Techno – economic and leachability effect of Ca$_2$SiO$_4$ interlocking composite brick

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Abstract. This work studied the possibility to produce the new novel calcium silicate ceramic kiln ash composite brick (CSCACB) which was the combination of the local Ratchaburi soil and calcium silicate kiln ash (CSCA) wasted from the ceramic industry. The chemical and physical properties of the composite brick were investigated. Also, the mechanical properties such as the compressive strength, flexural strength and as well as the leachability property were determined. By summary, this invented materials has enough quality to produce as local commercial products considered by the strength properties, environmental effect, price and appropriated implementation.

1. Introduction
Nowadays, the trend of global warming campaign is prevalent in many countries, including Thailand, which was ranked 71$^{st}$ in the world in gas emissions that destroy the Earth's atmosphere. There are many reasons causes of the global warming, for instance emissions from vehicles, factories, residences etc. To reduce these effects, green product or productions are currently used for example, the ecology house and so on. As mentioned above, over the past decade, the local manufacturing sector is one of many industries that use the thermal energy as the main source in the production process as well as a large factory, but are only different in the type of fuel for energy purposes. By collecting data, it was found that number of the local ceramic industrial in Ratchaburi province are 42 industries which 85%are a semi-ancient [1]. This is to say that the traditional ceramic kiln use the fuel supplied from thermal products of wood such as wood fragmented and small trees.

Resulting from this process is the environmental issues that arise while burning such as fumes from fuel and ash from the ceramic kiln and the construction industry uses ash in the products and to replace cement in concrete [2], for soil stabilization and in cement production [3-8]. Therefore, we have adopted this type of ash to study and analyze the features design as a soil brick with bearing and non-bearing types [9,10]. The purpose is to develop and design the local materials using for a low-energy building construction considered by the suitability of the production cost, standard, strength, appropriate technology and being environmentally friendly building materials that can be utilized for local residents as well as technology and research to continue in small and medium-sized communities effectively.
2. Methodology
For the property testing of soil bricks, samples were molded approximately 1,085 samples with the dimension of 125 mm in width, 500 mm in length and 100 mm in thickness. Types of brick sample were classified below, Unreinforced Soil Cement Composite Brick (filled mortar-USCCB) (control). This type of brick was filled with mortar 1:3 when was constructed as the composite system. Unreinforced Soil Cement Composite Brick (unfilled mortar-USCCB). Calcium Silicate Ceramic Kiln Ash Composite Brick(CSCACB). This type of brick was filled with mortar 1:3 when was constructed as the composite system. Calcium Silicate Ceramic Kiln Ash Composite Brick (unfilled mortar-CSCACB). For bricks type a and b, the cement contents were varied at 8, 13, 18, 23, 28, 33, 38, 43, 48 and 53 % by weight of soil basis at the water content of 9.74, 10.29, 10.52, 10.75, 10.88, 11.01, 11.38, 11.74, 13.31 and 14.87 at cure time of 3, 7, 14, 28, 60, 90, 120, 150 and 180 days, respectively. For bricks type c and d, a constant Portland cement type I content (OPC) of 3% was mixed with varying calcium silicate kiln ash (CSCA) contents of 15, 20, 25, 30, 35, 40, 45 and 50 % at cure time of 7, 14, 28, 60, 90, 120, 150 and 180 days, respectively.

3. Results and discussions
3.1. Chemical properties
Table 1 shows the chemical property of three material types such as Non-plastic Soil (NP-S), Ordinary Portland cement type I (OPC) and Calcium silicate ceramic kiln ash (CSCA) by using X-Ray Fluorescence (XRF). The total of the main oxide of calcium silicate ceramic kiln ash which effects to the strength development reaction such as SiO₂, CaO and Al₂O₃ is 48.32% and 90.31% for the ordinary Portland cement type I (OPC) as well as 80.25% for the local Ratchaburi soil. Also, the loss of ignition (LOI) of materials is 29.12, 2.31 and 2.19% respectively.

Table 1. The chemical composition of non-plastic Soil (NP-S), ordinary Portland cement (OPC) and calcium silicate ceramic kiln ash (CSCA) using X-ray fluorescence (XRF).

| Oxides    | Concentrations Non-plastic Soil (NP-S) | Concentrations Ordinary Portland cement type I (OPC) | Concentrations Calcium silicate ceramic kiln ash (CSCA) |
|-----------|----------------------------------------|-----------------------------------------------------|--------------------------------------------------------|
| Al₂O₃     | 24.73                                  | 4.77                                                | 1.26                                                   |
| SiO₂      | 37.89                                  | 19.83                                               | 4.31                                                   |
| SO₃       | 5.88                                   | 2.05                                                | 1.21                                                   |
| CaO       | 17.63                                  | 65.71                                               | 42.75                                                  |
| Fe₂O₃     | 7.85                                   | 3.82                                                | 0.20                                                   |
| LOI       | 2.19                                   | 2.31                                                | 29.12                                                  |

