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The effects of waste marble dust and polypropylene fiber contents on mechanical properties of gypsum stabilized earthen

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HIGHLIGHTS

- Mechanical properties of fiber-added adobe.
- Waste marble dust- and polypropylene-added adobe blocks.
- Stabilization with polypropylene fibers proposed.
- 132 samples prepared for 07 and 28 day periods.
- Results indicate increased compressive strength and flexural strength by using 0.5% polypropylene fibers.

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ABSTRACT

Adobe is one of the oldest and most widely used building materials in the world. It is a natural building material made from sand, clay, water, and some kind of fibrous or organic material, such as sticks and straws. Alker is just soil with a high content of clay stabilized with lime and calcined gypsum. It is composed of 10% gypsum, 2% lime, and 20–22% water in veneration to the weight of dry soil as a construction material. Earthen structures are extremely durable when built using skilled production and design principles. The strength and durability of earthen materials can be improved, if needed. Some kinds of fibrous, inorganic, or organic materials, like sticks, straw, dung, rice husks, asphalt emulsion, Portland cement, and lime, can be added to promote earth stabilization.

This study examines the effect of polymer fiber and waste marble dust contents on the compressive and flexural strength of Alker by using two soils from different locations. Mechanical properties of certain soil–fibers–marble dust combinations comprising different proportions of polymer fiber as 0.5%, 1.0%, 1.5%, and 2.0% and waste marble dust (by 10% and 20% dry weight of soil) were thoroughly investigated. The results showed that producing adobe samples with polymer fibers results in better mechanical properties than Alker. The most desired results for both soils were obtained using a ratio of 0.5% polymer fiber and 10% marble dust. The mix proposed satisfies the minimum compressive and flexural strength requirements of ASTM and Turkish standards.

1. Introduction

Earthen construction does not meet today's requirements due to certain limitations such as low water resistance and low earthquake resistance. Earth's strength and durability can be improved, if needed. The dense forms of stabilized earthen construction have a high thermal mass and are able to store heat as well as provide long-term energy savings for cooling in summer and heating in winter; as a result, they provide bioclimatic comfort for health with suitable humidity, thereby balancing the indoor climate. Given earthen structures' high thermal comfort and in light of the cultural characteristic properties of Cyprus, their sustainability is important. During ancient times, different building materials were used in Cyprus. In both the Luzinian (1192–1489) and Venetian periods (1489–1571), stone was the major construction material; however, during the Ottoman period (1571–1878), stone was used only for the ground floor, as adobe construction was employed for the upper floors of residential buildings. During the British period (1878–1930), stone was used as a structural material [1]. Sustainability requires resources to be conserved, the environment to be protected, and a healthy environment to be maintained. Sustainable development responds to the needs of the present without abandoning the ability of future generations to supply their own needs.

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Earthen construction is not meeting today's requirements because it has some limitations, such as low water resistance and low earthquake resistance. Earthen construction is labor intensive; instead of relying on labor-intensive conventional production, the new composite material offers advantages for the construction sector. The characterization of earthen buildings includes basic materials like clay type, gypsum, lime, and fibrous materials, using their physical properties. Cultural and environmental conditions highlight the reuse of the earthen materials today. Contemporary studies focus on earthen structures as most important subjects of sustainability throughout the world, as mentioned in [1,2]. Goodhew and Griffiths [3] examined how to build sustainable earth walls to meet building regulations. Pacheco-Torgal and Jalali [4] examined earth construction by considering the lessons learned from the past for the future eco-efficient construction. The utilization of Alker with low energy consumption contributes to sustainable indoor and outdoor construction and life cycle. The revival of earthen construction will protect earthen architectural integrity, but the rapid production of industrial materials can threaten earthen constructions. In addition, water causes the deterioration of earthen structures.

Earth building in Turkey has been used since ancient times. Adobe walls were used in Çatalhöyük as early as 9000 BC [5]. Gypsum stabilization was first developed in 1978 by Ruhi Kafesçioğlu at İstanbul Technical University [6]. Buildings constructed with Alker since 1980 have demonstrated the enhancement of the durability of earthen structures. As a new composite material with lower shrinkage value, Alker is suitable for being produced with machines. Alker as a construction material is composed of 10% gypsum, 2% lime, and 20–22% water in veneration to the weight of dry soil. Clay is the binding component of traditional earthen construction. The required binding property can only be achieved if the earth includes 30–50% clay content. However, the stabilization with gypsum makes a consequential contribution to binding, so earth with 8–10% clay content is sufficient for Alker composite. The presence of lime and gypsum dramatically reduces the time spent for mixing, molding, compacting, and removing samples from molds [7]. Gypsum reduces the amount of shrinkage in the building material while Alker possesses durability required for load-bearing wall construction [8,9]. In addition, Alker is lighter than unstabilized earthen materials because the gypsum sets before the clay dries [10,11].

