Construction and Building Materials 154 (2017) 411–423

Contents lists available at ScienceDirect

Construction and Building Materials

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

CoRncrete: A corn starch based building material

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HIGHLIGHTS

- A novel material which uses corn starch as a binder and sand as filler.
- Rapidly hardening material gaining strength by heating at a relatively low temperature (<=200 °C).
- CoRncrete has a compressive strength of up to 26 MPa.
- Biodegradable and light-weight compared to traditional concrete and brick.

ARTICLE INFO

Article history:
Received 17 October 2016
Received in revised form 15 July 2017
Accepted 25 July 2017
Available online 5 August 2017

Keywords:
Corn starch
Construction material
Gelatinisation
Biopolymer
Compressive strength

ABSTRACT

Starch is a natural polymer which is commonly used as a cooking ingredient. The renewability and biodegradability of starch has made it an interesting material for industrial applications, such as production of bioplastic. This paper introduces the application of corn starch in the production of a novel construction material, named CoRncrete. CoRncrete is formed by mixing corn starch with sand and water. The mixture appears to be self-compacting when wet. The mixture is poured in a mould and then heated in a microwave or an oven. This heating causes a gelatinisation process which results in a hardened material having compressive strength up to 26 MPa. The factors affecting the strength of hardened CoRncrete such as water content, sand aggregate size and heating procedure have been studied. The degradation and sustainability aspects of CoRncrete are elucidated and limitations in the potential application of this material are discussed.

1. Introduction

Starch is an abundant biopolymer that is produced and stored in photosynthetic tissue of plants. It is a cheap and biodegradable polymer that is derived from renewable sources. These advantages make it an attractive material for food and non-food applications. Starch forms an important source of energy in human diet in form of bread, pasta and bakery products. In recent years, it has been used as a substitute of crude oil derived components in numerous chemical application such as plastic, detergent and adhesives [1]. It is also widely used in paper making and manufacturing of corrugated boards.

Starch is known as a semi-crystalline material which contains alternate crystalline and amorphous regions [2]. It is a polysaccharide consisting of a large number of glucose units linked together by α(1,4) bonds. It is a heterogeneous material consisting of linear (amylose) and branched (amylopectin) molecules [3]. The composition of starch is more or less universal with a major component of amylopectin (75%) and a minor component of amylose (25%) irrespective of its source [4].

In Europe, starch is mainly extracted from potatoes, wheat and maize. According to the Starch Europe Association [1], European Union (EU) starch production has increased from 8.7 million tonnes in 2004 to 10.5 million tonnes in 2014. The EU consumes about 9 million tonnes of starch, of which 61% is in food, 1% in feed and 38% is used in non-food applications, primarily paper making.

The application of starch extends to the building and construction industry where it has been used as a binder in thermally insulating composites [5–10], an admixture for viscosity modification in concrete [11–17], a modifier in asphalt [18] and retarder in the cement hydration process [19]. In the investigation on thermally insulating composites, researchers utilised natural fibres, such as hemp [5–7], sisal [8] and jute [9], with starch acting as a binder and improving the mechanical performance. In their investigation, Balčiūnas et al. [6] utilised hemp hurds and corn starch to build composites, with a compressive strength of up to 1.9 MPa. Whereas composites manufactured by Gacoin et al. [7], using

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http://dx.doi.org/10.1016/j.conbuildmat.2017.07.184
0950-0618/

hemp and wheat starch, had a maximum compressive strength of 2.1 MPa. Starch based Ether has been utilised by Isik and Ozkul [11] and Cappellari et al. [12] in concrete and mortar respectively to improve the rheological property of the mix. Vieira et al. [15] and Crépy et al. [17] utilised modified starch as the dispersing agent in self-compacting concrete. Al-Hadidy et al. [18] improved the moisture and temperature susceptibility of asphalt material by adding starch. Peschard et al. [19] showed that starch enhanced the retarding effect on hydration of cement. In all these aforementioned investigations, the rheological and gelatinisation properties have been exploited to improve the flow and binding properties of different materials. The use of corn starch and its derivatives are wide, and in fact, the possibility of producing starches with different chemical properties from corn starch has made it the most used starch for industrial applications [3]: 47.5% of starch products are based on corn starch [1].

When corn starch is mixed with water in sufficient quantity, it forms a non-Newtonian fluid. Suspensions of corn starch in water show shear thickening behaviour, which means that the suspension can resist rapid deformation, but when left unperturbed, it becomes a thin liquid. Starch granules are insoluble in cold water. When the starch granules are heated in the presence of water, a phase transition occurs. When sufficient water is present, this transformation, called gelatinisation, results in near-dissolution of the starch [20]. Gelatinisation is an irreversible process that includes granular swelling, native crystalline melting, and molecular solubilisation [21]. The temperature at which gelatinisation occurs is called the gelatinisation temperature.

This work focuses on the application of un-modified corn starch as a binder in a new construction material named CoRncrete. CoRncrete is formed by mixing water with corn starch and sand, and heating the mix in a microwave or oven. This heating process results in the formation of a hardened material. Fig. 1 shows an overview of the production process of CoRncrete. An introductory video on how to make CoRncrete can be seen on YouTube [22]. The main objectives of the study, which is presented in this paper, was to determine the optimum mixture composition and heating procedure and to explain the physical behaviour of CoRncrete, with a focus on the factors affecting the compressive strength of the hardened material. Secondly, the durability with respect to water resistance and the environmental performance of CoRncrete are evaluated.