3.2. Mechanical properties
3.2.1. Compressive strength of unreinforced Soil Cement Composite Brick (filled and unfilled mortar-USCCB). Figure 1(a) and 1(b) show the compressive strength of both filled and unfilled mortar of USCCB with varying cement contents of 8, 13, 18, 23, 28, 33, 38, 43, 48 and 53% by weight of soil basis at the cure time of 3, 7, 14, 28, 60, 90, 120, 150 and 180 days with water content of 9.74, 10.29, 10.52, 10.75, 10.88, 11.01, 11.38, 11.74, 13.31 and 14.87% respectively. Both graphs show a similar trend which the compressive strength increases with increasing the cement contents and cure time. However, the increasing rate is not significant when the cure time is longer than 60 days. Comparing between filled and unfilled mortar, at cure time of 28 days the maximum compressive strength of filled and unfilled mortar occurs at the same cement content of 53% with values of 221.22 kg.cm⁻² and 121.25kg.cm⁻² respectively. Results show that the compressive strength of unfilled mortar is significant lower than those of filled mortar-USCCB. This can be explained that filled mortar USCCB
has a larger cross-section area which is proportional to the compressive strength and the strength of the mortar is relatively high compared to USCCB.

Figure 1. The compressive strength of unreinforced soil cement composite brick for filled mortar USCCB (a) and unfilled mortar-USCCB (b).

Figure 2. The unreinforced soil cement composite brick for filled mortar USCCB and unfilled mortar-USCCB (size 125x500x100 mm3)

3.2.2. Compressive strength of calcium silicate ceramic kiln ash composite brick (filled and unfilled mortar CSCACB). Figure 3(c) and 3(d) show the compressive strength of filled and unfilled mortar with varying the calcium silicate ceramic kiln ash content of 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 at the cure time of 3, 7, 14, 28, 60, 90, 120, 150 and 180 days. Results reveal that the compressive strength decreases with increasing of calcium silicate ceramic kiln ash. The maximum compressive strength occurs at calcium silicate ceramic kiln ash content of 5% with values of 39.01 kg.cm\(^{-2}\) and 27.71 kg.cm\(^{-2}\) for filled and unfilled mortar CSCACB, respectively at cured time of 28 days.

Figure 3. The compressive strength of Calcium Silicate Ceramic Kiln Ash Composite Brick for filled mortar –CSCACB (c) and unfilled mortar –CSCACB (d).
3.2.3. Flexural strength on Modulus of rupture of Unreinforced Soil Cement Composite Brick (filled and unfilled – mortar USCCB) The flexural strength of both filled and unfilled mortar USCCB is presented in Figure 4(e) and 4(f) respectively. Agreement to the compressive strength, the flexural strength increases with increasing of cement content for both cases. At 28 days, the maximum value of filled and unfilled mortar USCCB are showed at the cement content of 53% which values are 15.176 kg.cm\(^{-2}\) and 8.063 kg.cm\(^{-2}\). Form these results, it can be seen that the flexural strength of filled is higher than those of unfilled mortar approximately as 53.13%.

3.2.4. Flexural strength on modulus of rupture of calcium silicate ceramic kiln ash composite brick (filled and unfilled mortar–CSCACB) Similarly to the compressive strength, flexural strength on modulus of rupture of calcium silicate ceramic kiln ash composite Brick(filled and unfilled mortar-CSCACB) decrease with increasing the contents of calcium silicate ceramic kiln ash as shown in Figure 5(g) and 5(h). At 28 days, the maximum value of filled and unfilled mortar CSCACB are 1.62 kg.cm\(^{-2}\) and 1.14 kg.cm\(^{-2}\) occurred at 5% calcium silicate ceramic kiln ash. Moreover if compare to previous results of USCCB at 53% cement content for both filled and unfilled mortar, CSCACB5+3 are lower than those of USCCB at 53% considered as 10.67% and 14.13% respectively. According to the strength properties of materials, it can be concluded that:

The ratio of the flexural strength in rupture to the compressive strength of USCCB (filled mortar) and CSCACB (filled mortar) is approximated as 0.96 ~ 1.00. The ratio of the flexural strength in rupture to the compressive strength of USCCB (unfilled mortar) and CSCACB (unfilled mortar) is approximated as ~ 1.00. When considers the strength of filled and unfilled mortar CSCACB, it is clearly seen than none of them can qualify the bearing load type standard according to Thai Industrial Standards Institute 102-2517 [9] and the community standard 602-2547 [10]. However, with calcium silicate ceramic kiln ash of 5%and cement of 3% (CSCACB5+3) can be still used as the non-bearing type product.
Figure 5. The flexural strength on modulus of rupture of calcium silicate ceramic kiln ash composite brick for filled mortar-CSCACB (g), and unfilled mortar-CSCACB (h).

