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The mechanical and physical properties of unfired earth bricks stabilized with gypsum and Elazığ Ferrochrome slag

İbrahim Türkmen *, Enes Ekinci, Fatih Kantarci, Talha Sarici

Department of Civil Engineering, İnönü University, Malatya, Turkey

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Abstract

During the last few years, an increasing interest has been appeared for earth as a building material. Earth-based materials have been studied because of energy efficiency and ecologically sustainability. The chromite deposits, 10% of the world reserves, are processed in Elazığ Ferrochrome Factory in Eastern of Turkey. Elazığ Ferrochrome slag (EFS) as a by-product of the factory is produced roughly 50,000 tons in a year. The disposal, removal and storage of this by-product is a serious problem. Therefore, the utilization of this waste material in building applications is very important. The aim of this work is to investigate effects of gypsum and EFS additives on mechanical and physical properties of unfired earth brick (UEB) materials in order to assess their potential advantages in building applications. The earth material was characterized by laboratory tests. Four different UEB samples were produced by using different compositions of earth, gypsum, EFS and straw fibers. Compressive strength, water absorption coefficient, drying shrinkage, ultrasonic pulse velocity (UPV) and density of the prepared UEB samples were determined. The experimental findings have showed that the usage of gypsum and EFS in stabilizing process of UEBs was advantageous.

Keywords: Elazığ ferrochrome slag; Gypsum; Unfired earth brick; Compressive strength

1. Introduction

The demand to reduce CO_2 emissions and to find more sustainable construction materials constitutes nowadays are a major economic and ecological challenge. Earthen construction can lead to reduce environmental problems. Actually, raw earth is one of the most widely used building materials in human history. It is estimated that nearly a third of the world's population lives in some type of earthen houses. It is one of the oldest building materials used in many different ways around the world for centuries. Approximately 50% of the population of developing countries, the majority of rural populations, and at least 20% of urban populations live in earthen constructions (Houben and Guillaud, 1994). During the last few years, an increasing attention has been appeared for earth as a sustainable material, therefore has been investigated in the engineering laboratories around the world in the purpose of the certification of earth building materials. The reason for this interest is that it presents several advantages that allow it to be a current response to energy and climate issues. In fact, raw earth is an abundant natural and recyclable resource. It is

* Corresponding author.
E-mail address: ibrahim.turkmen@inonu.edu.tr (İ. Türkmen).
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low embodied energy building material, compared to fired clay bricks and concrete. It reduces the amount of energy required for construction as well as transportation needs (Morel et al., 2001; Fgaier et al., 2016).

Zami and Lee (2010) summarized advantages of unfired earth brick (UEB) as follows: i) earth construction is economically beneficial, ii) it requires simple tools and less skilled labour, iii) it encourages self-help construction, iv) suitable for very strong and secured, v) it saves energy, vi) it balances and improves indoor air humidity and temperature which ensures thermal comfort, vii) earth is very good in fire resistance, viii) earth construction is regarded as a local job creation opportunity, ix) earth construction is environmentally sustainable, x) easy to design and high aesthetical value, xi) earth building provides noise control, xii) earth construction promotes local culture and heritage, xiii) earth is readily available in large quantities in most regions.

The deterioration of porous building materials is mainly due to the interactions between their structures and water. Depending on the material characteristics, physical state of water (liquid or vapor) and environmental conditions, the quantity of water absorption and sorption mechanisms may be different (Pasculli and Sciarra, 2001). In particular, the absorption of humidity from air, the capillary rise, the rain penetration, and water condensation phenomenon can lead to the formation of superficial moisture (Ashour et al., 2015). In brick production, there are two types of moisture content required for molding. The first one is the shrinkage water (initial water) which helps molding process. It exists in the brick body among the particles. The shrinkage water is also necessary for clay plasticity. The second one is the porosity water (or interstitial water) (Mancuhan et al., 2016). Drying shrinkage of the bricks was primarily governed by the plasticity index and cement content. Water-loss also contributes to the shrink of the clay fraction. For low clay mineral content (index plasticity below 20%), drying shrinkage showed steady increase with the increase of clay content, but for plasticity index beyond 25%–30% drying shrinkage increased rapidly as the clay content also increased (Riza et al., 2010). The compressive strength is a mechanical property used in brick specifications, which has assumed great importance for two reasons. Firstly, with a higher compressive strength, other properties like flexure, resistance to abrasion, etc., also improve. Secondly, while other properties are relatively difficult to evaluate, the compressive strength is easy to determine (Azeez et al., 2011). In some countries such as Papua New Guinea clayey soils are stabilized with native materials, e.g. volcanic ash, finely ground natural lime, cement and their combinations (Hossaain et al., 2007).

There is a need to improve the durability, production, and workability of earthen construction technology. Throughout its history as a building material, earth has been stabilized with different additives. Istanbul Technical University recovered gypsum used as a stabiliser from historical buildings in Eastern Turkey. Ongoing research since 1978 (Kafescioglu et al., 1980) proves that this combination of earth and gypsum called Alker (an abbreviated form of the Turkish words for gypsum and adobe, meaning gypsum-stabilized adobe) has improved physical properties. There are Alker buildings constructed and inhabited since 1983. Construction of Alker Building, 1995, can be seen in Fig. 1a and Urfa Pilot Building 1999 on Fig. 1b. (Isik and Tulbentci, 2008). Except for these pilot studies, there are also new buildings constructed with gypsum-stabilized earth bricks in Malatya (Fig. 1c).

The chromite deposits, 10% of the world chromite reserves located within the boundaries of Maden town-Alacakaya village of Elazig, are processed in Elazığ Ferrochrome Factory. Apart from the main product, many by-products are produced in this factory. One of these by-products is Elazig Ferrochrome slag (EFS). The amount of slag generation is roughly 330 kg per ton of ferrochrome produced, and the annual production of EFS exceeds 50,000 tons. The disposal, removal and storage of by-products is a big problem. When considering accumulated amount of EFS so far and accumulate in the future, it is important to discover potential use of this by-product in UEB materials. The aim of this study is to examine effects of gypsum and EFS additives on mechanical and physical properties of UEB materials in order to assess their potential usage in building applications. Compressive strength, water absorption coefficient, drying shrinkage, ultrasonic pulse velocity (UPV) and density of UEB samples were tested.

2. Materials and methods

2.1. Materials

Four different materials were used, i.e. cohesive soil, gypsum, EFS and straw fibers. Cohesive soil used in this study was obtained from Malatya in Eastern of Turkey. EFS was obtained from Elazığ Ferrochrome Factory in Eastern of Turkey. EFS was ground to less than 45 μm particle size in order to increase the reactivity. Locally available gypsum and straw fibers were used. The average straw length was approximately 2 cm. The fibers were chosen because of their positive impact on drying shrinkage of earth building materials. Drinking water at a temperature of 20 ± 2 °C was used. The composition of the cohesive soil texture was as 18% clay, 23% silt, 54% sand and 5% gravel.

2.2. Sample preparation

Initially, oversized gravel was removed from the natural soil. The cohesive soil was put in an oven to obtain dry weight at 105 °C for 24 h. Presence of organic matters in a raw material is inconvenient and undesirable, because organic compounds significantly reduce the strength and binding properties of building materials. The content of organic matter in the soil was determined in accordance