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The mechanical and physical properties of compressed earth block stabilized with lime and filled with untreated and alkali-treated date palm fibers

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HIGHLIGHTS

- Effect of untreated and alkali treated date palm fibers on the properties of CEB with quicklime is discussed.
- The alkali treatment of fibers did not improve the strength of the blocks.
- The bulk density and thermal conductivity decreased with increasing fibers content.
- The fibers alkali treatment of date palm fibers has a negative effect on thermal insulation of CEB.

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ABSTRACT

Most developing countries have an urgent need to construct and build houses that are more durable at a low cost. The compressed earth block (CEB) has been identified as a low-cost material with the potential to redress the problem and reverse the shelter backlog. While its properties, using cement and lime, are well understood, the use of vegetal fibers with chemical stabilizers still raises a lot of questions. The principal objective of this research is to investigate the mechanical and physical properties of CEB stabilized with quicklime and filled with date palm fibers. The fibers have been chemically treated using an alkaline solution to enhance the fiber/matrix bonding consequently increases the mechanical strength. In this work, the effect of curing methods and curing time on mechanical strength of CEB was studied. The investigation results indicate that, although the strengths values of CEB filled with alkali treated fibers is slightly greater than that with untreated fibers, the fiber surface treatment did not result in an improvement in the fiber/matrix adhesion, leading to a decrease in strength of the blocks. The research findings show that the use of date palm fibers lead to a reduction in thermal conductivity and bulk density and increases the capillary absorption of the blocks. An adverse effect on thermal conductivity of CEB with alkali treated date palm fibers was observed.

1. Introduction

Many different materials are used around the world for walling. Where quarried stone and timber are not readily available, earth is the most common material used. Earthen construction has been used for several thousand years in various regions of the world [1].

But earthen buildings are suffering from certain deficiencies, like strength, water resistance and durability [2,3]. To overcome that, the technique of stabilization is used in order to enhance natural durability and strength of soil [4]. There are three soil stabilization processes: mechanical stabilization, Physical stabilization, Chemical stabilization [5]. These processes led to the development of several earth building techniques such as the compressed earth block (CEB). Among the variety of soil stabilizers used, cement has been the most popular stabilizer in the manufacture of CEB, but cement is more effective with coarse grained particles, while lime performs better with very fine particles such as clay case. This is confirmed by the results of some research [6,7]. In addition, the cement has adverse effects on the environment. Adding lime to clay, several chemical reactions occur, namely, cation-exchange, flocculation and agglomeration, carbonation, and pozzolanic reactions. These chemical clay-lime reactions lead to form calcium silicate hydrates and calcium aluminate hydrates [8,9]. Test results have indicated that there is an optimum lime dosage for a soil beyond this optimum the compressive strength decreases [9–11]. It was found also that the use of lime as soil-stabilizing additive results in long-term strength gain [12,13]. But this disadvantage can be avoided. Several researches have shown that higher temperatures accelerated the chemical reactions and soil strength development [14–16]. George

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et al.'s research [14] indicated that, an increase in the soil strength and modulus was only observed at the higher curing temperature of 50 °C, and so it is recommended that soil–lime stabilization work should be applied in hot weather. Another factor which significantly affects the strength of lime soil mixtures is curing time [17]. The idea of filling the soil with natural fibers for reinforcement purposes is very ancient. This approach creates a network of omni-directional fibers which improves notably tensile and shearing strengths and also helps to reduce shrinkage [5]. Recent researches results have shown that the use of natural fibers in compressed earth blocks leads to reduce the size of shrinkage cracks and to improve durability and tensile strength [18]. But other authors reported that adding natural fibers to reinforce the soil is incompatible with the CEB compression process as they make the mix too elastic [5,19,20]. Taallah et al. [20] have conducted an experimental research on the mechanical properties and sensitivity to water of CEB reinforced with raw date palm fibers. The authors concluded that the addition of raw fibers to CEB mixtures leads to reduced tensile strength with increasing fibers content. According to the authors, this is due to the low adhesion fiber/matrix caused by the decompression of CEB after unloading during its manufacture. So it is very important to improve the fiber/-matrix adhesion by increasing the surface roughness of the natural fibers [21]. In order to treat natural fiber surface, different physical and chemical methods are used [22].

Alkaline treatment is much used as a chemical treatment to dissolve hemicelluloses and lignin from natural fibers. This leads to obtain purified cellulose. Chemical analyzes of date palm fiber have shown that it's composed of cellulose, hemicelluloses, lignin and other minor components [23]. Cellulose and hemicellulose have more hydrophilic groups such as hydroxyl groups, while lignin has a phenol ring which is hydrophobic. Alsaeed et al. [24] investigated the effects of alkali treatment on interfacial adhesion of date palm fiber with epoxy matrix using single fiber pull out technique. The authors have studied the effect of sodium hydroxide treatment concentrations (0–9%), fiber length and fiber diameter on the adhesion between fibers and matrix. The finding revealed that 6% concentration of NaOH leads to a high interfacial adhesion and strength between date palm fiber and epoxy matrix. Amroune et al. [25] have investigated the effect of various NaOH concentrations and times of treatments on tensile mechanical properties of treated and untreated date palm fibers. The findings revealed that the chemical treatment increases the mechanical properties under quasistatic tensile loading.

