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*Article*

# The Reuse of Waste Glass as Aggregate Replacement for Producing Concrete Bricks as an Alternative for Waste Glass Management on Koh Sichang

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**Abstract.** The objective of this research is to manage waste glass in Koh Sichang, Chonburi province, used as a partial fine aggregate replacement in concrete brick production. An experimental approach aimed to determine the level of waste glass replacement for the optimal compressive strength. Five samples of 0, 10, 20, 30, and 100% waste glass aggregates by weight were tested at 7, 14, and 28 days. The microstructure and mineralogical phases of the concrete bricks were investigated by scanning electron microscopy and X-ray diffractometry, respectively. The experimental results showed that the compressive strength was improved by increments in replacing waste glass up to 20%; in contrast, the compressive strength was decreased with an increase of waste glass of over 20% in concrete bricks. The optimum compressive strength of concrete brick was 20% by weight, which had the highest values (46.51, 47.41, and 48.49 MPa at 7, 14, and 28 days, respectively) and the lowest water absorption. Therefore, waste glass can be used as a partial fine aggregate for producing concrete bricks, and it can be employed as an alternative material for waste glass management.

**Keywords:** Waste glass, concrete brick, economical feasibility.

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## 1. Introduction

Currently, municipal solid waste (MSW) in Thailand is increasing every year. From 2008 to 2017, 23.93–27.40 million tons of MSW was generated per year [1]. It represents the most importance pollution problem in the country due to urban development, a rapidly increasing population, and consumer behavior change, including the overuse of packaging. Consumption of natural resources is limited in terms of the raw materials used in packaging or construction; moreover, there is a shortage of disposal area after use [2]. In 2017, approximately 27.40 million tons (about 75,046 tons per day) of MSW was generated, increasing from about 340,000 tons in 2016. One of the greatest generators of MSW is Chonburi province, with about 3,000 tons per day, second only to Bangkok [3]. MSW in Chonburi province is only managed properly at a rate of 36%; 43% is improperly disposed, such as by burning outdoors, dumping, and leaving in the wilderness, and only 21% is recycled [1].

Chonburi province is a popular tourist destination in the eastern part of Thailand. Only 81 kilometers away from Bangkok, it has long been famous for its magnificent beaches and sea views. One of the major attractions is Koh Sichang [4], which is an important tourist attraction and has a shipping harbor, and as a result, it generates a lot of MSW. Waste management in Koh Sichang involves incineration, because a landfill cannot be created on the rock surface. About 20–30 tons of MSW are generated per day; 40% of this is organic waste, representing the largest proportion, followed by plastic (20%), glass (10%), and paper (10%) [5]. The main problem at Koh Sichang is that garbage collectors do not buy glass because of its high cost of transportation**.** Glass is non-biodegradable, and there is no burning disposal or recycling of glass in Koh Sichang [6]. The main component of glass is silicon dioxide ($SiO_2$), which is approximately in the range of 66–72.4% [7–12], making it close to sand (78.6%) [12]. The major raw material in concrete is sand, a natural resource, so it is interesting to consider using glass instead of sand to produce concrete.

Concrete is a mixed material used in construction that consists of three main components, namely cement, aggregates (coarse aggregate and fine aggregate), and water [13]. The demand for concrete in construction has increased due to the growth of the community and economy. Sand, gravel, and stone are used as aggregates. However, they are exhaustible natural resources when the demand increases; they are not present in sufficient amounts to meet the growing demand. Therefore, studies are being conducted on alternative materials that can replace natural resources as building materials.

Batayneh et al. [14] studied using recycled waste materials, including waste glass, plastics, and crushed concrete, as a fraction of aggregates of 0–20% in the concrete mix in relation to compressive strength; they found that up to 20% waste glass as a substitute for fine aggregates showed the best performance. In contrast, with the use of plastic as a substitute for fine aggregates and crushed concrete as a substitute for coarse aggregates, the compressive strength decreased when the replacement amount was increased.

