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Application of bacterial cellulose as reinforcement for 3d printed raw earth

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Abstract

New aims have emerged to reduce the environmental impact of human activities including construction. The use of natural, local, recyclable, traditional building material as earth associated with an innovative manufacturing technique like 3d printing would achieve a sustainable architecture that promotes the notion of a low-carbon, zero-waste design for a successful circular economy. Although ancient earthen constructions have proven the longevity of raw earth as construction material, it is still considered as a non-standard building material due to its sensitivity to water, low mechanical resistance and the high tendency to crack during the drying phase as a result of shrinkage phenomenon. This paper introduces a new circular earth based biomaterial compatible with 3D printing. A biodesign approach was used to achieve better performance of material. Micro-fibers, obtained from laboratory cultivated bacterial cellulose (BC), were proposed as a reinforcer for the soil matrix with the aim of reducing shrinkage impacts and increasing material mechanical resistance. In this research, the impact of bacterial cellulose addition on rheological behavior and shrinkage of the raw earthen mixture has been defined and measured. A simple methodology has been proposed for the development of an extrudable stabilized earthen mixture compatible with the 3D printing technique by extrusion. Finally laboratory-scale printed samples have been carried out and mechanically tested.

Keywords: Additive manufacturing, Biodesign, Bacterial cellulose, Raw earth, Rheology.

1. INTRODUCTION

Additive manufacturing of cement-based materials has shown economic and environmental benefits. In the current environmental context, bio and geo-sourced construction have become privileged and raw earth has become a center of interest and development. Several projects, which have shown that raw earth can be a better candidate compatible with additive manufacturing [1,2,3]. However, since good quality soil for construction is not necessarily easily found, specific studies to improve its performance are required. Several research projects have investigated methods of consolidating earthen material, for traditional construction techniques, so as to preserve the material's carbon footprint [4,5,6]. In the case of additive manufacturing, the choice of stabilizer is limited by the technical constraints imposed by the machine used. The compatibility of some stabilizers with additive manufacturing and their impacts on soil performance have been studied [7].

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Bacterial cellulose (BC) is a polysaccharide distinguished for its high purity of about 99% (plant-based cellulose is strongly associated with other molecules such as lignin). The purity of BC makes it a very attractive raw material in several domains. Engineering applications, in particular, in the production of bio-materials have been studied [8,9]. Verifying the compatibility of earth and BC association for 3d printing and defining the characteristics of this new material are the goals of this research.

2. MATERIALS AND METHODS

In this work, we hypothesized that a microfibrated biopolymer like BC can strengthen the soil matrix in a manner comparable to stabilization with fibrous materials. In addition, thanks to the sizes and lengths of microfibers, this additive can be compatible with the technical constraints imposed by 3D printing (nozzle and endless screw sizes). The BC used in this research was cultivated in the laboratory. The production of BC relies on a natural fermentation process of a tea-based, glucose-rich liquid called kombucha. Another method of cultivation through the fermentation of agricultural waste has been tested. Regarding the soil used, it is a commercial fine soil with a maximum particle size of 2mm. The choice of granulometric composition of the selected soil is due to the printer used for implementation (Delta WASP 40100).

The plasticity index of the used soil was determined according to the Atterberg limits method. Two cellulose contents were tested : 3% and 8% in mass. In order to define the optimal water contents for 3D printing and for each cellulose content, in a simplified way, we used the method of Pefferkorn, which consists in measuring the slump of a sample loaded by a disc. Thanks to this method, the water to earth mass ratio was fixed at 27% for the mixture without additives and at 32 and 35% respectively for the mixture of 3% and 8% of bacterial cellulose. The mixtures were prepared by mixing the soil with the BC, then water was added. The mixtures were left to homogenize for 48 hours before preparing the samples. The three mixtures were used to perform shrinkage and mechanical strength tests.

for shrinkage test, a 5*3cm cylindrical mold was used. However, for mechanical tests, the goals are to determine the impact of BC and the manufacturing technique on material's performances. Two types of samples were prepared (molded and printed) in the form of prisms of 40*40*160mm for bending test, 40*40*80mm for compressive strength test. Extrusion tests to ensure extrudability, constructability and to set printing parameters (air pressure, speed, layer sizes) were also carried out.

3. RESULTS AND DISCUSSION

The study showed the compatibility of bacterial cellulose as a soil additive for additive manufacturing. BC has positive impacts on increasing mechanical resistance in compression and bending. A decrease in dimensional change (shrinkage) was detected and no cracking was observed in samples stabilized with BC even with high water contents.

In future work, we are interested in the durability analysis of stabilized and unstabilized printed bricks (Figure 1). The printed brick wall will be installed in sense city (UGE). Another idea is to associate another natural additive(s) with BC which can further enhance the performance of raw earth for construction.



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