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Textile-reinforced rammed earth: Experimental characterisation of flexural strength and thoughness

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HIGHLIGHTS

- Flexural toughness of unreinforced and fibre grid reinforced rammed earth.
- Flexural strength of unreinforced and fibre grid reinforced rammed earth.
- Comparison of textile reinforcing systems for rammed earth.
- Grid spacing and bending stiffness: influent variables for the reinforcing.

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ABSTRACT

Rammed earth is a building material that has gained attention because of its sustainable advantages. However, its negligible tensile strength and its lack of strain energy dissipation may compromise some structures. This work proposes the use of textile grids as reinforcement systems for rammed earth. An adapted methodology to assess the effect of embedding fibre grids is presented. The maximum bending moment and the flexural toughness was determined for 26 specimens by using different types of grids. It was determined that using a flexible fibre grid with large spacing between fibre tows was the most efficient option, as it duplicated the flexural strength and increased the flexural toughness by a factor of sixty.

1. Introduction

Earthen building technologies (such as earth block masonry, adobe, rammed earth, or cob, among others, see the work by Miccoli et al. [1]) have been used worldwide for thousands of years because of the simplicity of the construction procedure, the availability of materials (earth) and the properties of the resulting structures. However, the use of these traditional construction techniques became sparse with the development of concrete and steel materials, which allowed for the production of buildings with lower workforce requirements. As a result, in comparison with other construction technologies, research on earthen construction has received significantly less attention.

However, earthen architecture is increasingly gaining supporters due to the sustainable advantages of using earth as a building material. The most important benefits include the use of a local material obtained in situ, thereby eliminating transportation costs and associated CO_2 emissions; the complete recyclability of the building structure, the thermal inertia; and the architectural plasticity. The survey carried out by Niroumand et al. [2] certified that there is an increasing interest in earthen construction, but that this interest is limited by some drawbacks. These drawbacks include the most important limitation that earthen construction lacks a scientific basis and the corresponding standards to use it with the same confidence levels as other current construction materials.

Recent research attempts to fill this gap in knowledge. The research on earthen construction has covered a wide range of issues, but most of the investigations have focused on two main aspects, namely, the thermal efficiency and the requirements of the component materials (clay, silt, sand, gravel, water and additives) to reach an optimum solution in terms of strength and durability. In the context of thermal efficiency, it is worth highlighting the work by Heathcote [3], who pointed out that earth buildings have poorer thermal isolation than clay brick buildings. However, the larger thermal inertia of earth softens the temperature changes, which translates into a comfortable sensation for people.

The influence of the moisture on the earth mixture is important with respect to the requirements of the component materials. Schroeder [4] analysed the drying process of earthen elements

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and concluded that there is a relationship between the initial moisture, the drying process and the final strength of rammed earth walls. Additionally, research was carried out by Ciancio et al. [5], Jiménez et al. [6] and Da Rocha et al. [7] on determining the dosage and specifications of the solid component materials (clay, silt, sand, gravel) and the expected properties of the mixed material before it was used to achieve the maximum density, compressive strength or erosion strength. A few studies have focused on the durability of earthen constructions and potential alternatives to enhance the lifespan of earthen constructions. Maldonado [8] focused on analysing the influence of superficial treatments and using consolidating additives to improve the strength of rammed earth walls against water erosion. However, Ciancio et al. [5] noted that the variability of the earthen properties and their composition makes it impossible to specify general rules about the components. It is only possible to propose and analyse the minimum requirements of the final earthen elements.

Although knowledge about earthen construction has increased due to past research, there are still some technical issues that limit the practical use of earthen construction, including the almost negligible tensile strength and limited capacity to dissipate energy once the material is cracked. With respect to these issues, there have been a few proposals to overcome the tensile strength and energy dissipation limitations. These proposals can be divided in two groups, namely, proposals aimed to externally strengthen earthen structures and proposals aimed to provide a reinforcing system placed inside earthen material when casting the structure. In fact, some types of ancient earthen techniques (such as adobes and cobs) involve adding natural fibres to the earth mixture. However, this particular practice was more oriented to prevent shrinkage cracking than to provide effective tensile strength. Moreover, there is a paucity of research assessing of the energy dissipation capabilities of these particular buildings.

Reinforcing rammed earth walls allows the introduction of a new construction methodology to produce safe buildings in areas where it is difficult to procure Portland cement, wood or steel. Developing cheap fibre grids that are composed of available materials would be a sustainable evolution for this particular application if these reinforcing techniques prove to be efficient. Reinforced rammed earth walls would also open new construction possibilities in those territories where the environmental responsibility is a priority, but where there are strict requirements for structural safety. Developing and improving reinforced rammed earth would allow the production of environmental-friendly small and medium height low-cost buildings. Given these reasons, research on reinforcing and strengthening rammed earth has gained attention in recent years.

