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Engineering properties of recycled Calcium Carbide Residue stabilized clay as fill and pavement materials

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HIGHLIGHTS

- Engineering properties of recycled Calcium Carbide Residue (CCR) stabilized clay.
- Surrounded CCR in the clay–CCR clusters is free to react with clay after remolding.
- Strength development of the recycled material is due to pozzolanic reaction.
- Possibility of using recycled CCR stabilized clay as fill and pavement material.

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ABSTRACT

Reuse of waste materials for pavement applications is of great international interest. This paper presents basic and engineering properties of the recycled Calcium Carbide Residue (CCR) stabilized clay. Scanning electron microscopic images show that the recycled CCR stabilized clay particles are larger than the CCR and clay particles due to the attached pozzolanic products. The large grains reduce linear shrinkage and free swell ratio of the recycled CCR stabilized clay. For the same compaction energy and CCR content, the unit weight of the recycled CCR stabilized clay is lower than that of the CCR stabilized clay because the harder attached pozzolanic products resist the compaction. The strength development and the reduction in void ratio with time confirm that the pozzolanic reaction still prevails even after remolding. This implies that the pozzolanic reaction occurs mainly on the surface of the clay–CCR clusters. The remolding of CCR stabilized clay breaks down the cementitious bonds between the CCR–clay clusters and the unreacted CCR and clay particles in the clusters are then free to interact with water. The research outcome reinforces the possibility of using the recycled CCR stabilized clay as fill and pavement materials. The strength and resistance to compressibility are slightly lower than those of the original CCR stabilized clay for the same CCR content while the unit weight of recycled CCR stabilized clay is much lower, which reduces the overburden on the foundation.

1. Introduction

Reuse of waste materials for pavement applications is of great international interest. The urgent need for reuse of waste materials is driven mainly by environmental considerations, due to the increased scarcity of natural resources and the increasing cost of land fill in most countries [1]. The previous studies included recycled crushed brick [2–5], recycled crushed glass [6–10], recycled concrete aggregate [11–14], other types of construction, demolition and excavation wastes [1,15,16] and waste biosolids [17,18]. Besides, the improvement of engineering properties of recycled asphalt pavement materials by the cementing agent is an alternative means [19–21].

Calcium Carbide Residue (CCR), a by-product of acetylene production process, was proved as one of the waste cementing agents for soil stabilization [22–24]. Its production is described in the following equation:

$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2 \tag{1}$$

From Eq. (1), it is seen that 64 g of calcium carbide (CaC_2) provides 26 g of acetylene gas (C_2H_2) and 74 g of CCR in terms of $Ca(OH)_2$. Presently, the demand of CaC_2 for producing acetylene gas in

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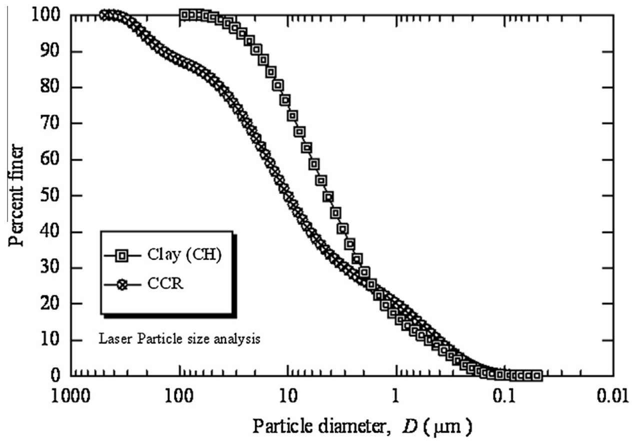

Fig. 1. Grain size distribution of the clay and the CCR.

Table 1
Chemical properties of clay, CCR and hydrated lime.

Chemical composition	Clay (%)	CCR (%)	Hydrated lime (%)
SiO_2	20.10	6.49	1.29
Al_2O_3	7.55	2.55	0.24
Fe_2O_3	32.89	3.25	0.49
CaO	26.15	70.78	90.13
MgO	0.47	0.70	0.22
SO_3	4.92	0.66	0.87
Na_2O	ND	ND	ND
K_2O	3.17	7.94	3.30
LOI	3.44	1.35	1.21

Thailand is 18,500 tons/year. This provides 21,500 tons/year of CCR and the demand is continuously increasing every year.

