Construction and Building Materials 187 (2018) 205–213

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Assessment of the mechanical performance of three varieties of pine needles as natural reinforcement of adobe

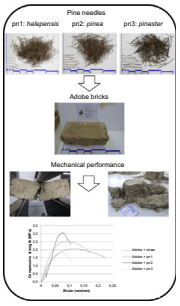
Félix Jové-Sandoval [a], M. Mar Barbero-Barrera [b,*], Nelson Flores Medina [c]

[a] Dep. Architectural Construction, ETSA, University of Valladolid (Spain), Avenida de Salamanca 18, 47014 Valladolid, Spain
[b] Dep. Construction and Technology in Architecture, ETSA, Polytechnic University of Madrid (Spain), Avenida Juan de Herrera 4, 28040 Madrid, Spain
[c] Dep. Projects and Representation of Architecture, School of Architecture, Universidad Europea de Canarias, Tenerife (Spain), Inocencio García 1, 38300 La Orotava, Spain

HIGHLIGHTS

- Pine needle can be used as vegetable fibre for adobe bricks.
- Mechanical performance of adobe bricks is defined by the pine needle ductility.
- Fibres pn1 and pn2 show better mechanical behaviour than pn3.
- Adobe brick with pn1 shows high kinematic ductility.
- Adobe brick with pn1 shows the best elasto-plastic behaviour.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 April 2018
Received in revised form 22 July 2018
Accepted 25 July 2018

Keywords:
Adobe brick
Pine needle
Natural reinforcement
Alternative
Fibre
Pinus halepensis
Pinus pinea
Pinus pinaster
Ductility
Elasto-plastic

ABSTRACT

Different types of vegetable fibres are used in the manufacture of adobe bricks to control the cracking during the drying process. In Spain, and in many other countries of the world, the fibre commonly used in the manufacture of adobe bricks is cereal straw, usually wheat. The purpose of this research is to determine the behaviour of three types of pine needles as a vegetable fibre in the adobe mass: *Pinus halepensis* (pn1), *pinea* (pn2) and *pinaster* (pn3), all of them abundant in the Iberian Peninsula. The results obtained show their viability, providing high resistance and ductility to the adobe.

1. Introduction

In recent decades, the importance of sustainability and the use of recyclable natural resources have led to the development of numerous investigations related to natural materials linked to unconventional technologies. From this point of view, construction with adobe has attracted growing interest due to its availability, its economy and its easy workability. These aspects give it exceptional characteristics as a sustainable material, with low energy consumption in its production and recyclability. The importance of building with earth has been evident in the field of traditional

* Corresponding author.
E-mail address: mar.barbero@upm.es (M.M. Barbero-Barrera).

https://doi.org/10.1016/j.conbuildmat.2018.07.187
0950-0618/

architecture, low cost contemporary social housing and the restoration of heritage [1].

Of the techniques of earth construction, adobe brick is one of the most used due to its ease of handling and its similarity to conventional brick [2]. Adobe is a block of clay soil kneaded with water into which plant fibres are generally incorporated. The vegetable fibres serve to control the cracking of the adobe during its drying process and give it an increase in the flexo-compression resistance, acting as microarmour against tensile stresses [3–6]. A wide variety of natural and synthetic fibres have been used for soil reinforcement [3]. Of them, the most used in cereal areas has traditionally been wheat straw. Its behaviour has been studied by different authors analysing the effect of straw with different lengths [7–10] and different percentages [6]. Additionally, chopped barley straw [11], wheat straw mix, barley straw and wood shavings [12] have been studied. The mechanical behaviour of adobe has also been studied by several authors [13–16].

In places where cereal is scarce, other types of more abundant vegetable fibres have been used, such as coconut and sisal fibres [4], sheep's wool [17,18], hemp fibre [19,20], fibre palm leaf [21,22], and pineapple leaf fibres [23]. The use of synthetic fibres, such as plain and crimped polyester fibres with a triangular section [24] and polystyrene [5,25], has also been studied in a mixture with clay, cement, pumice, lime, gypsum and straw. In fact, the use of vegetable fibres has been widely covered by different investigations when the matrix is cementitious [26].

On the use of pine needles, only one investigation is found using *Pinus roxburghii* along with the natural fibre *Grewia optiva*, but its purpose was to study the durability of the adobe against the action of water [27]. In spite of this, it is known that pine needles have been commonly used by local populations in the region of the Highlands of Chiapas, in southern Mexico. The importance of this type of fibre in Mexico – known locally as *juncia [sedge]* – has been studied in a preliminary investigation by one of the authors of this research [28]. In Europe or in the case of Spain, the use of needles for the manufacture of adobes has not been found in the literature.

The objective of the present investigation is to analyse precisely the behaviour of three types of pine needles from three varieties of pine present in the Iberian Peninsula [29]. The result of the investigation will serve to determine the behaviours of these types of natural fibres and analyse their feasibility and suitability for the manufacture of adobes as an alternative to the use of cereal straw.

2. Materials

2.1. Fibers

Wheat straw, provided by local farmers, was used as reference material (straw). In addition, pine needles from three varieties of pine were analysed (Fig. 1): *Pinus halepensis* (pn1), *Pinus pinea* (pn2) and *Pinus pinaster* (pn3). Each of them presents different physical characteristics in terms of length, thickness and rigidity [30,31]. These three varieties coexist normally in forest masses, so to collect the needles without them being mixed with each other, it was necessary to travel to selected monovarietal forests in collaboration with the University Institute of Sustainable Forest Management (INIA) of the University of Valladolid/Palencia. *Pinus halepensis* needles were collected in Cerrato (Palencia), *Pinus pinea* in Tudela de Duero (Valladolid) and *Pinus pinaster* in Hontalvilla (Segovia).

2.2. Adobe bricks

The soil used for the manufacture of adobes was characterized by laboratory tests by the University of Valladolid [32]. It is called Land Reference GT02AMY, presenting the following main constituents fraction: 65.48% sand, 9.28% silt and 26.24% clay. The

Fig. 1. Natural fibers used. (a) Straw fibers: ref; (b) *Pinus halepensis*: pn1; (c) *Pinus pinea*: pn2; (d) *Pinus pinaster*: pn3.