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Enhance the rheological and mechanical properties of clayey materials by adding starches

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HIGHLIGHTS

- The performances of clay/starch mixes are shown for their fresh and hardened state.
- The choice of the optimal paste is based on the flow test.
- The starch increases both of the water demand and the mechanical strengths.
- The starch changes the rheological behavior of clayey materials.

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ABSTRACT

This research work highlights the rheological and mechanical behavior of clayey/starch mixes.

Several native and derivate starches have been studied in association with two types of clayey materials: quarry fines and kaolinite. The mixes were manufactured with a constant starch/clayey material ratio of 1%. The optimal water content has been determinate by the flow test. The rheological and mechanical tests have shown a significant effect of starch on the properties of mixes. In the rheological part, most starches have induced an increase up to four times the thixotropic index for quarry fines, while a decrease of this parameter has been observed with the kaolinite. From a mechanical point of view, all starches increase mechanical strengths whatever the clayey material.

1. Introduction

For millenaries, earth has been used in the construction of buildings and approximately one third of the world population still lives in earthen structures [1]. Mainly compounded of clay and/or silt, earth as a building material is economical, environmentally friendly and abundantly available. It has been used extensively for wall constructions around the world. Moreover, Romans usually used raw earth as building material in-situ [2]. They knew very well that it was hardly possible to use only earth to produce large bearing bricks because of their excessive shrinkage and consequently cracking, and because of the limited workability of the mixture. Then, they found that sand or coarse sand added to the mixture was a solution [2] to “degrease” clay and to turn it into a mixture. However, the construction of dwellings using local materials, in developed countries, has become marginal. Several investigations have been consecrated on the study of various methods of construction: compressed earth blocks, adobe blocks, adobe walls or earth-straw mixes, to find the best mechanical and thermal properties of products made with raw earth, stabilized or unstabilized. These techniques were disused, because it is not possible to standardize the composition of materials with variable properties according to their localization. Raw earth construction is no exception.

In the present environmental context, civil engineering companies aim to use materials with low environmental impact (local resources, low energy consumption and low gas emission during manufacturing…etc.). The raw earth materials (REMs) may fulfill this criterion and provide a sustainable and healthy alternative to conventional construction materials. Moreover, raw earth

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materials require very little energy to produce and induce little CO_2 outgassing.

The main drawback of raw earth is the high water supply necessary to achieve adequate workability for placement operations. Contrary to concrete which hardens through a chemical process, REMs solidify when losing water during drying, which can take a long time for elements of considerable sizes. Furthermore, REMs have low mechanical performances and require large units to build bearing walls.

To be competitive in comparison with concrete or plaster, REMs need to widen their use domains thanks to, for example, an easier use at fresh state and an improvement of mechanical performances while keeping their environmental advantages. A combination of REMs with environmentally-friendly admixtures could be a solution.

In the literature, cement or lime treatment is a classical solution for reinforcing the raw earth materials. However, this solution requires high energy consumption and high greenhouse gas emissions for the production.

With the development of green construction in the last decade, there is necessary need for development of bio-based admixtures that may perform as equally well as the traditional materials. Hence, several researchers have been devoted to make a green composite with starch. For example, A.T. Le et al. [3] explain, in their experimental study, the substitution of lime by starch in lime–hemp concrete to obtain a lighter density between 170.8 kg/m^3 and 158.9 kg/m^3, with satisfying compressive strength between 0.4 MPa and 0.5 MPa, whereas for lime–hemp concrete the average compressive strength varies from 0.1 MPa to 0.8 MPa for the density between 330 kg/m^3 and 470 kg/m^3. Despite of these good results, the starch-hemp concrete had a very low Young modulus, which does not allow to use this composition as a construction material [3]. Also, Akindahunsi et al. [4] studied the influence of two types of starches on some properties of concrete. Their results showed that both starches have a positive impact on the compressive strengths with not more than 1% of starch additional to concrete especially at the early age, while the raise of starch percentage to 2% gives lower compressive strengths results.