Waste glass has competency to use as raw materials in building constructions [15]. Many research studies have been conducted on replacing sand (fine aggregate) with waste glass. Limbachiya [16] studied the surface area of clear and colored glass using scanning electron microscopy (SEM) and reported that their surface areas were not different. Degirmenci et al. [17] also reported that colored glass has no influence on concrete properties, and using 10%, 30%, and 100% proportions of waste glass, they found that the 10% replacement resulted in the highest compressive strength. Tan and Du [18] and Hooi and Min [9] recommended the use of mixed glass; they compared the chemical compositions of clear and colored glass using X-ray fluorescence (XRF). The main component was $SiO_2$, and some compounds were similar. From this research, mixed glass can be used, reducing the need to sort post-consumer colored glass.

Castro and Brito [19] studied the influence of size in aggregate replacement (fine and coarse aggregates, separately or simultaneously); they found that the optimum replacement amounts of waste glasses as fine and coarse aggregates (separately) were 20% and 5–10%, respectively, but simultaneous replacement of waste glass as fine and coarse aggregates had the worst value. Moreover, using SEM, Ali and Al-Tersawy [10] found that glass cured for 28 days had better compressive strength than that cured for 7 days, and the performance decreased with the increase of waste glass content; this was due to the internal structure, as there was poor contact between the cement paste and waste glass, causing high smoothness of the waste glass, thereby leading to cracks. The optimum replacement in this study was 10%. Magesware and Vidivelli [20] studied the effect of sheet waste glass as a substitute for fine aggregate at 10% and 20% and found compressive strength increase; especially, 10% exhibited the highest compressive strength compared with normal concrete. Nishikant et al. [11] concluded that the compressive strength, water absorption, and density of concrete brick decease with the increase of waste glass content because the internal voids of waste glass increased; in their study, compressive strength showed an increase at 15–30% waste glass replacement, and after 45%, it exhibited a decrease. From these results, it is clear that waste glass can be used as a replacement material in concrete production.

Despite the findings listed above, there are not enough data on the materials available in Thailand; specifically, the optimum percentage of fine aggregate replacement is unclear. The objective of this research is investigating the physical properties, chemical properties, and microstructure of concrete bricks for managing waste glass in Koh Sichang, Chonburi province, used as a partial fine aggregate replacement in concrete brick production, and assessing the primary economic feasibility for alternative waste glass management.

**Definition:** Concrete bricks in this research consist of cement, sand, waste glass and water with the size of 5 $cm^3$.

## 2. Materials and Methods

### 2.1. Materials

The main materials used in this research were Portland cement type I, water, sand, and waste glass used as a fine aggregate, as shown in Fig. 1. The waste glass was from clear and colored soda-lime bottles obtained from the post-consumer stage in Koh Sichang, Chonburi Province, Thailand.

The waste glass was first crushed using a ball mill (Sprecher Schuh, USA). The fineness of the waste glass was ensured by dry sieving through a no. 4 (4.75 mm) sieve as fine aggregate replacement sand. The size of the aggregates used in the study was 100% passing through the no. 4 sieve (4.75 mm) and 100% retained on a no. 200 sieve (0.075 mm). The particle size distribution (PSD) of the aggregates had a nominal size range of 0.075-4.75 mm with no. 4, 10, 20, 40, 100, and 200 sieves. The results are presented in Fig. 2. The chemical compositions of the cement and aggregates were analyzed using an XRF spectrometer (S8 Tiger), and the results are given in Table 1. The findings showed that the major components of cement were CaO and $SiO_2$, while $Al_2O_3$ was a minor component; meanwhile, the major component of sand and waste glass was $SiO_2$, while $Al_2O_3$ was still a minor component. The physical properties of aggregates are shown in Table 2.

### 2.2. Mix Proportion and Preparation

In this study, five different series including sand substitution with waste glass at 10%, 20%, 30%, and 100% by weight and the standard concrete (with no waste glass) of samples were prepared for the test, depending on replacement of waste glass. Thirty samples were produced for each concrete mixture for assessing the physical properties of the concrete mixture; 50 x 50 x 50 mm concrete cube molds were cast using the ASTM C109 standard procedure for compressive strength, water absorption tests, and density at 7, 14, and 28 days. Each sample was also prepared with a water-cementitious (w/c) ratio = 0.5 and aggregate to cement ratio = 3:1. The used mix proportions are shown in Table 3. After mixing and pouring down the mold, compacting, and smoothing the surface with a steel trowel in the cube mold, the samples were wrapped with plastic film to protect them from moisture loss. After casting for 24 h in moist conditions, the samples were demolded and transferred to a water bath for curing until reaching the age for testing.

