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Contribution to the development of a sand concrete lightened by the addition of barley straws

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HIGHLIGHTS

- The barley straws can be introduced into a cement matrix.
- Improvement of lightness, thermal properties, deformability and tensile strength.
- Barley straws do not alter the development of microstructural species of concrete.
- At the vicinity of the vegetal material only calcium species are observed.
- Economical composite and more efficient in thermal insulation and energy saving.

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ABSTRACT

It is an experimental work that aims to study an eventual contribution to the development of a eco-lightweight concrete destined to be used in arid environments by using local and renewable materials and waste. Its main objective is the assessment of the effect of the addition of barley straws on the physico-mechanical properties and the microstructure of a concrete which consists only of sand as main aggregate. Indeed, the study was devoted, firstly to determine the optimal composition of sand concrete based on barley straws by researching a good compromise between compactness and workability, and secondly, to study its physical, mechanical, thermal and microstructural properties. The obtained results showed that the addition of barley straws to the sand concrete significantly improves its thermo-physical properties. According to the quantity of straws introduced in the sand concrete, the improvements in the flexural strength have reached 6%. Significant improvements have also been recorded in other properties, such as lightness, deformability, ductility, toughness and thermal characteristics. However, the increase of barley content decreases the compressive strength and increases the dimensional variations. But it should be noted that obtaining acceptable strength values is possible according to the straw content and the shrinkage values are in general less than the recommended limit for wood concretes. As to the microstructure of the studied composite, the SEM analysis showed that the presence of lignocellulosic aggregates did not alter the development of species within the cementitious matrix. Moreover, and contrary to the case of wood aggregates, only calcium species are observed in the vicinity of the lignocellulosic material, there are no silica species. Finally, it should be also noted the easy introduction of the cementitious material inside the tubular pores of some straws.

1. Introduction

Let us recall that the sustainability is one of the main focuses of the recent international housing development strategy. Indeed, the development of eco-materials in construction constitutes an environmental and sustainable approach, which aims to limit greenhouse gas emissions, conserve natural resources, protect health, increase the comfort level, etc. [1].

Moreover, the approach of using local materials and agro-industrial waste could be a crucial contribution, where a consensus is needed to improve the performance and behavior of materials, while minimizing both the expenses and the energy consumption [2].

In this context, sand concretes [3] have already been lightened by addition of wood shavings and significant results have been

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found, especially in lightness and thermal insulation [4]. Nevertheless, high shrinkage and low mechanical strength were recorded [5]. To solve this problem, and in order to reduce the maximum shrinkage value (lower than the recommended value, generally adopted (1 mm/m) [6]) and to increase furthermore the mechanical strength, different treatments were applied to the wood shavings before their use. The latter also led to significant improvements [5].

In the same way and hoping to improve other characteristics proper to the sand concrete, another lignocellulosic material has been added to the sand concrete in order to develop a different lightweight concrete. This material is local and abundant in the city of Laghouat (south of Algeria) which is classified as an arid region. In fact, this material is the barley straw which is considered as an ecological material characterized by a renewable nature. Among its main characteristics, its lightness and good thermal insulation which is even better than that of wheat straw [7].

As a first work, the new lignocellulosic material has been used as a partial substitution of wood shavings and good results have been found either in shrinkage or in thermo-mechanical properties of the studied composite [8]. In a second work, which represent the present study, a total substitution of wood shavings by barley straws will be established, i.e. a sand concrete lightened by only barley straws [9].

Indeed, among the objectives of the incorporation of lignocellulosic materials in composites composed of cementitious matrix is the obtaining of new lightweight concretes having good insulating properties which represents a topical research subject [10].

As to the barley straw, this lignocellulosic material is produced in surplus, compared to local requirements almost anywhere in the world; so it is a natural product which is an economic material and easy enough to get it in most countries. Thus, the reuse of this material in concrete could contribute to the realization of a sustainable and ecological construction [11]. Let us note that several studies have been performed on the incorporation of lignocellulosic materials in different matrices. Bouhicha et al. used barley straws for the reinforcement of soil composites [12]. Li et al. used hemp fibers in a cementitious composite [13]. Yang et al. used the rice straw fibers in composites according to various massic ratios 'rice straw/wood particles' [14]. Soroushian et al. used wheat straws instead of wood for the preparation of a cementitious composite [15]. Ashour et al. used wheat and barley straws in earth plaster [7]. Nozahic et al. used hemp fibers and the sunflower rod which had been selected as an alternative of the by-product of the lignocellulose due to its apparent similarities with hemp fibers [16]. Merta et al. used hemp fibers, elephant grass and wheat straw [17].

Basing on all these works and attempting to give a certain novelty to the present study, the latter focused on the introduction of barley straws in a cementitious matrix composed of sand concrete. Its main objective is to study the contribution of barley straws in the lightening of the sand concrete (with the use of river and dune sands) as well as in the improvement of its thermo-physical properties. For this and on the basis of the search for a better compromise between the studied properties, namely workability, thermo-physical properties, mechanical properties and shrinkage, it was really necessary to firstly start the searching of the optimal composition which can give an eco sand concrete usable in arid environments and then study its main properties.