Blondet et al. [9] worked on both reinforcing and strengthening techniques and proposed using reeds embedded into earth walls to produce seismic-resistant earthen constructions and placing steel grids that are externally bonded with an inorganic plaster (mostly mud) to repair earthquake damaged walls. Liu et al. [10] proposed a strengthening system consisting of high performance fibres, which can be externally bonded to earth walls using adhesives. Furthermore, Tarque et al. [11] proposed a numerical model to simulate externally strengthened adobe walls in which the strengthening system was mechanically attached to the wall.

The procedure of using a high performance fibre grid embedded into an inorganic matrix to externally strengthen structures is commonly known as Textile Reinforced Mortar (TRM) or Fabric Reinforced Cementitious Matrix (FRCM). Several studies have focussed on the application of this strengthening technique on masonry and concrete elements. These involve different points of view, including experimental (see [12,13]), analytical (see [14]) and numerical simulations (see [15,16]).

The aim of this paper is to apply the knowledge that was generated through the study of the TRM in the recent years to propose a reinforcing system for rammed earth walls. This technical solution holds the potential to increase the dissipated energy in flexion based on which earth-quake resistant low cost buildings of reinforced rammed earth can be produced. This follows the proposals of Blondet et al. [9] and Barrionuevo [17].

A comprehensive experimental campaign focused on analysing the structural response of fibre grid reinforced rammed earth specimens is presented herein. Different types of fibre grids were considered, and the influence of the reinforcement pattern was also analysed for a particular fibre grid. The tests focused on analysing the flexural toughness (which is an indirect measurement of the applied energy to break a specimen) of samples tested under three-point bending conditions. Thus, the Japanese Standard JSCE-SF4 [18] was taken into account as a reference, as in previous experimental studies (see [19]).

2. Methodology. Experimental campaign

The experimental campaign aimed to analyse the variation of the flexural strength and toughness of rammed earth specimens when fibre grids were embedded into them. Additionally, the influence of the fibre grid type on the mechanical response was also studied as a main property defining a reinforcing system.

2.1. Materials and specimens

For the experimental campaign, 26 prisms of rammed earth were produced. These prisms were 350-mm long and had a cross section of 100 mm × 100 mm. Four of them were not reinforced, and the rest were reinforced with embedded fibre grids.

Clay, silt, sand and water were mixed; moulded; and pressed to produce rammed earth prisms. The manufacturing technology used here can be directly used to manufacture compressed earth blocks (CEB). However, the resulting CEB specimen represents a small portion of the rammed earth material.

A local company (*Sorres i graves Egara S.A.*) provided the earth components. The particle size distribution of the earth components mixed together (nomogram) is presented in Fig. 1. This resulting distribution was analytically obtained from the particle size distribution of each component provided by the supplier and the dosage of each component (40.0% of clay/silt, 45% of sand with particles up to 2 mm and 15% of sand with particles up to 5 mm). It should be noted that the used mixture had a slightly higher portion of sand and less clay/silt than the general recommendations for rammed earth, as summarised by Jiménez et al. [6]. This may contribute to reducing the mechanical performance of the specimens, highlighting the effect of the reinforcing system. However, the tests on the unreinforced specimens (presented later in the paper) suggest that the specimens reached the expected flexural strength. This is in comparison with prior research, such as that of Ciancio et al. [5], who proposed a flexural strength of approximately 0.25 MPa or slightly higher.

Suitable amount of water to be mixed with soil were experimentally determined by comparing the results of drop ball tests with different water contents. The drop ball test is a method that is used to assess the workability and binding capacity of soil mixtures that are to be used in earthen construction. It consists of

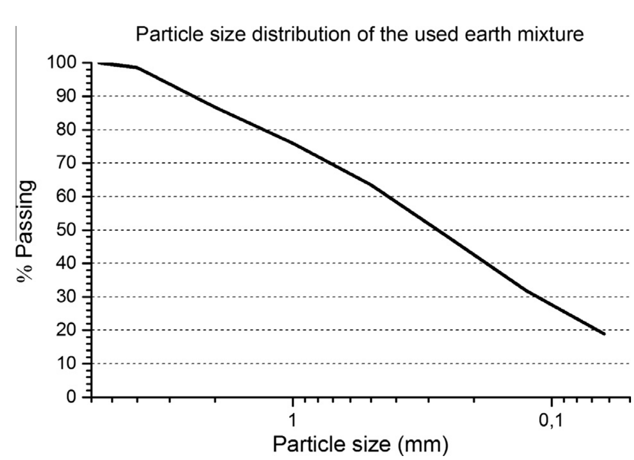

Fig. 1. Nomogram of the particle size distribution of the earth components of the mixture which was used to produce the specimens.