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Technical Note

# Strength of sustainable non-bearing masonry units manufactured from calcium carbide residue and fly ash

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## HIGHLIGHTS

- Calcium Carbide Residue (CCR) and fly ash (FA) as cementing agent.
- Sustainable CCR–FA non-bearing masonry units.
- Role of water/binder ratio, CCR/FA ratio and curing time on strength.
- Cost analysis for manufacture of CCR–FA masonry units.

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## ABSTRACT

This paper aims to study the viability of using Calcium Carbide Residue (CCR) and fly ash (FA) as a cementing agent (binder) for the manufacture of non-bearing masonry units without Portland Cement (PC). CCR and FA are waste products from acetylene gas factories and power plants, respectively. The test samples were made up at a binder to stone dust ratio of 1:8 by weight. The studied water to binder (W/B) ratios were 0.50, 0.75 and 1.00, and the CCR/FA ratios were 80:20, 60:40 and 40:60. The W/B ratio of 0.75 and CCR/FA ratio of 40:60 were found to be an optimal mix proportion providing the highest both unit weight and strength. The higher CCR/FA ratios provide lower strength values because the silica and alumina in FA are insufficient to react with abundant $Ca(OH)_2$ in the CCR for the pozzolanic reaction. The optimal mix proportion provides the strength of the CCR–FA based material greater than 20 MPa, which is acceptable for non-bearing masonry unit. The cost analysis showed that the material costs of the CCR–FA masonry unit were 40% lower than those of the PC masonry unit. Besides the cost effectiveness, the outcome of this research would divert significant quantity of CCR from landfills and considerably reduce carbon emissions due to PC production.



## 1. Introduction

Portland Cement (PC) based masonry unit is an extensively used construction and building material worldwide. The high unit cost and energy intensive process for the production of PC are however the predominant driving forces for the constant need within the industry to seek alternative cementitious additives with low carbon dioxide release. Production of 1 kg of PC consumes approximately 1.5 kWh of energy and releases about 1 kg of $CO_2$ to the atmosphere [1–3].

In recent years, there has been an environmental push worldwide to continually seek new reuse applications for various waste materials inclusive of demolition wastes [4–6], municipal solid waste [7–9], commercial and industrial wastes [10–16]. Waste materials are increasingly being implemented in various projects in pavement and concrete applications [17–22].

A waste $Ca(OH)_2$ rich material, Calcium Carbide Residue (CCR), can be utilized together with waste pozzolanic materials such as fly ash, and biomass ash to develop a cementing agent [15,23]. CCR is a by-product of acetylene ($C_2H_2$) production process through the hydrolysis of calcium carbide ($CaC_2$). Its production is described by the following equation [24]:

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$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2 \quad (1)$$

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 $Ca(OH)_2$. The CCR is generated as an aqueous slurry and is composed essentially of calcium hydroxide ($Ca(OH)_2$) with minor parts of calcium carbonate ($CaCO_3$), unreacted carbon and silicates [24,25]. The characteristics of CCR are influenced by the processing parameters during acetylene fabrication. Presently, the demand of $CaC_2$ for producing acetylene gas in Thailand is 18,500 tons/year. This provides 21,500 tons/year of CCR and the demand is continuously increasing each year.

Fly ash (FA) is a pozzolanic waste material extracted from flue gases of furnaces fried with coal at electric power plants. In Thailand, a major source of FA is the Mae Moh electricity power plant, Lumpang. Lignite is used as a raw material for the electricity generation. The sum of major components in FA ($SiO_2$, $Al_2O_3$ and $Fe_2O_3$) is between 72% and 80%. Its generation is far in excess of utilization. FA is commonly used together with PC for civil engineering works [21,26,27]. Due to its lower early strength of CCR and FA compared to Portland cement, the application of CCR and FA is limited previously to pavement and geotechnical application [14–18,23,24,28–30]. The innovative application of CCR and FA for the manufacture of building materials is however possible for low strength requirement such as masonry units. This investigation is very limited and needs to be addressed due to a large demand of construction activities. The application of the CCR with FA as a sustainable cementing agent to develop non-bearing masonry units in this paper is thus novel and innovative particularly in the Asia-Pacific region. Stone dust is generally used as a raw material for the manufacture of masonry units. The stone dust is obtained from open-air dumpsite of marble and limestone plants. The in situ water content ranges from 1% to 2%. The dried stone dust was composed of individual particles and lumps. The lumps resulted from the fragmentation of compacted slurry slabs obtained in the water recovering operations held at the processing plant.

This paper aims to study the possibility of using two waste materials (CCR and FA) as a sustainable cementing agent for manufacturing masonry units without PC. The compressive strength of the CCR–FA based material will be examined to ascertain it as non-bearing masonry units. The compressive strength requirement for non-bearing masonry units is 20 MPa according to the Thailand Industrial Standard (TIS). Only short-term (<14 day) strength is investigated because the masonry units are generally on sale within 14 days of curing. Based on the strength analysis, the optimal mix proportion is suggested. Subsequently, the cost analysis based on this suggested mix is performed to compare the production costs between PC masonry units and CCR–FA masonry units. Both strength data and cost analysis illustrate the advantage of using CCR and FA as a binder in terms of engineering and economical viewpoints. In addition to strength test, water absorption, durability and heavy metal leaching tests are required and needed further investigation. The outcome of this research would divert significant quantity of CCR from landfills and considerably reduce carbon emissions due to PC production.