Extensive literature is available on soil improvement through the application of additives—notably, cement and lime. Bell [12] and Yong and Ouhadi [13] mentioned lime stabilization of clay soils. Guney et al. [14] studied swelling soil stabilization with lime. Bhattacharja and Bhatty [15] examined the comparative performance of Portland cement and lime stabilization of moderate to high plasticity clay soils, and Nagaraj et al. [16] mentioned the role of lime with cement in the long-term strength of compressed stabilized earth blocks.

Recently, many researchers have reported on additives that could substitute lime as a soil modifier. Stabilization characteristics of waste marble dust are mainly due to their high lime (CaO) content, [1]. One of the major problems for the marble industry is the by-production of fine particles (<2 mm) while cutting marble. When a 1 m^3 marble block is cut into 2 cm thick slabs, the proportion of fine particle production is approximately 25% [9]. When cutting marble blocks, water is used as a coolant, but the fine particles can be easily dispersed after losing humidity in some atmospheric conditions, such as wind and rain. Thus, fine particles can cause more pollution than other forms of marble waste. Marble dust is indestructible, and adverse effects include those listed below [17,18]:

- adverse effects on the productivity of land
- transportation of marble dust by wind or water affects water quality, which damages underwater life
- vegetation becomes impossible in dust-dumped areas
- fine particles cause air pollution
- particles on the soil surface fill the voids, which adversely affect underground water availability

This study tested compressive and flexural strengths using different mixtures that have a different percentage of polymer fibers produced in plastic industries affecting the environment and waste marble dust and soil from two different places to produce Alker. The study compares their effects on mechanical properties as well as with the control mix, which does not contain any fibers or waste marble dust, to be able to correlate the results with physical properties of materials. Ultimately, the study aims to find a utilization area for waste materials. Conclusions about polymer fiber and marble dust content, as well as the practicability of these materials, are drawn.

2. Experimental program

2.1. Materials

This work uses different materials, including soil as the main matrix; marble dust, gypsum, and lime as stabilizers; polymer fiber as fibrous materials; and water as the lubricant. Levent Stonite Company produces approximately two tons of marble dust daily through the locally available marble cutting and polishing industry located in the Turkish Republic of Northern Cyprus (TRNC). The wastes are collected outside the factory pools. The specific gravity of marble dust used in this investigation was 2.54 g/cm^3, and the average value for $CaCO_3$ was 90.4%. The chemical compositions of the marble dust, lime stone, gypsum, and soil are presented in Table 1. The lime is hydrated calcium lime. The specific gravity of lime and gypsum are 2.83 g/cm^3 and 2.32 g/cm^3, respectively. Two different types of soil were used in this study, which were obtained from Haspolat and Taskent in North Cyprus. The specific gravity for Haspolat and Taşkent soils are 2.47 g/cm^3 and 2.54 g/cm^3, respectively.

Grain-size distributions of soils were determined according to ASTM D6913 [19] and ASTM D7928-16 [20], and particle-size distributions are given in Fig. 1. In addition, the Atterberg limits (liquid and plastic limits) of both soils are given in Table 2.

The polypropylene fiber used in this research is shown in Fig. 2, and its properties are given in Table 3.

The aspect ratio of the polypropylene fiber used is 353. Due to the availability of this material in Turkey, which is very near North Cyprus, it is preferred for use in this research work [21].

2.2. Sampling

2.2.1. Mixing of raw materials

Alker as a composite material is composed of 2% lime, 10% gypsum, and 20–22% water by dry weight of soil. In this study, the water was increased to 25% due to the existence of polymer fibers in order to satisfy workability. Lime was integrated into the water before adding the gypsum in other to delay the setting time. Both the soil and marble dust were introduced into the mixer together with a part of the mixing water, and the drum was rotated for 1 min. After that, gypsum and polymer fibers were added and mixed all together approximately for 4 min. The mixes were then cast and consolidated through vibration for 30 s. In the modified Alker produced in this work, 10% and 20% marble dust and 0.5%, 1.0%, 1.5%, and 2.0% fiber by weight of soil were integrated into