### 2.3. Characterization of Concrete Bricks

The physical properties of concrete brick, comprising compressive strength per ASTM C109 [21], water absorption, and density per ASTM C642-06 [22]. The effects of the addition of waste glass and curing time on the microstructure characterization of concrete bricks were investigated by Scanning Electron Microscopy and Energy Dispersive X-Ray Spectroscopy (SEM-EDS) (JEOL, JSM-IT300). The mineralogical phases of concrete bricks were achieved using X-ray diffractometry (XRD, D8-Discover).

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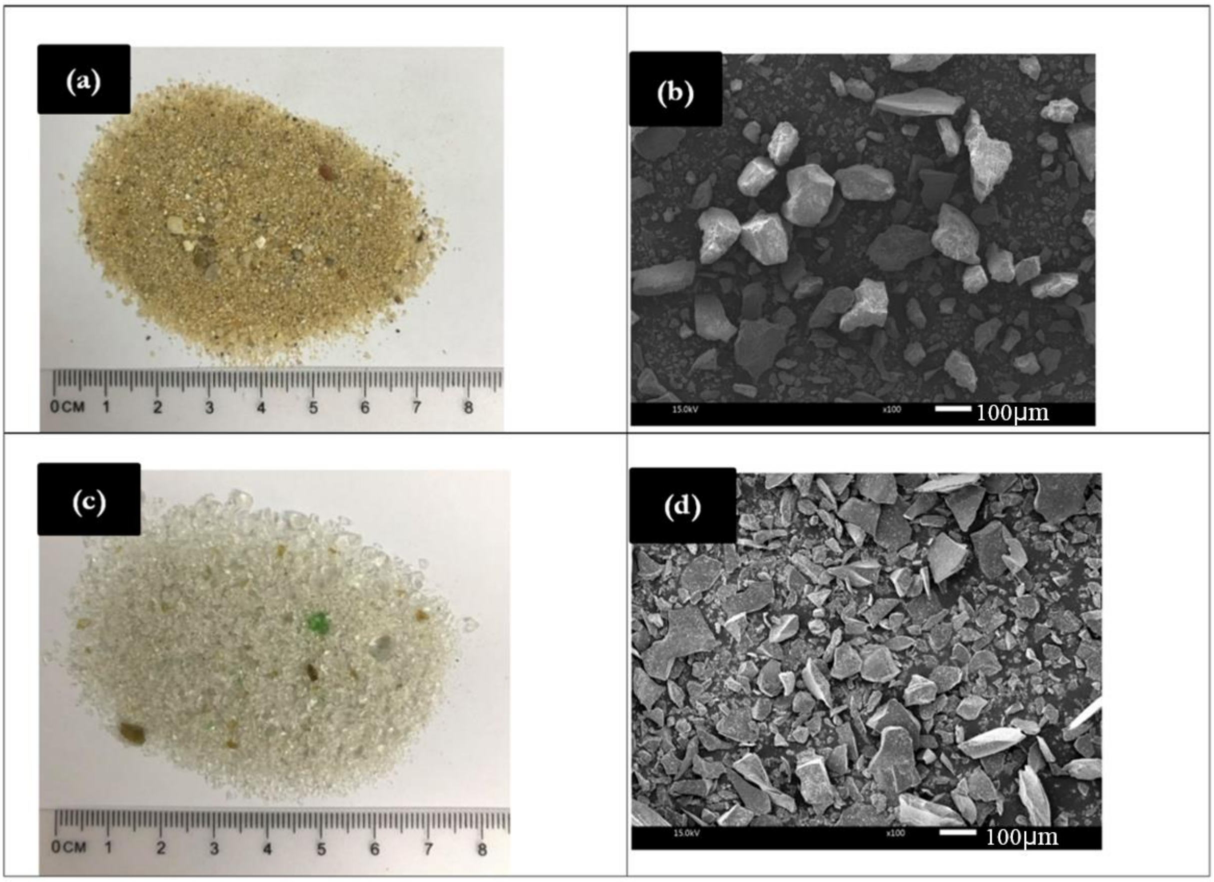


Fig. 1. Aggregates used in this study: a) Sand; b) SEM image of sand (x100); c) Waste glass; d) SEM image of waste glass (x100).