Horpibulsuk et al. [22,23], Kumpala and Horpibulsuk [25,26] and Kumpala et al. [27] investigated the engineering properties of the CCR stabilized clay to ascertain the performance in the fill and pavement applications. They ascertained that the CCR stabilization is more effective than the lime stabilization in terms of engineering, economic and environmental viewpoints. The shear strength of the CCR stabilized clay gradually increases with time mainly due to pozzolanic reaction. The pozzolanic reaction is the chemical reaction between siliceous and aluminous materials and calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. The strength improvement for a particular curing time is classified into three zones: active, inert and deterioration. In the active zone, the strength increases remarkably with increasing the CCR content. All the input $Ca(OH)_2$ in the CCR is consumed by the natural pozzolanic materials in the soil for pozzolanic reaction. This active zone can be determined from the CCR fixation point, which is simply obtained from the index test. The CCR fixation point is defined as the CCR content that the plasticity index of the CCR–clay mixture insignificantly changes with the input of CCR. The strength development in the inert zone slows down; the incremental gradient becomes nearly zero and does not make any further significant improvement. This is because the natural pozzolanic materials in the clay are not sufficient to react with excess $Ca(OH)_2$ from the CCR. The strength reduction is observed for very high CCR contents in the deterioration zone. The excess free lime causes the unsoundness of the clay–CCR structure. In practice, the CCR fixation point is the maximum CCR content for soil stabilization.

With a large number of cyclic loads by heavy traffic, the large permanent deformation and radial tensile strain cause the pavement damage. Even though there is current research on engineering properties of the CCR stabilized soils to ascertain their performance on pavement applications, very few researchers have focused on the possibility of reusing this damaged material (over their service life) in pavement applications such as pavement recycling technique. This paper attempts to investigate basic and engineering properties of the recycled CCR stabilized clay to ascertain its possibility of using as backfill and subbase materials. The basic properties involved are specific gravity, grain size distribution, index properties, linear shrinkage and free swell. The engineering properties are compaction behavior, compressibility and strength development. The scanning electron microscope (SEM) was used to illustrate the presence of pozzolanic products attached on the recycled CCR stabilized clay particles. The knowledge obtained from this research can be applied to the other recycled clayey soils stabilized with different $Ca(OH)_2$ rich materials to explain and analyze the strength development.

2. Materials and methods

2.1. Materials

A silty clay, collected from the Suranaree University of Technology campus in Nakhon Ratchasima province, Thailand, was mixed with the CCR at different contents. Then, the CCR stabilized samples were crushed and remolded at water content of about 1.5 times liquid limit. The grain size distribution (Fig. 1) shows that the clay is composed of 2% sand, 43% silt and 55% clay. The specific gravity is 2.72. The liquid and plastic limits are approximately 55% and 27%, respectively. Based on the Unified Soil Classification System (USCS), the clay is classified as high plasticity (CH). The free swell test proposed by Prakash and Sridharan [28] shows that the clay is classified as low swelling with a free swell ratio (FSR) of 1.6. The Cation Exchange Capacity, CEC is 27.6 meq/100 g. Scanning electron microscope (SEM) image of the clay shown in Fig. 2 indicates that its particles are irregular in shape. The chemical composition of the clay is shown in Table 1. A X-ray diffraction (XRD) pattern of the clay (Fig. 3) shows that main chemical composition is SiO_2. The sum of SiO_2, Al_2O_3 and Fe_2O_3 is 60.54%, which is considered as high for pozzolanic reaction.

Calcium Carbide Residue (CCR) from the Sai 5 Gas Product Co., Ltd. was used in this study. The CCR was oven-dried at 100 °C for 24 h and ground in a Los Angeles abrasion machine. The CCR was passed through a sieve no. 40 (425 μm). The specific gravity is 2.32. Table 1 shows the chemical composition of CCR compared with that of a hydrated lime. The chemical composition (Table 1) shows the CaO contents

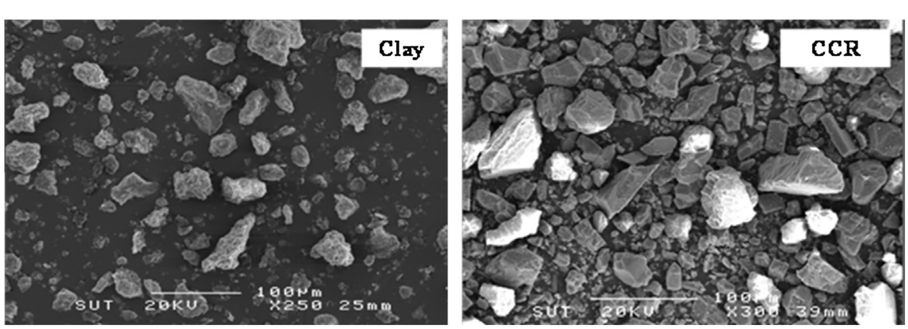

Fig. 2. SEM photos of the clay and the CCR.