3.3. An economically assessment of products
The cost analysis of the building prototype constructed by CSCACB5+C3 is compared to other brick types such as cement brick, light weight brick, composite brick and local soil brick. The price of CSCACB5+C3 at the total water ratio of 12.69% is calculated as 3.6 baht/piece. For the price of other bricks used for construction with the non-bearing wall type in an area of Chombueng district, Ratchaburi during 2015-2016 is given as 4.5 baht/piece for cement brick, 0.8 baht/piece for local soil brick, 8 baht/piece for composite brick and 18 baht/piece for light weight brick. As this information, it can be seen that the price of CSCACB5+C3 is lower than other brick except the local soil brick. The cost summary of the wall constructed by each brick type is shown in table 2.

Table 2. The price of brick products in area of Chombueng district studied during 2015-2016.

| Product                  | Product price (Baht/m²) | Mortar 1:3 (Baht/m²) | Labor price (Baht/m²) | Plaster price (Baht/m²) | Total price (Baht/m²) |
|--------------------------|-------------------------|----------------------|-----------------------|-------------------------|-----------------------|
| CSCACB5+C3               | 144                     | 64                   | 80                    | None                    | 288                   |
| Lightweight brick        | 162                     | 50                   | 80                    | 190                     | 484                   |
| Composite brick          | 320                     | 64                   | 80                    | None                    | 464                   |
| Local soil brick         | 140                     | 64                   | 80                    | 190                     | 474                   |
| Cement brick             | 55                      | 50                   | 80                    | 190                     | 375                   |

**CSCACB5+C3 is appropriated proportion of Ca₂SiO₄ interlocking composite brick**

3.4. Leachate test
Accord to the study above, it found that the suitable formulation to produce as the commercial brick is CSCACB with 3% cement content and 5% calcium silicate ash by dry soil weight, CSCACB5+C3 (an appropriated proportion of Ca₂SiO₄ interlocking composite brick). Then this brick was tested to find the concentration of 8 types of hazardous substances following by U.S EPA SW-846(1992) Method 1311 [11]. Result shows that the concentrations of hazardous substances are lower than the maximum standard limit as shown in table 3. For environmental effect and the safety of the residents, with considered by leachate test, it is found that there are virtually no heavy metals and deterioration of hazardous substances such as Lead (Pb). However, only Chromium (Cr) and Arsenic (As) are found with small amount of quantity compared to the standard limit of 5.00 mg/l.¹
**Table 3.** The leachate test of CSCACB5+C3 (an appropriated proportion of Ca2SiO4 interlocking composite brick)

| Metals          | CSCACB3+5** | Standard                  |
|-----------------|-------------|---------------------------|
| Arsenic (As)    | 0.15        | not more than 5.0 mg.l⁻¹   |
| Barium (Be)     | None        | not more than 100.0 mg.l⁻¹ |
| Cadmium (Cd)    | None        | not more than 1.0 mg.l⁻¹   |
| Chromium (Cr)   | 0.10        | not more than 5.0 mg.l⁻¹   |
| Lead (Pb)       | None        | not more than 5.0 mg.l⁻¹   |
| Mercury (Hg)    | None        | not more than 0.20 mg.l⁻¹  |
| Selenium (Se)   | None        | not more than 1.0 mg.l⁻¹   |
| Silver (Ag)     | None        | not more than 5.0 mg.l⁻¹   |

**CSCACB5+C3 is appropriated proportion of Ca₂SiO₄ interlocking composite brick**

4. **Conclusions**

According to this study, varying the contents of calcium silicate ceramic kiln ash was added in soil cement brick. The purpose is to apply the use of waste from the ceramic industry to develop as the local commercial product. Results show that both compressive strength and flexural strength decrease with increasing calcium silicate ceramic kiln ash content. At cured time of 28 days, it is found that the maximum compressive strength occurs at cement content of 3% and calcium silicate ceramic kiln ash of 5% (CSCACB5+3) with values of 39.01 kg.cm⁻² (filled mortar) and 27.71 kg.cm⁻² (unfilled mortar) respectively. Also, the maximum flexural strength occurs at the same content (CSCACB5+3) which values are 169 kg.cm⁻² (filled mortar) and 1.639 kg.cm⁻² (unfilled mortar) respectively.

By comparing between filled and unfilled mortar of materials in this work, results reveal that filling mortar in the hole of the brick can increase the strength of the brick composite unsurprisingly. That means CSCACB is a better heat resistant material compared to USCCB. For environmental factor, result shows that the product pass the hazardous substances testing following by U.S EPA SW-846 Method 1311(TCPL). Finally, according to the property investigation in this work, it can be concluded that CSCACB5+C3(Ca₂SiO₄ interlocking composite brick) shows an enough quality to produce as the local economic material effectively considered by various factors such as the strength properties, heat resistance, low price, simple technology, and safety including environmental friendly.

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