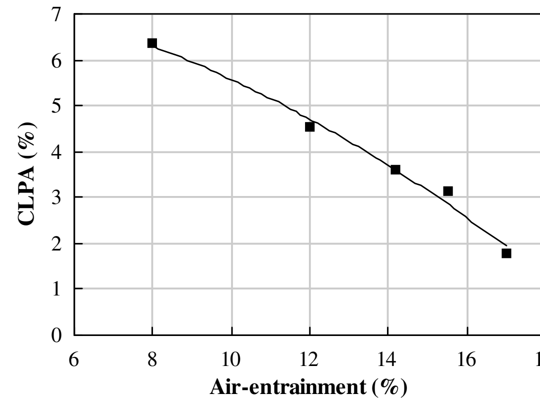

Fig. 10. Relationship between Air-entrainment and CLPA of composite.

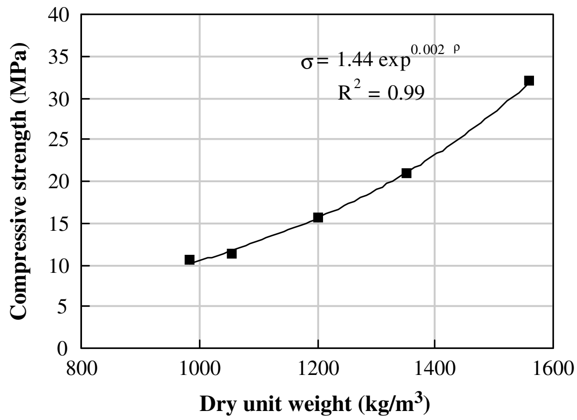

Fig. 9. Relationship between dry unit weight and compressive strength of composite.

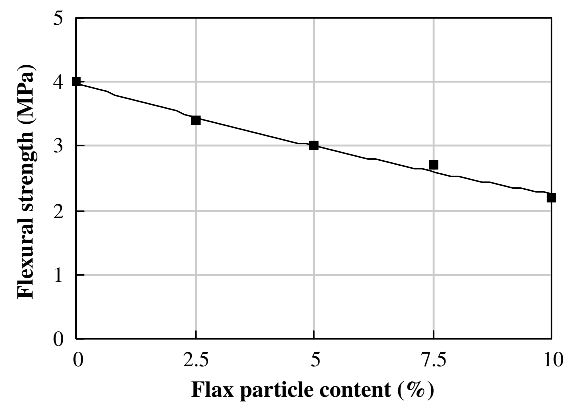

Fig. 11. Variation of flexural strength of composite vs. flax particle content.

compressive strength loss, between sample without protein agent and that with protein agent for a given flax particle content, per air-entrainment is given by Eq. (2),

$$\text{CLPA } (\%) = \frac{(\sigma' - \sigma)/\sigma'}{A} \cdot 100 \qquad (2)$$

where σ' and σ are, respectively, the compressive strength of sample without and with protein air-entraining agent, A is the air-entrainment.

The calculated values of the 28-days CLPA of the composite with protein agent are listed in Table 6. Results on the effect of air-entrainment on the 28-days CLPA are displayed in Fig. 10. It indicated that the value decreases from 6.3% to 1.8% for sample containing flax particle ranged from 0% to 10%. However, although the increase in air-entrainment, the CLPA decreases. It should be observed that this CLPA is lower than that for conventional aerated concrete, which has the CLPA typically in the range of approximately 4% to 6% [28]. These results highlight the effect of the protein air-entraining agent on the improvement of the compactness of the matrix, as regards the mechanical strength of the composite. As shown in previous work conducted on the properties of aerated composite containing rubber particles, the protein entraining agent is likely responsible for the additional particles being bound in the matrix [15]. Similar results were obtained by Yand et al. [29] on the properties of aerated concrete produced by means of saponin air-entraining agent: for air-entrainment of 7%, the aerated concrete displayed a higher compressive strength than a traditional concrete with 2% of air-entrainment.

We have previously observed that air-entrainment increases the workability and the fluidity of the fresh composite. However, the compressive strength can be improved by reducing total mixing water in order to achieve a same workability as that of the sample without air-entraining agent.

3.2.5. Flexural strength

The variation in 28-days flexural strength with flax particle content is shown in Fig. 11. A reduction in the flexural strength of the composite is observed. Value decreases from 4 MPa to 2.3 MPa, as the flax particles increased from 0 to 10%. It corresponds to reduction of up to 42.5%. The flexural strength reduction observed is due to both mechanical properties of flax particles and porous structure effects. Results also indicated that for a given flax particle content, the decrease in flexural strength is lower than that in compressive strength. When no air-entraining agent was used, the decrease in flexural strength is about 34.5%. This finding suggests that the sample's porous structure predominates the effect of flax particles, due to the air-entrainment. The reduction in mixing water for achieving the same workability as that of the sample without air-entraining agent may enhance the mechanical properties of the composite.

4. Conclusion

This study explores the possibility of use of flax by-product in the cement matrix to produce lightweight construction materials. The work presented herein has focused on the properties of the cement composite containing flax particles. The composite was aerated by means a protein air-entraining agent. The hydration test has shown that the addition of flax particles inhibits cement hydration set. The mixture containing 10% of flax particles was classified as being of "high inhibition", even without chemical additives. Calcium Chloride enhanced the performance of the mixture, improving the classification to that of "low inhibition".

The test conducted on the fresh composite properties has shown that the addition of flax particles favours air-entrainment in the matrix. Workability is enhanced as well. A study carried out on hardened material properties concluded that the composite containing 10% of particles reached a dry unit weight of 985 kg/m^3 with compressive and flexural strengths of 10.5 MPa and 2.2 MPa, respectively. The reduction in flexural strength with flax particles addition is lower than that in compressive strength. However, the presence of flax particles and air bubbles in the cement matrix reduces the elasticity dynamic modulus, which indicates a high level of sound insulation of the composite. Although the mechanical strengths were reduced, the composite satisfies the basic requirement of construction materials, and could be used for load-bearing wall, according to the RILEM functional classification. In addition, the porous structure of the composite could provide a high degree of thermal insulation.

The application in civil construction of cement composite based on flax by-products appears to be feasible considering the results obtained from analysis of its properties. This research has demonstrated the potential of aerated cement-flax composites in attaining substantial physico-mechanical properties and allows considering a broad range of applications in the field of cellular concrete. It would be valuable to investigate the thermal and hydraulic transport properties of the composite. This study contributes toward the program of vegetable residue recycling and pollution reduction, since this material is biodegradable.

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