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Eco-friendly modification of earthen construction with carrageenan: Water durability and mechanical assessment

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HIGHLIGHTS

- Carrageenan bioadditives positively modified properties of earthen construction.
- Increments in compressive strength of up to 85% were observed in admixture samples.
- Tensile strength was increased up to 52% according to three-point bending tests.
- Water repellence and erosion resistance were enhanced by using coating treatments.
- Admixtures remained water resistant after 95 days of environmental exposure.

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ABSTRACT

Carrageenan, a biodegradable natural polymer, was evaluated as a bioadditive to improve the physical and mechanical properties of adobe constructions. The results show that its incorporation in the mixture during blocks fabrication, or as a coating in existent earth constructions, positively modify their behavior providing water impermeability and resistance to erosion by water drops. Results of mechanical tests also show a considerable enhancement in compressive and tensile strength when the bioadditive is incorporated during the blocks fabrication process. The obtained results show the feasibility of using natural and eco-friendly compounds to modify the behavior of traditional construction materials.

1. Introduction

The development of modern construction techniques is essential to satisfy the needs of housing for our growing societies. However, given the extensive use of natural resources, the construction sector is accountable for the generation of large quantities of wastes and greenhouse gases [1]. The main cause of this pollution is the production of building materials which require the consumption of high amounts of energy and leave a large carbon print [2,3].

In this context, earthen construction represents an attractive traditional alternative for housing since its embodied energy and carbon dioxide (CO_2) emissions are low. Several authors have determined that raw earthen constructions are much less energy consuming and do not generate as much equivalent CO_2 as modern materials like concrete or steel [2,4,5]. Additionally, the low costs of earthen construction and its simple techniques make it an excellent material for massive building, especially in rural areas where, often, neither trained workers nor modern materials are available [6].

Despite the advantages of earthen constructions, they present several drawbacks regarding mechanical resistance like poor compressive strength and durability with poor resistance to moisture and water attack [6]. From a mechanical point of view, this material presents brittle behavior and low resistance to tensile stress. These facts and the high mass of the resultant buildings, make this type of construction system highly vulnerable to seismic events [7]. As a matter of fact, earthen constructions were severely damaged during earthquakes in seismic areas as reported in different

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studies [8,9]. Durability is another aspect to consider about this material since, in general, it is considered less durable than conventional materials [6,10]. High humidity and rainfall have catastrophic effects on the strength and stability of earthen constructions. Once the water content increases in earthen structures, even in relatively small percentages, their mechanical strength is reduced significantly [11]. Another important aspect to take into account, is the high probability that these structures harbor plagues, especially when they have suffered erosion [12] or cracking because they become ideal environments for the proliferation of insects and bugs. Some examples of this type of problem, such as the presence of the triatomine bugs, can be found in the literature [13,14].

Given these adverse characteristics of earthen constructions, several techniques have been proposed for the improvement of earthen constructions' properties. Most of these methods involve the use of natural or synthetic additives and the increase in density of the soil by mechanical compaction. According to the literature, these modification methods might be classified as mechanical, physical or chemical [15,16]. The mechanical methods consist on the densification of the soils by applying different compaction techniques, which does not imply the use of any additive. The physical methods aim to increase density adding minerals or reinforcing the soil by addition of randomly distributed natural or synthetic fibers [6,19].

Sharma and his colleagues published several works with natural fibers like Grewia Optiva and Pinus Roxburghii for enhancing the durability of abode and it resulted in a remarkable increase in both mechanical strength and durability [6,19]. The chemical methods are based on techniques as cementation, chemical linkage, imperviousness and waterproofing. Cementation consists on creating a solid matrix to bind the soil together [20]. Chemical linkage aims to generate bonds between clay crystals. Imperviousness requires the use of a waterproof film to enclose the earthen particles [21]. The object of waterproofing is to reduce the entry of water and water vapor into the soil by reducing the affinity of clay to water. It must be noted that the use of additives could combine the effect of several of the mentioned methods at the same time [16].

