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Influence of various starch/hemp mixtures on mechanical and acoustical behavior of starch-hemp composite materials

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ABSTRACT

The starch-hemp composite materials are manufactured from the natural raw materials (water, starch and hemp shives) and a new durable material for construction and building. In this work, experimental investigation was carried out to study the mechanical and acoustical performance of starch-hemp composite materials. The starch-hemp composite materials specimens with five Hemp/Starch ratios (H/S = 6, 8, 10, 12 and 14), were manufactured by using the optimal binder and two hemp shives (0–15 mm and 0–20 mm). Density of the starch-hemp composite materials varies with the H/S ratio. The dry density for the starch-hemp composite materials is lower, between 163.6 kg/m^3 and 169.1 kg/m^3 in case of the hemp shives 0–15 mm and between 168.1 kg/m^3 and 174.3 kg/m^3 for the hemp shives 0–20 mm. The relation between stress and strain of the composite materials is not linear. The ultimate compressive stress can reach 0.55 MPa and the compressive strain is up to 30%. The results obtained by test show that the tensile strength depends strongly on the Hemp/Starch ratio and the hemp shives sizes. The variation of elasticity modulus and Poisson's ratio in function of the H/S ratio was also analyzed in this paper. The mechanism of the cracks or failure of the specimens was studied by using ARAMIS optical system. The study on acoustical behavior shows that the starch-hemp composite materials are a good sound absorber material for medium and high frequencies with a value around 0.7. The influence of the H/S ratio on the absorption coefficient is small. The results show that the starch-hemp composite materials have a good mechanical and acoustical performance and can be used as building materials.

1. Introduction

Nowadays, there is a great need to use plant particles as building material in construction. It is because sustainable development has become a subject of major attention in international and national organizations, in developed and developing countries. It involves the development of methods and techniques guiding the use, recycling and replacement of natural resources and the upholding of the earth's productivity. To build sustainable and affordable building it is needed to design efficient building materials (thermal insulation, sound absorption and sound insulation) with lower environmental impact especially in regard to the carbon footprint.

There is currently a significant growth in the development of use of natural materials like as hemp, straw, flax and bamboo, specially the hemp shives, as building materials. Hemp shives is more resistant to biological decay than some other bio-based building materials (e.g. straw). The hemp plant can grow up to 4 m in some months, with low fertilizer and irrigation demand, making it very efficient in the use and material resources [1–4]. Hemp is one of the most interesting renewable materials. Like many natural fibers, it has been used for centuries as a reinforcing binder in concrete, in drainage work and for rope and cloth making [5].

The study made on a building with the hemp concrete shows that the building provides a significant amount of attenuation of the oscillations in the external environment which will assist in maintaining comfortable summertime conditions within the building. The tests also demonstrate air permeability levels, which will significantly reduce energy use associated with winter-time infiltration heat losses [1]. Comparing to cellular concrete, the building with the hemp concrete can reduce energy consumption up to 45% [6].

The mechanical, thermal and hydric properties of the lime-hemp concrete are influenced by the drying stage in manufacture. The initial moisture can be also decreased by spraying process

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[7,8]. The properties mechanical and thermal stability of the hemp shives can be improved after some chemical treatments on the shives surface. The flexural strength can be increased 40%. However, the elasticity modulus lightly decreases [9–11].

Up to now, all studies show that the lime-hemp concrete has a low compressive strength and a low elasticity modulus and the lime-hemp concrete in its present form cannot be used as a load-bearing material [12].

The lime-hemp concrete are generally used in the construction for filling a wood frame, prefabricated slabs, wall coverings, bricks or blocks. The advantages of the lime-hemp concrete are that [2,3,12–17]:

- The lightweight particles impact, on the strength/density ratio, on the deformability and the matrix (formed by the binder) in the mechanical behavior;
- The porosity between the particles which provide low thermal conductivity;
- The same porous aspect that includes pores of varying sizes (micro-pores of the constituent materials and macro-pores related to their imperfect arrangement) strongly influences the exchange of water vapor.
- Finally, the appearance of porous surface that gives the material a good sound absorption;

This paper focuses on the mechanical and acoustical performances of new starch-hemp composite materials. This type of the starch-hemp composite materials is made by the binder solution based on the starch as matrix and the hemp shives. The starch-hemp composite materials are entirely material natural. In the first section of this paper, the different constituents of the starch-hemp composite materials were presented, as well as the results of their characterization measurements. Two critical parameters, the dynamic viscosity and the surface tension were applied to select the binder solution as adhesive in this work. The variation of mechanical resistances like compressive and flexural strength in function of the starch/hemp ratio was analyzed and discussed. The origin of the first cracks and the distribution of the strain during loading were illustrated by Stereoscopic method [18]. The results obtained by test, using the measurement of the reverberation time T60, show that the starch-hemp composite materials has a very good sound absorber material for medium and high frequencies and that the influence of the H/S ratio on the absorption coefficient is small.