2. Materials and methods

2.1. Preparation of fresh CoRncrete

Fresh CoRncrete was prepared by mixing corn starch (Duryea Maizena, Unilever, Netherlands), sand of grain size 0.125–0.25 mm (Sibelco, Netherlands) and tap water. Mixing was performed for 2 min at 50 RPM in an electric mixer (Model: KMM760, Kenwood, UK). Prior to electric mixing, corn starch and sand were manually mixed in order to prevent the clustering of wet corn starch particles in the electric mixer. A constant corn starch to sand dry-weight proportion of 1:5 (i.e. 16.6%) corn starch) has been adopted throughout this work based on preliminary test results (compressive strength) that were carried on CoRncrete prepared by mixing different proportions of corn starch and sand.

2.2. Physical behaviour of fresh CoRncrete

2.2.1. Fallcone test

The fallcone test was performed on sand, corn starch and fresh CoRncrete to study the physical behaviour of the fresh CoRncrete mixture. The fallcone test is typically used in geotechnical engineering practice to determine the undrained shear strength of fine grained soils (clays or silts) and is one of the prescribed standard methods to determine the liquid limit. The liquid limit is one of the consistency limits which is used for the classification of fine grained soils. It is defined as the water content, which indicates an empirically defined boundary at which fine grained soils undergo a transition from a viscous liquid state to plastic solid state [23]. A recent study used this test to provide insight in the saturation dependent strength of unsaturated sand [24]. The test equipment consists of a standard cone with a cone tip angle of 30° and a mass of 80 g, and a sample cup of internal diameter 55 mm and 40 mm height (capacity: 100 ml). The samples were prepared by adding water in increments of 3.3% (wt). In the case of only corn starch, equivalent increments of 20 wt% of water were added to ensure a similar water to corn starch ratio, as in CoRncrete. The sample cup was filled in 3 layers, where each layer was tamped 10 times with a rubber capped steel rod. Excess material was flattened off along the rim and the weight was measured, which was used to calculate bulk density. The tip of the cone was lowered down to the top of material and released. Readings were taken to the nearest 0.1 mm at 5, 10, 20 and 30 s. A sample of approximately 30–50 g from the middle of sample cup was then taken in a glass crucible for determination of the water content. The water content was determined by measuring the mass loss when heated at 105 °C for 24 h in an oven, and used to determine the dry density.

2.2.2. Proctor test

The Proctor test was carried out on the wet CoRncrete mixture and sand following the guidelines of BS 1377:part4:1990 [25]. The Proctor test is an extensively used laboratory compaction test to determine the relationship between dry density and water content for medium to fine grained geo-materials such as clay, silt and sand [25]. In this test, the soil particles are compacted by mechanical means, thereby increasing the dry density of soil. The obtained dry density depends on the amount of compaction energy applied and the amount of water present in the soil. The water content corresponding to maximum dry density is termed as the optimum water content. At this water content, maximum compaction is achieved (high packing density and minimum voids). The test setup consists of a compaction mould (1 L capacity) and mechanical rammers. An adaptation was made to the code by compacting samples with lower energies, 22.1 kJ/m^3 (150 g rammer with 20 cm drop height) and 51.5 kJ/m^3 (350 g rammer with 20 cm drop height) as opposed to 595.5 kJ/m^3 (2500 g rammer with 30 cm drop height). The samples were prepared by adding water in increments of 3.3% (wt). The increment was changed to 1.5% when significant difference in bulk density of consecutive readings was observed. The prepared sample was filled in the mould in 3 layers, where each layer was tamped 25 times with a rammer. Excess material was flattened off along the rim and the weight of the sample was measured from which the bulk density was calculated. The water content and the dry density of sample were then determined by heating a representative sample taken from the mould for 24 h in an oven at 105 °C.

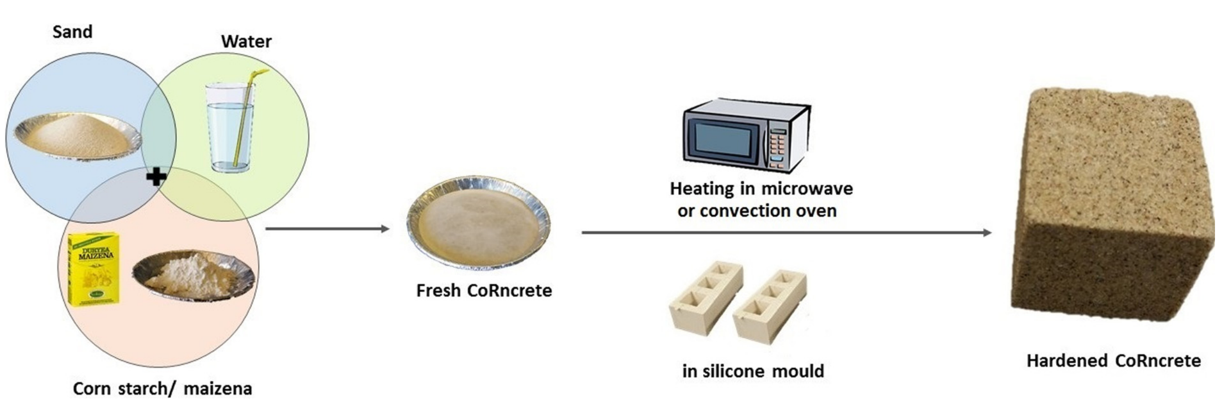

Fig. 1. Preparation of hardened CoRncrete by heating fresh CoRncrete (filled in a silicone mould) in a microwave or a convection oven.