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Improving the compressive strength of mortar from a binder of fly ash-calcium carbide residue

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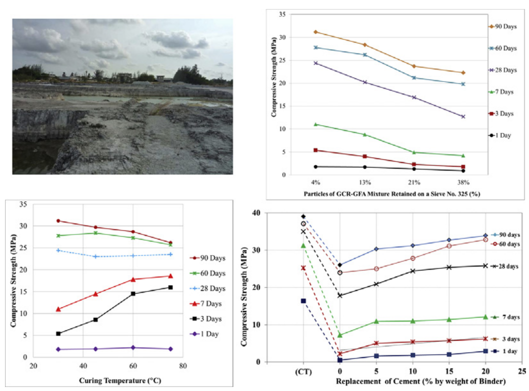
HIGHLIGHTS

- We created a binder from two kinds of waste materials.
- Finenesses of binder, curing temperatures, and cement contents were studied.
- The more fineness of the binder yields large increases in compressive strength of mortar.
- The mortar cured at a high temperature attained a greater strength in the short term.
- The mortar containing 10% Portland cement of a binder yielded 31.2 MPa.

GRAPHICAL ABSTRACT



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ABSTRACT

The aim of this research is to improve the compressive strength of mortar made from fly ash (FA) and calcium carbide residue (CR) as a binder. FA is a by-product from a thermal power plant while CR is a by-product from an acetylene gas industry. They were used together to form a new binder material for concrete. Due to low strength at the early age, several processes were introduced to increase the compressive strength of the new binder. Finenesses of binder, curing temperatures, and cement contents were the studied parameters in this study. Mortars cast for 24 h were oven-cured at temperatures of 30, 45, 60 and 75 °C for 24 h, and then cured in water at room temperature until the testing age. The results showed that the fineness of CR-FA binder is the most important factor to increase the compressive strength of CR-FA mortar. At 90 days, the compressive strength could increase from 15.6 MPa to 26.0 MPa as a result of an increased fineness of the binder. In addition, a high curing temperature enhanced the compressive strength of mortar at an early age but was less effective at a later age. Moreover, substituting some of the GCR-GFA binder with Portland cement can accelerate and increase the mortar strength at various rates. The mortar SC0T30 (no cement) has a compressive strength of 26.0 MPa at 90 days and could be increased to 30.3 and 31.2 MPa with 5 and 10% of cement in the binder, respectively.

1. Introduction

Most buildings and construction projects all over the world currently use concrete extensively. This is most likely because concrete has several advantages, such as a high compressive strength, high resistance to fire, high ability to resist weather conditions, high durability, low construction costs, and low maintenance costs. The most commonly used binder today is cement. Consequently, as the demand for concrete rises, so does the demand for cement. Unfortunately, the production of cement has a number of negative side effects. Firstly, the process is energy

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intensive, requiring heating of the raw materials in a kiln to 1500 °C. Secondly, each ton of cement production releases 900 kg of CO_2 into the atmosphere, contributing to global warming [1]. Thirdly, cement production also creates chemically active dust that negatively affects the nearby environment. In an effort to mitigate environmental impacts of cement production, various supplementary cementitious materials such as fly ash and pozzolanic materials are often used to replace Portland cement in concrete. In addition, there have been several research studies [2–10] that investigated and developed new cementitious materials to substitute for cement that are environmentally friendly.

Several pozzolans are abundant in Thailand and have shown promise as cement replacements in a growing number of studies [11–16]. At the moment, however, they have not been widely adopted due to low consumer confidence and a lack of convincing data. A wide range of agricultural and industrial waste products, which currently land in landfills, have the potential to become useful construction materials including ashes from rice husk, bagasse and palm oil production as well as fly ash from coal-fired power plants.

Calcium carbide residue (CR) is another industrial by-product that is treated as a waste but could be utilized to replace of cement. The calcium hydroxide ($Ca(OH)_2$) in this material can react with pozzolanic materials to form binder for concrete. In a simple industrial process, calcium carbide (CaC_2) and water are combined to yield acetylene (C_2H_2), a flammable gas, and CR as shown in (1):

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

In Thailand, more than 21,500 tons of CR are produced annually in a single industry with significant increases forecast for the near term [17]. Most CR waste is disposed of in landfills (Fig. 1) where, if not properly managed, it can lead to groundwater contamination and high alkalinity in local aquifers. Even though CR is sometimes used in wastewater treatment, the waste disposal issue is growing as production accelerates [18].