## 2. Materials and methods

### 2.1. Materials

Stone dust from Saraburee province in Thailand, CCR from the Sai 5 Gas Product Co., Ltd, FA from the Mae Moh power plant in the north of Thailand, and tap water were used in this study. The stone dust was passed through 19 mm sieve to remove coarser particles. The grain size distribution of the stone dust is shown in Fig. 1 and the specific gravity is 2.64. Both the CCR and FA were passed through sieve No. 4 (4.75 mm) and there was not any particles remaining on the sieve. In other words, the original CCR and FA were used directly as a cementing agent. The specific gravity values are 2.32 and 2.39, respectively. Table 1 shows the chemical composition of both FA and CCR compared with that of a hydrated lime and PC. Total amount of the major components ($SiO_2$, $Al_2O_3$ and $Fe_2O_3$) in FA are 81.48%. The chemical composition (Table 1) shows the CaO contents of 90.13%, 70.78%, and 65.41% for hydrated lime, CCR and PC, respectively. This result is in agreement with the X-ray diffraction (XRD) pattern (*vide* Fig. 2). The XRD pattern of the CCR is similar to that of the hydrated lime, showing the $Ca(OH)_2$ as a main composition. The $Ca(OH)_2$ contents are about 96.5% and 76.7% for hydrated lime and CCR, respectively. The high $Ca(OH)_2$ and CaO contents of the CCR indicate that it can react with a pozzolanic material and produce a cementitious material. The grain size distribution curves of tested FA and CCR are also shown in Fig. 1. The curves were obtained from the laser particle size analysis. The average grain size ($D_{50}$) of FA and CCR are 0.0035 and 0.01 mm, respectively. Scanning electron microscope (SEM) photos of FA and CCR are shown in Fig. 3. From the grain size distribution and the SEM photos, it is found that the stone dust and CCR particles are larger than the FA particles. The CCR is irregular in shape while the FA is spherical.

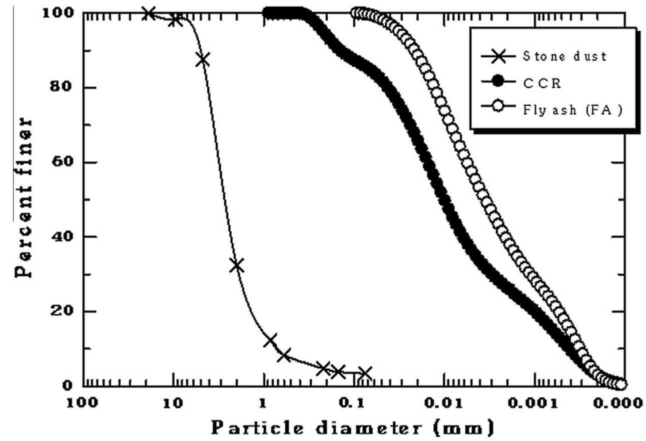


**Fig. 1.** Grain size distribution of stone dust, FA and CCR.

**Table 1**
Chemical properties of FA, CCR, hydrated lime and cement.

| Chemical composition (%) | FA | CCR | Hydrated lime | Portland cement |
|---|---|---|---|---|
| CaO | 11.30 | 70.78 | 90.13 | 65.41 |
| $SiO_2$ | 39.18 | 6.49 | 1.29 | 20.90 |
| $Al_2O_3$ | 22.64 | 2.55 | 0.24 | 4.76 |
| $Fe_2O_3$ | 15.45 | 3.25 | 0.49 | 3.41 |
| MgO | 1.69 | 0.69 | 0.22 | 1.25 |
| $SO_3$ | 4.29 | 0.66 | 0.86 | 2.71 |
| $Na_2O$ | 1.81 | – | – | 0.24 |
| $K_2O$ | 2.02 | 7.93 | 3.3 | 0.35 |
| Loss of ignition, LOI | 1.61 | 7.65 | 3.48 | 0.97 |

### 2.2. Methodology

The stone dust was mixed with different water to binder (W/B) and CCR/FA ratios. The studied W/B ratios were 0.50, 0.75 and 1.00, and the studied CCR/FA ratios were 80:20, 60:40 and 40:60. The binder/stone dust ratio was fixed at 1:8 in this study. The mixture of water, CCR, FA and stone dust was thoroughly mixing for 15 min and transferred to a cube mold with a dimension of $150 \times 150 \times 150$ mm$^3$. The mold was then vibrated for 15 min to follow the tradition method of manufacturing stone dust non-bearing units. After 24 h, the samples were dismantled from the mold, wrapped in vinyl bags and stored in a chamber of constant temperature (25 ± 2 °C) and humidity (45 ± 2%). Uniaxial compression test was undertaken on the samples after 7 and 14 days of curing. Only 7-day and 14-day strengths were measured because in practice masonry units are on sale for construction works within 14 days of curing. Because the chemical reaction between CCR and FA is pozzolanic, the long-term strength is higher than the measured 14-day strength. According to ASTM D 2166, a rate of vertical displacement is between 0.5% and 2.0%/min for uniaxial test. The rate of vertical displacement was then fixed at 1 mm/min (0.7%/min). For each curing time, W/B and CCR/FA ratios, at least five samples were tested under the same condition to check for consistency of the test. In most cases, the results under the same testing condition were reproducible with low standard deviation, *SD* ($SD/\bar{x} < 10\%$, where $\bar{x}$ is mean strength value). Table 2 summarizes the mix proportions of the tested samples.