2. Materials and experimental methods

2.1. Raw materials

The matrix of the studied composite is composed of sand concrete which consists of a mixture of sand, cement, fillers, water and admixtures [18,19] and the barley straws as inclusions. All components used for the development of this composite are characterized hereafter.

2.1.1. Sand

It is in the context of the valorisation of local materials that 'RDS' sand was prepared by correcting the fine part of a river sand (0/5 mm) with a dune sand (0/0.63 mm) according to a mass ratio: (RS/DS) = 1.7 [20]. Both of these sands present a continuous particle size distribution with a fraction of fine elements below 5% and a rounded grain shape. The X-ray Diffraction analysis demonstrates its essentially siliceous nature [8,20]. The high values of the "Sand Equivalent" show that RDS is a clean sand. The set of the physical characteristics of RDS is listed in Table 1.

2.1.2. Cement

Portland limestone cement (CPL) of type CPJ CEM/II A-L 42.5 R was used as a binder. It is a new class of cement that provides a performance similar to that of conventional Portland cement but emits 10 times less CO_2. Currently, the use of PLC is much recommended in order to help mitigate climate change through energy savings and reduce gases emissions. The physical characteristics of the used cement are: apparent density: 1030 ± 20 kg/m^3, specific density: 3030 ± 25 kg/m^3 and Blaine specific surface area: 444.9 ± 12 m^2/kg [8].

To give more importance to the economic, environmental and even technical aspects, 10% of the cement quantity was substituted with mineral additions. The latter are limestone, natural pozzolan and lime (1/3 limestone, 1/3 natural pozzolan and 1/3 hydraulic lime) [8]. Their physical properties are: their Blaine specific surface areas are 280 ± 13, 388 ± 15 and 650 ± 16 m^2/kg, their specific densities are 2700 ± 22, 2850 ± 25 and 2750 ± 23 kg/m^3 and their apparent densities are 1530 ± 18, 1005 ± 14 and 666 ± 8 kg/m^3 respectively. It should be noted that the used cement contains initially only one mineral addition which is the limestone.

2.1.3. Barley straw

The used lignocellulosic materials are barley straws harvested in 2012 (Fig. 1a, b). Locally, these materials are commercialized in the form of a bale of about 1.08 × 0.48 × 0.30 m of dimension. They are characterized by a water absorption coefficient of about 3.30 and a slow absorption kinetic, which is in contrast with wood shavings whose water absorption kinetics is faster. At wet state, the straws present a high flexibility. Their diameter ranges from 1 to 4 mm (Fig. 1c–e). Their chemical composition consists mainly of cellulose (37.6%), hemicelluloses (34.9%) and lignin (15.8%) [21]. Their specific density is about of 506 ± 12.19 kg/m^3. The chosen straw lengths are 3.5 cm when using 7 × 7 × 28 cm samples and 2 cm when using 4 × 4 × 16 cm samples. Their shape, as well as the shape of their cover can also be seen in Fig. 1a–f.

Concerning the mixture "straw tube" and covers (and broken straws), the proportions of each of them were determined basing on a series of preliminary tests. It has been found that the used quantity of straws is constituted from 70% of tubular straws and 30% of covers and broken straws.

2.1.4. Limestone filler

It is well known that the use of fillers in a sand concrete composition is essential [19]. In this work, the used fillers have been obtained by sifting (to a sieve opening of 80 μm) a local crushing waste. This enters also within the scope of waste recovery [20]. The X-ray Diffraction analysis highlights their limestone nature (Fig. 3). Their Blaine specific surface area is 280 ± 13 m^2/kg and their specific and apparent densities are 2700 ± 22 kg/m^3 and 1530 ± 18 kg/m^3 respectively.

2.1.5. Admixture

The last material, whose use is essential in the case of sand concrete, is an adjuvant of type "MEDAPLAST SP 40", in conformity with the EN 934-2 Standard. It is a high range water reducer superplasticizer which allows the obtaining of a high quality of concrete and mortar. In addition to its main function as a superplasticizer, it greatly reduces the water content. This product is presented in a liquid form that is easily diluted in the mixing water. The used proportion is 2% (in mass) of the binder content.

2.2. Elaboration of the composite

The optimal composition of the sand concrete taken as a reference concrete and as a matrix for the studied composite is inspired from the works of Bederina et al. [20]. This composition is shown in Table 2.

Table 1
Physical properties of the used sand.

Physical characteristics	
Apparent density (kg/m^3)	1590 ± 15
Specific density (kg/m^3)	2485 ± 26
Compactness (%)	0.64 ± 0.001
Porosity (%)	0.36 ± 0.001
Fineness modulus	2.81 ± 0.08
Visual sand equivalent (%)	93.2 ± 2.33
Sand equivalent (%)	80.3 ± 2.49