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Impact of accelerated climatic aging on the behavior of gypsum plaster-straw material for building thermal insulation

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HIGHLIGHTS

- Freezing-thawing and wetting-drying accelerated aging tests are considered to simulate outdoor conditions.
- Two straw-gypsum plaster composites were designed.
- Long-term durability under changing climate conditions is investigated.

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ABSTRACT

Accelerated aging methods are needed to estimate the potential long-term serviceability of building materials under environmental conditions of use. In this paper, we examine the effects of dry-wet and freeze-thaw cycling on the thermal and mechanical properties of new straw-plaster composite materials proposed for building insulation. The material specimens used in the present study were manufactured with two straw varieties, wheat and barley. The gypsum plaster is used because of his thermal properties and ease of manufacture. Only the optimized mixture was used to perform the accelerated aging tests. In order to evaluate the long-term behavior of the straw-plaster composite, the non-aged specimens were characterized at constant conditions of temperature and humidity for three different curing times of one, three and six months. Comparisons between the properties of the aged and unaged material showed that freezing-thawing cycles had only a slight effect on the thermal and mechanical response of the composites compared with drying-wetting cycles.

1. Introduction

Interest in the development of composite-based natural and synthetic fibers is not new and several authors have proposed materials with specific properties for targeted applications. Most of these materials involve the addition of fibers to a brittle matrix in order to improve mechanical strength and reduce cracks [1–4]. The use of natural fibers in building materials has gained importance recently for repair and rehabilitation applications, in part because of the reduction in energy consumption for environmental considerations: as these fibers are usually an agro-residue, they require less energy for their manufacture. They also offer good thermal properties [5] due to their porous nature which ultimately results in low energy consumption in building uses [6]. Moreover, they have many other advantages that make them a viable competing material for synthetic fibers in various engineering applications [7]. Various types of natural fibers are used, depending on the biomass production and climate of different regions and countries in the world [8]. In the domain of building materials, different matrices are also used such as soil (adobe), lime, lime-pozzolana mixture and cement. The choice of the type of fiber and matrix depends on the intended application of the final material, the aim being to improve mechanical and thermal properties and durability by taking into account economic, ecological and life-cycle analysis using different impact assessment indicators [9,10]. For a complete study that takes human health, climate change and depletion of natural resources into account in addition to energy consumption and CO_2 emissions, a large number of experimental studies of the proposed material is essential. Early on in the development phase of laboratory material, the choice of the basic components of the composite is often based on the literature and on economic considerations.

The present study is part of the larger project "PROMETHE", which is a research program funded by the Region Centre (France). The objective of this project is to provide thermal insulation materials based on cereal straw and their implementation and

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production for the thermal rehabilitation of existing buildings or the insulation of new buildings. The Region Centre is the leading producer of cereals in Europe and cereal straw is a fiber that is available in large quantities at low cost but that has been little used until now. The aim is to use cereal straw as a component of insulation material to benefit from its high porosity in order to decrease the thermal conductivity of the material, as demonstrated by the bale straw construction experiment [11]. After an initial study in which different lime and lime-cement mixtures were tested as binders [12], we chose here another matrix, gypsum plaster. This type of plaster has long been used in the building sector due to its physical and chemical properties. Its use has increased recently in building applications or for the restoration of historical buildings [13,14] thanks to new additives that enhance its thermal and acoustic performance and remarkable fire resistance [15–19]. Therefore, based on all these positive results, the mixture of cereal straw fibers and gypsum plaster to obtain a lightweight composite for insulation rehabilitation is a low cost solution to reduce the energy consumption of buildings. Besides its thermal performance, the straw-plaster material must also ensure the long-term durability and safety of the structure under changing climate conditions. Except for cases of accident or fatigue [20], the deterioration of building materials is mainly due to aggressive environmental conditions [21]. Variations in temperature and humidity can significantly degrade the material and have an adverse impact on safety and comfort. It is therefore necessary to take the long-term behavior and the durability of the material into consideration in order to meet the technical and safety criteria for its implementation in the structure. In order to understand the interaction between various mechanisms and evaluate the contribution of the binder or the fiber, both natural and synthetic, to the deterioration of the composite material, accelerated aging conditions are generally used in the laboratory to simulate long-term exposure to variations in environmental conditions [22–26]. The accelerated aging conditions commonly practiced in laboratory investigations are freezing-thawing and wetting-drying cycles. Among several aging conditions, Wei & Meyer found that the wetting-drying treatment had a more aggressive effect on the strength and toughness of sisal-reinforced cement samples [22], while Yun et al. found that freezing-thawing cycles dramatically reduced the static strength and the resistance to fatigue failure [23].