Other studies proved that the addition of starch enhances the workability of cementitious pastes and can be used in replacement of petrochemical high range water reducing admixtures [5]. Crépy et al. [5] show that a graft of sulfopropyle or sulfobutyle side chains on a starch polymer can lead to slump flows on grouts comparable with the ones obtained on PolyNaphtalene Sulfonate (PNS) based grouts.

The particle-solution interface has influences on the rheology of concretes, in particular on the formation of hydrates, the adsorption of polymers, the surface chemistry and charges, the water-powder ratio and the particle morphology [6]. At this scale of the particle-solution interface, studies have shown that: starches can modify the rheological behavior of concrete by increasing the plastic viscosity, yield stress increases with increasing solid particle volume fraction [7] and starches affect also the cement hydration characteristics and the performances of superplasticizers.

Starch is a polysaccharide with vegetable origin, which has an important weight fraction in a large number of agricultural commodities such as tubers (60–90%), cereals (30–70%) and legumes (25–50%). The polysaccharides provide a potential solution as rheology modifying admixtures for the construction industry such as concrete or mortar. In view of that, the stabilizing agents, used to avoid the risk of segregation in the concrete by adding to superplasticizers, are typically based on polysaccharides such as cellulose, sphingan gum, or starch. Starch, major energy reserve in plants, is one of the most abundant biomasses on earth, and can be found in grains, stems, tubers, roots, leaves, and fruits. Starch is composed of two macromolecules: amylose and amylopectin. Amylopectin has a strong influence on the dispersion and stabilization of particles [8], which differentiate the starch from others polysaccharides. Starch is usually used as a thickening agent thanks to its capacity to jell; when it is put in a solution, its temperature is increased. According to the botanic origin, the jelling temperature and the jelling level are different (e.g. 70 °C for maize or waxy maize starch, 65 °C for potato starch, 59 °C for wheat starch etc.…). Several types of modifications have been developed by industrials to use easier the starches: pregelatinization, esterification… The pregelatinized starches were obtained by heating, in manufacture, the native starches in the presence of water. Through this process, which is irreversible, the particles of starches eventually lose the semi crystalline structure and change their viscosity. After preparation, these pregelatinized starches are dried and sold in the form of fine powder. The gelling power can be found again in mixing these starches with water at ambient temperature, without heating.

Chemical modifications of native starch essentially take place on the hydroxyl groups of the anhydroglucose unit. Among the large number of chemical modifications [9], esterification is an easy way to introduce various functional groups in the starch structure. These functional groups could either be obtained by reaction between native starch and organic or inorganic reagents. These chemically modified starches then possess specific properties (more moisture resistant, lower thermal degradation and biodegradation, better compatibility, etc…[10].

In this research work, the combination of REMs with starch is studied in order to design mixes for use in prefabricated products. The use of starch is chosen for its capacity to modify the rheological behavior of materials and for its "glue effect", very much like wallpaper glue. For prefabrication, mixes must fit into molds easily in order to be handled after manufacturing, have a short drying time and satisfy long-term mechanical performances.

2. Materials

In this section, the characteristics of materials used in our experimental study are shown.

2.1. Quarry fines (QF)

The clayey materials, chosen for the experiments, are quarry fines (QF) from the storage site of "Carrières du Boulonnais", a company located in the north of France. These materials are produced through the process of aggregates washing in the quarry according to the EN 12620 standard [11]. This quarry fines (QF) include clay and limestone, therefore, according to the USCS classification, they are defined as Ap (low plastic clay). QF properties were measured by 'Carrières du Boulonnais'. Tables 1 and 2 give the average mineralogical compositions and properties of the quarry fines. Despite a relatively small proportion of clay in these materials (19%), they present physical behavior of clay. The clay

Table 1
Average mineral composition of the quarry fines by X-ray diffraction [12].

Composition	Percentage
Limestone	62%
Kaolinite	12%
Quartz	11%
Illite	7%
Dolomite	5%
Goethite	3%

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