2. Materials

2.1. Hemp

Hemp is an interesting plant that grows quickly and renewable, without fertilizers or treatment. It happens a lot, does not damage soils and water saving shows. One kind of hemp shive (Fig. 1) from "Technichanvre®, city Riec sur Belon, country France" was used to manufacture composite materials. The length, thickness and the width were obtained by sieve analysis and showed in the Table 1.

The maximum dimension and the characteristics of the hemp shives are given in Table 1.

2.2. Wheat starch

The hemp shives are embedded in optimal binder solution containing wheat starch and water, the aim of which is to hold the shives together, thus giving and stabilizing the shape of the ago-composite structure and to transmit the shear forces between the hemp shives. Table 2 gives the density of the starch used in this research.

Starch is a carbohydrate composed of a large number of glucose units joined by glycoside bonds (Fig. 2). Starch is produced by all green vegetable as an energy store. It is contained in large quantities in staple foods such as potatoes, wheat, maize (corn), rice and cassava. The pure starch is a white, tasteless and odorless, which is insoluble in cold water or alcohol. The dissolution of the starch in hot water gives wheat dough which can be used as a thickening agent, a stiffener or adhesive. The industrial use (non-food) of the starch is mainly used as an adhesive in the manufacture of paper.

2.3. Optimal binder solution determination

The failure in the hemp concrete design is often due to a non-adequate binder composition or a competition between the binder solution and the hemp for absorbing water. The binder must contain wheat starch as much as possible (which has the effect of increasing the viscosity of the binder) but if the binder has insufficient water for the hydraulic components to set, then the result can be a mixture of damp hemp and dry powder (starch in this study). In our precedent works [19] the optimal binder was study. The optimal binder solution can be obtained by the analysis of dynamic viscosity and the surface tension. Indeed, the penetration and adhesive quality of the binder solution within the hemp shives may be characterized by the wettability (surface tension) and the sheer stress induced by the viscosity of the fluid. Wettability could be improved with surfactant/wetting aids. With reduced surface tension, the binder based starch can penetrate through smaller openings and spread over a greater area. However, an increase in the viscosity of the binder solution will decrease the wetting coefficient, the amount of water absorbed and the rate of absorption. Diminishing the water absorbed by the hemp shives is beneficial for drying rate and allows therefore a low time processing and a high quality concrete, free of bacteriological development.

Based on the obtained experimental results, there are two optimum S/W ratios (0.18 and 0.22) where the dynamic viscosity is the highest (more than 2.210^{-3} Pa s) and the surface tension is the lowest (about 45–50 10^{-3} N/m). The binder solution (S/W) chosen for the specimens elaboration is 0.18 [19].

3. Mechanical properties

3.1. Experimental procedure

After determining the optimal binder, a series of specimens (15 specimens 15 × 15 × 15 cm and 15 specimens 10 × 10 × 40 cm) were made on varying the Hemp/Starch (H/S) ratio (H/S = 6, 8, 10, 12 and 14), for size S1 and size S2.

The specimens were made by applying the following procedure. First, it is necessary to prepare correctly the binder. The prepared binder was then added in the hemp shives in order to mix two materials. After 10 min of mixture in concrete mixer machine 60L, the obtained material composite was used to make standard specimens of 15 × 15 × 15 cm and 10 × 10 × 40 cm. All starch-hemp specimens were compacted with 0.25 MPa pressure by help of a press. Finally, the drying of the specimens takes place in a climatic chamber stabilized in a temperature at 20 ± 2 °C and with humidity between 45% and 55%.

Compression test and bending test in four-point (Fig. 3) are realized by using respectively a constant rate 0.2 mm/s for the compressive test and 0.1 mm/s for the bending test, by help of Instron 8800 machine. Due to the fabrication process, most hemp shives tend to stack in planes normal to compacting pressure. Compression and bending test were always performed in the