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# Earthen construction materials: Assessing the feasibility of improving strength and deformability of compressed earth blocks using polypropylene fibers

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ABSTRACT

Earthen construction materials are often ecologically friendly and locally available. They are however weaker and poor in damage resilience compared to mainstream walling materials like fired bricks and concrete masonry units (CMU). Compressed earth blocks (CEB), a modern form of the adobe brick, are gaining popularity as a construction material globally because they are stronger and more dimensionally stable compared to earlier forms of earthen construction methods/techniques. Despite the strength improvement achieved through using CEBs over other traditional forms of earthen construction, they are still more brittle and weaker in bending and compression in comparison to CMU and fired bricks. This research investigated the potential of addressing some of the shortcomings of earthen construction materials by assessing the influence of polypropylene fibers on the strength, ductility, and deformability of CEBs. CEBs were produced using different fiber weight fractions and tested in both compression and bending. Overall, performance in bending and ductility were improved by the addition of fibers. The quantity of fibers present was found to have an influence on block strength, post-crack response, and deformability. The findings presented in this paper suggest that polypropylene fibers are a feasible fiber option for CEB production.



## 1. Introduction

Globally, about a third of the human population resides in earthen shelters. In developing countries, the number is estimated to be as high as 50% [1]. There is a resurgence in the use of earthen construction materials mainly due to their lower embodied energy and cost compared to mainstream walling materials like fired bricks and concrete masonry units (CMU) [2–4]. However, earthen construction materials in comparison to concrete masonry units (CMU) and fired bricks have lower resistance to bending moments and lower tensile and compressive strength properties [5]. These identified deficiencies make earthen construction materials brittle, weak and poor in damage resilience. Compressed earth blocks (CEB), a modern form of the adobe brick are gaining popularity as a construction material globally because they are stronger and more dimensionally stable compared to earlier forms of earthen construction materials. Despite the performance improvement achieved through using CEBs, they are still very brittle and of lower strength in comparison to mainstream walling materials like concrete masonry units (CMU) and fired bricks.

Historically, fibers have been used as reinforcement in earthen construction methods and techniques. Straw and horsehair were used to provide tensile reinforcement for sunbaked bricks and masonry mortar and plaster respectively [6]. The use of fibers as reinforcement in traditional earthen masonry has carried over into CEB production. Both natural (obtained from plants and animals) and synthetic fibers are used to reinforce soils for CEB production [7]. The inclusion of fibers into soil–cement mixes for CEB production creates a network of fibers, which improves tensile and shearing strengths, and also helps reduce shrinkage [7–10]. Fiber-reinforced blocks can withstand higher stresses by absorbing high amounts of energy making them particularly important in earthquake prone regions [8]. It has been demonstrated that sisal [11,12], coconut fiber [13–15], straw [16], polyethylene [10], jute [17,18], are all feasible options for CEB reinforcement. Improvement in ductility is widely accepted as a key benefit of fiber reinforcement in soil–cement composites. An improvement in ductility prevents catastrophic failure of earthen structures during events such as high winds and earthquakes. The delay in collapse as a result of improved ductility can be the factor determining if people get out alive or remain trapped inside a collapsing structure [19,20].

Fibers typically used for CEB production have been either natural untreated fibers or fibers derived from post-consumer plastic

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waste products. Where untreated natural fibers are used, there is the potential of fiber degradation in the highly alkaline environment resulting from the hydration of ordinary Portland cement (OPC). This can negatively affect durability [6]. The net impact of such reactions on the strength properties of CEBs, especially durability due to the effect of the alkaline environment present in OPC, is a subject that needs to be further investigated before scaling up the use of natural fibers in CEB production [15]. Synthetic fibers used in CEB production are often derived from chopped post-consumer plastic waste products. This introduces the possibility of variations in CEB quality and strength properties especially when fibers derived from different waste plastic materials are used in the same mix (matrix). In order to promote replicability and ensure consistency in results, commercially available macro polypropylene fibers used in concrete production were used in the experimental work presented in this paper.

Structural performance of earthen construction/masonry systems can be improved in two main ways. The first is a system level approach that uses structural reinforcement (steel rebar), reinforced concrete bond beams, roof to wall connections, and other established guidelines for unreinforced masonry practice. The second approach is improving block and mortar properties such as strength, ductility, toughness, and block-mortar bonding [17,21,22]. The study presented in this paper adopts the latter approach by evaluating the influence of polypropylene fibers at different weight fractions on the strength (compressive and 3-point bending), ductility, failure mode, and deformability at the block level. Structural design is based on known values and anticipated conditions. The performance of earthen buildings when subjected to earthquakes, hurricanes, or typhoons must be predictable. Such predictability can only be enhanced with the accumulation of data on earthen construction materials allowing engineers and inspectors to gain the needed confidence [22]. The findings of this paper adds to the pool of data available to help with the performance prediction of earthen masonry systems.

