



Research paper

Retrieving clay minerals from stabilised soil compacts

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ABSTRACT

Stabilised soil products such as stabilised soil blocks, rammed earth and stabilised adobe are being used for building construction since the last 6–7 decades. Major advantages of stabilised soil products include low embodied carbon, use of local materials, decentralized production, and easy to adjust the strength, texture, size and shape. Portland cement and lime represent the most commonly used stabilisers for stabilised soil products. The mechanism of strength development in cement and lime stabilised soils is distinctly different. The paper presents results of scientific investigations pertaining to the status of clay minerals in the 28 day cured cement and lime stabilised soil compacts.

XRD, SEM imaging, grain size distribution and Atterberg's limits of the ground stabilised soil products and the natural soil were determined. Results reveal that clay minerals can be retrieved from cement stabilised soil products, whereas in lime stabilised soil products clay minerals get consumed in the lime–clay reactions and negligible percentage of clay minerals are left in the stabilised soil compacts. The results of the present investigation clearly demonstrate that cement stabilisation is superior to lime stabilisation in retrieving the clay minerals from the stabilised soil compacts.

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1. Introduction

Soil is formed due to natural weathering of rocks and it takes millions of years for soil formation. Clay minerals are the essential component of a soil in controlling its engineering characteristics and are essential for supporting the plant growth on soils. Soils are used for the manufacture of construction materials such as burnt clay bricks, which are consumed in bulk quantities. Also, it is used in the form of stabilised soil for the manufacture of blocks (stabilised soil blocks and stabilised adobe) and in-situ construction (rammed earth). Stabilised soils have been successfully used for the construction of road sub-bases (Chasten, 1952; Lambe, 1962; De, 1964; Ingles and Metcalf, 1972; Robertson and Blight, 1978). The use of stabilised soils for the construction of buildings can be noticed since thirties. Soils blended with stabilisers are generally compacted when used for either building construction or any other application like road sub-base, and retaining structures. Varieties of stabilisers have been explored for stabilised soil products. Inorganic stabilisers such as cement and lime are commonly employed for the production of stabilised soil products. Stabilised soil blocks (also known as stabilised compressed earth blocks), stabilised rammed earth and stabilised adobe represent some of the stabilised soil products being used for building construction since the last 6–7

decades. These products are considered energy efficient and have low embodied carbon when compared to the conventional materials like burnt clay bricks (Venkatarama Reddy and Jagadish, 2003; Venkatarama Reddy, 2009; Venkatarama Reddy and Prasanna Kumar, 2010).

Generally, soils contain larger amount of clay fraction. Clay content of such soils is adjusted to an optimum level by diluting with sand and then used for stabilised soil block (SSB) production and stabilised rammed earth construction. Ordinary Portland cement (OPC) and lime are the commonly used stabilisers. Soil characteristics, density and stabiliser content play a crucial role in controlling the properties of SSB and stabilised rammed earth construction. Vast amount of knowledge has been accumulated on SSB technology and rammed earth (Olivier and Ali, 1987; Heathcote, 1991; Keable, 1996; Walker and Stace, 1997; Hall, 2002; Houben and Guillaud, 2003; Walker, 2004; Hall and Djerbib, 2004; Venkatarama Reddy and Gupta, 2005; Walker et al., 2005; Venkatarama Reddy et al., 2007; Jayasinghe and Kamaladasa, 2007; Easton, 2007; Venkatarama Reddy and Prasanna Kumar, 2009; Venkatarama Reddy and Prasanna Kumar, 2011a, 2011b, 2011c and many other publications).

The mechanism of strength development in cement and lime stabilised soils is distinctly different. In a wetted soil–cement mixture, cement hydrates and cementitious products such as calcium–silicate hydrate (CSH) and calcium aluminate hydrate (CAH) are formed apart from the release of small percentage of calcium hydroxide (lime). These hydration products establish water insoluble bonds and bind the gravel, sand and silt particles. Cementitious products such as CSH

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and CAH do not react with clay particles, whereas the small percentage of lime released in the cement hydration process can react with clay minerals forming additional cementitious products. The strength development in cement stabilised soil compacts (CSSC) is mainly attributed to the formation of cementitious products such as CSH and CAH.

The clay minerals are pozzolanic in nature and can readily react with lime in the presence of moisture. Therefore, the lime–clay reactions lead to the formation of water insoluble cementitious gel of silicate and silicate–aluminates and this gel finally crystallises into hydrates of calcium silicate, calcium aluminates, etc. with time. The cementitious products formed in lime–clay reactions are similar to those formed during hydration of OPC. The cementitious gel coats the soil particles and establishes bonds between them. The pace of lime–clay reactions is very slow at ambient temperature and curing conditions.

There are arguments favouring lime stabilisation of soils instead of cement stabilisation with the assumption that there will be re-carbonation of lime in the lime stabilised soil leading to carbon dioxide mitigation. A comparison between the mechanisms of strength development in cement and lime stabilised soils reveals that both the clay minerals and calcium hydroxide get consumed in the lime stabilised soils, whereas clay minerals are nearly intact in the cement stabilised soils. The present investigation attempts to prove this point.

Stabilised soil products as well as burnt clay bricks use soil as the main ingredient. The manufacture of burnt clay brick results in irreversible structural changes to clay minerals and permanently changes the soil into a nearly rock form. It is not possible to get back the natural clay minerals from the burnt clay bricks, unless allowed to undergo weathering for millions of years. Whereas there is a possibility of retrieving the clay minerals from some of the stabilised soil products after the end of life of such products without much environmental costs.