In addition to the research conducted on mechanical properties of composites based on natural fibers, there are several studies which have focused on their thermal properties. Khedari et al. [19] investigated the development of a new type of block manufactured with soil and cement and coconut coir, which is characterized by its low thermal conductivity. Their results showed that the use of coconut fiber as an admixture can reduce the thermal conductivity and yield a lighter block. Rim et al. [26] examined the effect of the weight percentage of wood aggregates on the thermal conductivity, compressive and flexural strengths of a clayey concrete with wood. Their test data showed that the addition of wood to clayey concrete improves its insulation characteristics. Millogo et al. [27] investigated the effect of fibers content and lengths on thermal conductivity of compressed earth blocks filled with *Hibiscus cannabinus*. Their findings showed that thermal conductivity decreased with increasing the fibers content and lengths. In their study, Bachar et al. [28] have concluded that the use of the aggregates of cork (3/8) improves significantly the thermal conductivity for optimal content by mass of cork, and at the same time the strengths values are acceptable.

Date palms are cultivated in many regions of the world, especially the arid areas. In Algeria, there are more than 17 million of palms [29]. Annually, maintenance work of date palms generate high amount of waste composed mainly of palms and surface fibers, which can be used as fiber reinforcement in earth products.

This research aims at investigating the effect of untreated and alkali treated date palm fibers content on mechanical and physical properties of compressed earth blocks (CEB) mixed with quicklime. In order to reduce storage time of the CEB before its use in masonry walls, due the slow lime pozzolanic reaction, the effect of curing time and curing method on CEB mechanical properties will be investigated.

2. Experimental program

2.1. Materials

The materials used in this study for fiber reinforced compressed earth block were soil and crushed sand as main matrix; lime as stabilizer; date palm fibers as fibrous materials and water as lubricant.

The soil used was taken from a site in Biskra (Algeria). It is characterized by its availability and abundance in the area. Fig. 1 presents the diffractograph of the tested soil. The mineralogical composition shows that the soil contains 29.5% quartz, 30.5% gypsum, 29.5% calcite, 6.5% Kaolin and 3% K-feldspar. Table 1 illustrates the soil chemical composition. The distribution of grain size of soil is displayed at Fig. 2, it was carried out according to NF P 18-560 and NF P 94-57 standard. Atterberg limits done according to NF P 94-051 standard yielded a liquid limit of 36 and a plasticity index was 13. It has a pH of 8.3, a methylene blue value of 1.36 according to NF P 18-592 and 1.91% of organic matter (<2%, recommended limit by Doat [30] and Vénuat [31]). A check against the triangular textural classification of the soil [30] reveals that it was sandy silt. This soil has 61% sand, 23% silt and 16% clay. Its bulk and specific density are 1210 kg/m^3, 2579 kg/m^3, respectively. The sand used is crushed sand passing sieve size 5 mm, brought back from local quarry, near the city of Biskra. Fig. 2 illustrates the grain size distribution of this sand. The physical properties of the sand are tested according to AFNOR standard. they were presented in Table 2. The lime used in this study is quicklime produced in the city of Saida (Algeria). Its chemical and physical properties are presented in Table 3. In the present work both untreated and alkali-treated date palm fibers were used. The untreated fibers used are from the surface of the trunk of male date palm MDPSF. It was obtained from oasis of Biskra, Algeria. Initially they are in the form of almost rectangular meshes and formed with three superposing layers, in the second stage, these layers are separated into individual fibers, and then the fibers were cut into small pieces, with a length ranging between 2 cm and 3.5 cm. (Fig. 3). The physical and mechanical properties of MDPSF are already presented in the previous work of Taallah et al. [20], according to the previous research of Kriker et al. [32]. In order to modify the fibers surface, date Palm fibers have been subjected to alkaline treatment. The fibers were immersed it in 6% by weight of sodium hydroxide solution for 24 h at laboratory temperature, according to the study of Alsaeed et al. [24]. After treatment, the fibers were washed with distilled water to eliminate the excess of sodium hydroxide and dried at 50 °C for 24 h in at ambient temperature laboratory. The blocks were produced using tap water.

2.2. Preparation of specimens

In order to make blocks, the static compaction was applied on the mixtures, according to C.D.E (Centre for Development of Enterprise) method [33], at compaction pressure of 10 MPa. Soil and crushed sand are mixed such as to give grading curve, as presented in Fig. 2, within the limits recommended by the AFNOR standard (XP 13-901) and Guettala et al. Study [34]. The purpose of the water is to hydrate the lime and to enable the mix to be compacted at optimum moisture content. The optimum moisture content and dry density for soil crushed sand lime mixture filled with date palm fibers were determined by the C.D.E method [33], for example, for 10% lime content, their values are 12% and 1930 kg/m^3, respectively. In order to maintain a standard specimen preparation procedure, the amount of dry material placed in the mould was kept constant for all blocks; it is taken equal to 2000 g. The mixtures were prepared and placed in the mould using the procedure described in the previous study of Taallah et al. [20]. Experimental mixture proportions are shown in Table 4.

The specimen was then removed from the mould and stored in the laboratory at 20 ± 2 °C for 24 h before being subjected to different curing methods. Each block is covered with plastic film to ensure its sealing, allowing the hydration process takes place in standard conditions. The reported results are the average of three specimens.

The specimens were submitted to three curing methods until testing:

– Air curing in the laboratory environment at 20 ± 2 °C, for 28 days (specimen covered with plastic film).
– Oven curing at 65 ± 2 °C, for 1, 3, 5 and 7 days (specimen covered with plastic film).