In this paper, the durability of a straw fiber-plaster composite exposed to accelerated aging by drying-wetting and freezing-thawing cycles was investigated. After a comparative study of different mixtures to find the best compromise between thermal performance and mechanical strength, one composite was chosen for accelerated aging. In the absence of consensus and standards for the new natural fiber based material, the number and the duration of the aging cycles were determined based on the project's research program and the literature. After accelerated aging, mechanical and thermal characterization was carried out to highlight the effect of temperature and moisture changes on the properties of the proposed insulation material. A comparison was also performed between the aged samples and the mechanical and thermal properties of samples cured in constant conditions of temperature and humidity for three different curing durations. This work constitutes an initial investigation on the effect of accelerated aging on the thermo-mechanical behavior and will be pursued by other studies to complete the understanding of deterioration mechanisms.

2. Material and methods

This section details the specimen manufacturing procedure, the accelerated aging procedures, and the composite test methods.

The gypsum plaster used is a quick-setting (10–15 min) Diall Commercial Plaster used in construction to reduce the time needed to remove the molds. Following a comparative study between different varieties of cereal straw in the Region Centre carried out in the initial stages of the research program [27], two varieties of straw, wheat and barley, were used to manufacture the composite specimens.

2.1. Specimen manufacture

Based on previous work on a lime-straw composite [12], four mixtures using two water/binder (W/B = 1.1 and 1.6) and three straw/binder (S/B = 0.2, 0.3, 0.4) ratios were tested to find the optimal composite with the lowest thermal conductivity and mechanical strength under its own weight in accordance with the European standard. Three sample preparation methods for the aging tests were explored in order to determine the optimal manufacturing procedure. In the first method, the fibers were used their initial length in the straw bales. After pre-wetting the straw fibers in the mixer with one third of the water calculated from the W/B ratio for 60 s, the plaster powder was added and mixed for 60 s to the remaining water. Due to the length of the fibers, this resulted in mixing difficulties, with poor results of composite blocks. The second method consisted in first crushing [27] the fibers and then mixing them with the plaster in the same way as above. This procedure gave poorly resistant, brittle blocks with a number of problems such as the absence of binder between the fibers and segregation of the plaster at the bottom of the mold, as shown in Fig. 1.

The method finally adopted was based on the procedure used in previous work, with a change in the quantity of water for preparing the water-binder mixture outside the mixer. Briefly, this procedure consisted in first mixing the straw fibers with 15% of the water for 60 s, followed by the addition of the binder-water mixture and mixing for 5 min. The binder was mixed with 85% of the water prior to addition in the mixer in order to obtain a good

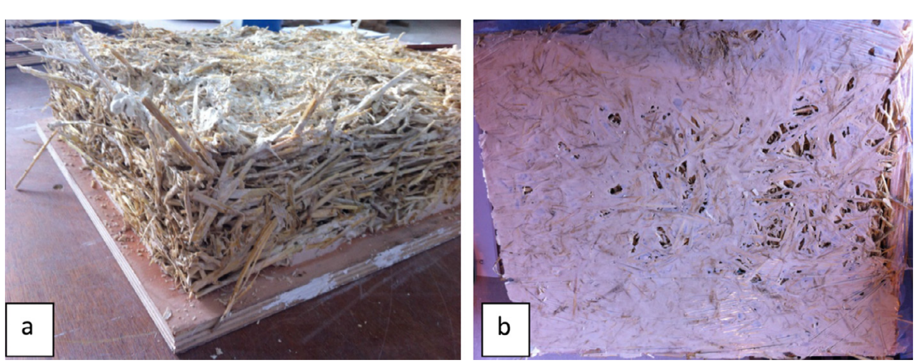

Fig. 1. Manufacture of the composite blocks with problems: (a) absence of binder between fibers, (b) Segregation of plaster in the mold bottom.