In the context of sustainability and green buildings there is an emphasis on developing low embodied carbon materials effecting minimum changes to the natural raw materials. In the framework of life-cycle and sustainability analysis of buildings attention has to be paid to the end of life use of a building material. At the end of life if a building material can go back to its native state with minimum environmental costs, then it can be classified under the category of green and sustainable building materials. Considering the Portland cement and lime as soil stabilisers the present investigation attempts to examine the status of clay minerals in the stabilised soil compacts. This is mainly to address the question of recyclability of soil based materials as soil at the end of life of such construction materials. The results of the experiments carried out on the 28 day cured cement and lime stabilised compacted specimens are discussed in the present investigation.

2. Methodology and the experimental programme

X-ray diffraction (XRD) analysis and specific surface estimation were carried out on the ground stabilised soil compacts. Details of XRD analysis and specific surface area estimation are as follows.

The XRD patterns were generated from less than 2 μm size samples obtained from the ground samples. The sample passing 75 μm was mixed with distilled water in a beaker, then the mixture was poured into a jar and again agitated. The agitated mixture was allowed to settle down. The silt particles will settle first leaving a suspension containing floating fine clay particles and crystalline CSH, CAH, etc. The suspension with floating particulate matter was decanted and dried. XRD analysis was run on these dried samples which are basically either clay or crystallised CSH and CAH, and calcium hydroxide. The particle size of the aggregated CSH particles in hydrated cement paste will be in the range of 0.8 to 3 μm (Kumar Mehta, 1986). XRD patterns of powdered samples were collected on a fully automated Bruker D8 Advance diffractometer operating at 40 kV and 40 mA using $\text{CuK}\alpha$ radiation. Data was collected between 5° and $100^\circ 2\theta$. The SEM images were obtained using Quanta LV/ESEM with the capacity for operation at high pressures as well as under environments such as water vapour, in addition it is

equipped with a standard secondary (Evehat–Thorley) and solid state scatter detector.

The Brunauer, Emmett, and Teller (BET) gas adsorption theory is the foundation for the measurement of surface area in high specific surface materials. Measurements in this study were conducted using gas sorption analyser. Nitrogen was selected as the absorbate. The samples were outgassed at 100 $^\circ\text{C}$.

The experimental work involved the preparation of stabilised soil compacts, curing them for 28 days, crushing the cured samples and examining for the presence of original clay minerals in the crushed samples. A natural soil having kaolinite clay mineral was used in the investigations. The natural soil has a specific surface area of 5.40 m^2/g and when it was ground in a mixer grinder for 12 min its specific surface increased to 8.1 m^2/g . The mixer grinder consists of a metal blade set rotating at 1500 rpm in an enclosed plastic jar. Such grinders are used for grinding solid particles of less than 5 mm to fine powder form in dry condition.

Grain size distribution curves for the natural soil and ground soil are shown in Fig. 1. Table 1 gives the details of the characteristics of both the samples. The reasons for grinding the soil sample are discussed in Section 2.2. The grain size curves for the natural soil and the ground soil (ground for 12 min) show the variations in the particle sizes among the two soils. When the soil was ground for 12 min (specific surface = 8.1 m^2/g) the percentage of clay and silt size fractions increase whereas the sand size fraction decreases when compared with the grain size fractions of the natural soil. During the grinding process, some of the sand and silt size particles get crushed to clay and silt size, and resulting in higher clay and silt size fractions. The liquid limit and plasticity index values of the ground soil sample are 33.9% and 25.1 respectively. As the particles become much finer their water holding capacity increases as indicated by the increase in the value of liquid limit.

Generally, the stabiliser content used in the production of stabilised soil blocks, rammed earth, stabilised adobe, etc. will be in the range of 5–10% by weight. Therefore, lime and cement contents were varied between 4 and 10% representing the wide range of stabiliser percentages.

2.1. Preparation and testing of compacted stabilised soil specimens

Ordinary Portland cement and laboratory grade lime (with 95% assay) were used for the preparation of compacted cylindrical specimens. The procedure adopted to prepare the cylindrical specimen of size: 38 mm diameter and 76 mm height is as follows.

- The soil was oven dried at 60 $^\circ\text{C}$ to constant weight and then blended with cement or lime by mixing in a ball mill for 10 min. Ball milling is to ensure uniform mixture.
- Requisite quantity of potable water was sprayed on to the dry mixture of soil and stabiliser, and then a uniform mixture was

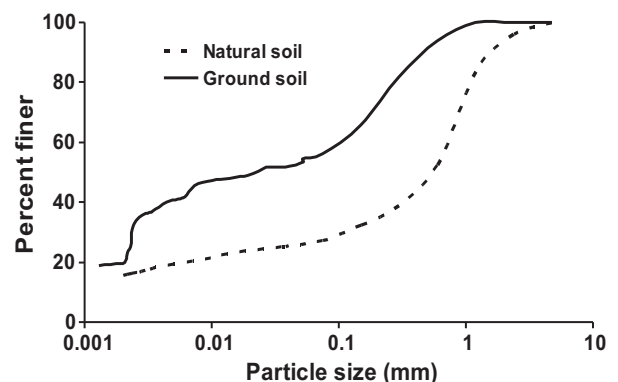


Fig. 1. Grain size distribution curves of natural soil and ground soil.

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