Fly ash (FA) has been widely used as a pozzolanic additive to cement for decades. ASTM C 618 [19] defines pozzolanic materials as those rich in silica and alumina but lacking cementitious qualities. They will, however, react with calcium hydroxide at room temperature forming cement-like compounds. FA contains significant quantities of SiO_2, Al_2O_3, and Fe_2O_3 which, when combined with $Ca(OH)_2$, yield calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). These compounds improve the quality of concrete by increasing its compressive strength, sulfate resistance and water impermeability [20–22].

The feasibility of using the pozzolans generate as agricultural and industrial by-products in Thailand has not been thoroughly investigated to date. Krammart et al. [13] found that an admixture of CR and FA could yield compounds similar to the results of Portland cement hydration. Jaturapitakkul and Roongreung [23] created a binder using CR and rice husk ash to obtain a maximum compressive strength of 15.6 MPa after curing for 28 days. Additionally, Rattanashotinunt et al. [24] demonstrated that a blend of CR and finely-divided bagasse ash could produce concrete with a compressive strength of 6.8 MPa at 7 days and increased to 30.6 MPa at 90 days without Portland cement. These studies indicated that CR and pozzolanic materials could produce cementitious compounds in concrete. However, it was found that the new binder demonstrates relatively low compressive strength at early age.

Fig. 1. Disposal area of calcium carbide residue.

Thus, the current study aims to investigate methods to improve the strength of mortar made from a binder of CR and FA with little or no Portland cement included. To increase the compressive strength of mortar, tests were conducted with variable material fineness and higher curing temperatures. Moreover, compressive strength was improved using 5, 10, 15, and 20% of cement by weight of binder. Ordinary Portland cement (OPC) was introduced only as an accelerator to encourage the hydration reaction between ground calcium carbide residue (GCR) and ground fly ash (GFA). Major environmental benefits would result from the determination of a suitable method to use these non-recyclable materials in concrete production. Moreover, alternative binder for concrete mixture which is from two different wastes is proposed.

2. Experimental program

2.1. Materials

Fly ash (FA) and calcium carbide residue (CR) were the major fundamental materials used in this study. FA was obtained from the Mae Moh power plant in Lumpang province, Thailand. Recently, about 70–80% of the total amounts (approximately 1.8–2 million tons) of fly ash have been used annually as a pozzolanic material and most of it has been used to substitute cement in concrete. In this study, fly ash has been used as a main binder which is the way to increase its value and increase the usefulness of this waste. CR slurry was obtained from the landfill site of an acetylene gas production factory in Samutsakorn province, Thailand (see Fig. 1). Due to the high moisture content (approximately 52%), it was first sun-dried for three to four days to reduce the water content and then dried in oven at 110 ± 5 °C for 24 h.

Ordinary Portland cement (OPC), natural river sand (passing a No.16 sieve and retaining on a No.100 sieve), water, and superplasticizer (naphthalene formaldehyde, Type F) according to ASTM C494 [25] were used during the entire experiment. OPC was varied to substitute GCR-GFA binder in 5% increments from 5% to 20% by weight.

CR and FA were mixed together at a ratio of 30:70 by weight to use as a binder. The CR-FA mixture was sieved through a 45-μm sieve and 38% by weight was retained on the sieve and was assigned as "O" size. To reduce the particle size, the mixtures were ground together by a ball mill until the particles retained on a 45-μm sieve were 4%(S), 13%(M), and 21%(L) by weight; this resulting mixture was called GCR-GFA.

2.2. Mix proportions of mortars, casting, and testing

To maximize compressive strength, a ratio of GCR to GFA of 30:70 by weight was used as a binder for casting mortars in this experiment as suggested by Krammart et al. [13]. GCR-GFA was replaced by Ordinary Portland cement at the rate of 5, 10, 15, and 20% by weight of the binder (GCR-GFA + OPC). The binder mixture was then combined with sand at a constant ratio of 1:2.75 by