The modification techniques for improving the characteristics of earth can also be grouped together based on the properties required to be enhanced. Additives commonly aim to improve reduction of shrinkage cracks, stabilization against water erosion, enhancement of binding forces, increment in the compressive strength, resistance to abrasion and increment of thermal insulation [22,23]. For the reduction of cracks produced by shrinkage, several additives might be used, such as sand, sodium waterglass (Na_2O_3-$4SiO_2$), soda (Na_2CO_3), humus acid, tannic acid, and fibers etc. [6,15,17–19,21,24–27]. The stabilization against water erosion can be achieved by the addition of mineral stabilizers as cement, lime, bitumen and sodium waterglass. Some animal products like blood, urine, manure, casein and animal glue, as well as the extract of some plants as sisal, agave, bananas and algae have also been used to improve stabilization and mechanical properties [28]. On the other hand, artificial stabilizers such as synthetic resins, paraffin, synthetic waxes and synthetic latex also have stabilizing properties [25]. The binding force between soil particles can be enhanced by increasing the clay content or using certain additives [17–19,24–27]. To increase the compressive strength, mineral or organic additives, such as fibers, might be included [20]. Improvement of the resistance against abrasion can be achieved using soda waterglass and linseed oil. Thermal insulation can be increased by adding straw, minerals, cork or wood. These additions aim to reduce the weight of the loam raising its porosity [22–23]

Interest and importance of biodegradable polymers in building construction is remarkably increasing with diffusion and acceptance of environmental awareness [26]. Consequently, natural or modified biopolymers are getting great attention as eco-efficient sustainable construction and building materials. These have been studied to optimize the properties of building materials [26]. Biopolymers are obtained from renewable natural sources reducing the dependence on fossil fuels with the consecutive reduction of carbon dioxide emissions [27]. There are numerous studies regarding the application of bio-admixture to optimize material properties with a variety of molecular weight: low molecular weight like tartaric acid and sodium gluconate and macromolecules like lignosulfonates, cellulose ether, xanthan gum, seaweed and chitosan, etc. [26,29,30].

In this article, the effects of the addition of carrageenan on earthen constructions are presented. Carrageenan comprises a group of natural lineal sulfated polysaccharides that are present in red algae. The repeating units of these biopolymers are D-galactose and 3,6-anhydrogalactose, some of which are sulfated and are linked through $\beta(1 \rightarrow 4)$ and $\alpha(1 \rightarrow 3)$ bonds [31], as shown in Fig. 1. The sulfate groups give the anionic polyelectrolyte character to these polysaccharides when dissolved in water. Due to their excellent rheological properties in solution, such as thickening, gelling and stabilizing abilities, carrageenan has been widely employed in the food industry [32]. There are few studies of the application of carrageenan as an additive in construction materials [27,33]. The use of carrageenan in concrete preparation as a flexural modifier has been reported, resulting in a high compressive strength, flexural strength, and impact toughness [33]. Carrageenan has also been applied in the preparation of fly ash-based geopolymer pastes. In this case, increments of strength and pre-peak toughness of the geopolymer were observed [27]. In the present study, the effect of the addition of this biopolymer to earthen building blocks will be studied regarding its durability against water and its mechanical resistance.

2. Materials and methods

2.1. Carrageenan

Carrageenan was extracted from red algae, *Chondracanthus chamissoi*, from the central Peruvian coast. Extraction was carried out in alkaline aqueous medium (0.1 M sodium hydroxide for 4 h, followed by precipitation of the polysaccharide in 2-propanol, and drying at 50 °C for 24 h. Characterization of the extract by fourier transform infrared spectroscopy (FTIR) and proton nuclear magnetic resonance (^{1}H NMR) spectroscopies resulted in a mixture of polysaccharides in which κ- and ι-carrageenan predominate (more than 70% molar). The polymer chains have a

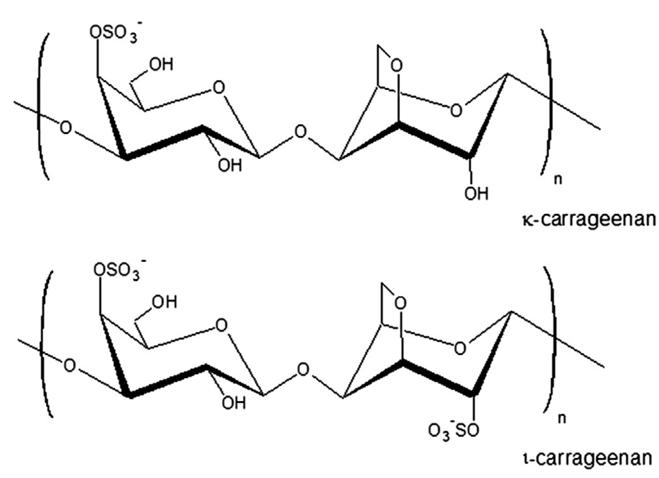

Fig. 1. Chemical structures of κ- and ι-carrageenan.