## 2. Materials and methods

### 2.1. Materials

The materials used included local soil (from Gainesville/Newberry, Florida), ordinary Portland cement (OPC), and; commercially available "MasterFiber MAC Matrix" macro synthetic polypropylene fibers obtained from the BASF Corporation. The use of these commercially available fibers used for concrete production was to ensure that all matrices contained fibers of the same quality. This reduced the variability in results associated with differences in fiber quality. The fibers had a length of 54 mm, an equivalent diameter of 0.82 mm, aspect ratio of 67, tensile strength of 585 MPa, and specific gravity of 0.91. The fibers are composed of two circular filaments that are cross-linked into a single "stick-like" fiber with an embossed surface with depths from peak to valley of about 0.005–0.006 mm. The deformations provide mechanical anchorage between the fiber and matrices. The fibers are shown in Fig. 1. The fibers have been successfully used in shotcrete and floor slab applications to improve flexural toughness, impact resistance, residual strength, and durability [23].

The grain size distribution of the soil used in this study was determined using the American Association of State Highway and Transportation Officials (AASHTO) soil classification system [24]. The physical properties of the soil are presented in Table 1.

### 2.2. Preparation of specimens

Two sets of specimens were produced: one set for compressive strength testing and the other for the 3-point bending test. In order to remove lumps from the dry soil for block production, the soil was passed through a manual sifter with a sieve size of 3.40 mm. With the fiber-reinforced matrices, the fibers were gradually introduced into the mix after the initial hand dry mix of sand and OPC had been observed to be thorough. After an additional 20 min, the mix appeared uniform and thoroughly mixed with the fibers well dispersed. The dry mix was then watered gradually in a uniform manner while mixing continued. Approximately 0.6 kg of water was required for every 45.36 kg of soil–cement–fiber mix. The mixing process continued for 10–20 more minutes depending on the quantity of fibers present. The fiber-reinforced matrices were produced with fibers at 0.2, 0.4, 0.6, 0.8, and 1.0 weight fractions (Table 2). When the fiber content exceeded 0.6% (by weight), it took a longer time to attain good fiber dispersion and homogeneity.

A hydraulic operated block-making press was used to produce the blocks. The press exerted a force of 1.6 MPa on the soil–cement–fiber mixes for about 30 s. After compression, the blocks were ejected from the mold (Fig. 2), moved, and placed on pallets

**Table 1**
Soil properties.

| Property | Composition |
|---|---|
| Liquid limit (%) | 33% |
| Plastic limit (%) | – (non-plastic) |
| Plasticity index (%) | – |
| Sand (%) | 87.3% |
| Clay (%) | 12.2% |
| Silt (%) | 1.5% |
| Optimum moisture content | 9% |
| Maximum dry density | 1784.5 kg/m$^3$ |

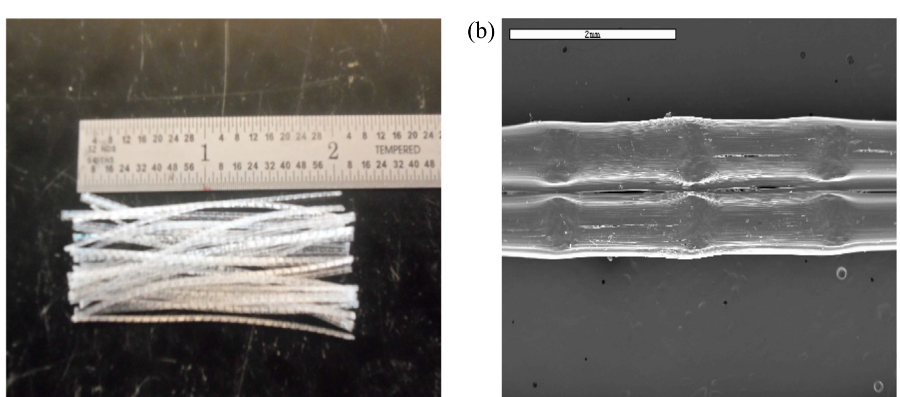
(a) (b)


**Fig. 1.** MasterFiber MAC Matrix fibers (a) Photograph of fibers (b) SEM image of fiber showing cross-linked filaments.