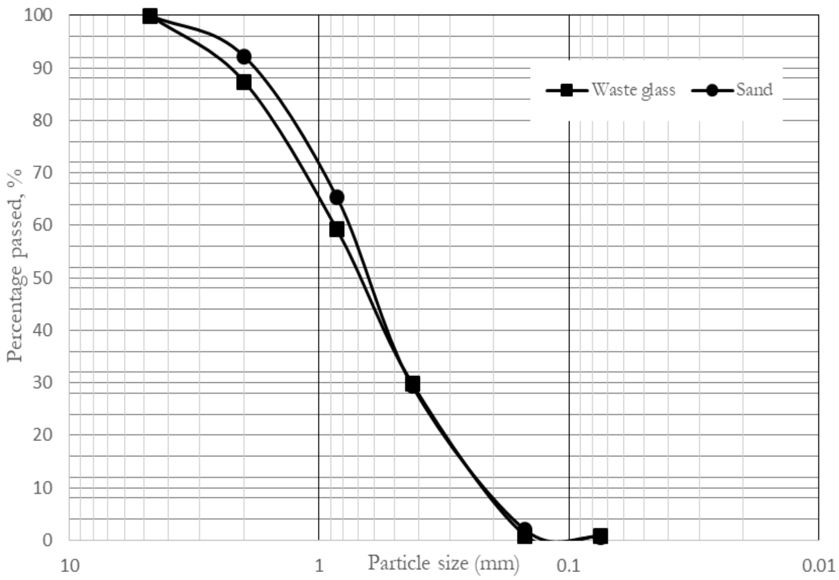


Fig. 2. Particle size of sand and waste glass.

Table 1. Chemical composition of cement and aggregates.

| Compounds | % by weight | | |
|---|---|---|---|
| | Cement | River Sand | Waste glass |
| CaO | 56.7 | 0.142 | 11.4 |
| $SiO_2$ | 15.4 | 89.7 | 71.1 |
| $Al_2O_3$ | 3.48 | 5.56 | 1.89 |
| $SO_3$ | 3.35 | - | - |
| $Fe_2O_3$ | 2.53 | 0.479 | 0.223 |
| MgO | 1.58 | 0.131 | 1.98 |
| $K_2O$ | 0.524 | 3.29 | 0.209 |
| $Na_2O$ | 0.386 | 0.335 | 12.7 |
| $TiO_2$ | 0.189 | - | - |

Table 2. Physical properties of aggregates.

| Characteristic | Sand | Waste glass |
|---|---|---|
| Specific gravity | 2.46 | 2.32 |
| Water absorption (%) | 3.93 | 0.28 |
| Fineness modulus | 2.92 | 3.08 |

Table 3. Proportions of concrete mixture (wt. %).

| Name | Cement | Sand | Waste glass | Water |
|---|---|---|---|---|
| WG0 | 22.22 | 66.67 | 0.00 | 11.11 |
| WG10 | 22.22 | 60.00 | 6.67 | 11.11 |
| WG20 | 22.22 | 53.34 | 13.33 | 11.11 |
| WG30 | 22.22 | 46.67 | 20.00 | 11.11 |
| WG100 | 22.22 | 00.00 | 66.67 | 11.11 |

### 2.4. Statistical Analysis

The significant differences resulting from replacing sand with waste glass at 0%, 10%, 20%, 30%, and 100% and curing time data were calculated using the SPSS program.

### 2.5. Economic Feasibility

To assess the economic feasibility and analyze costs and benefits of the production of concrete bricks (10 cm x 20 cm x 6 cm) from the optimal percentage of waste glass was evaluated by using the following equations:

Breakeven point (Q)

$$Q=\frac{F}{P-V} \tag{1}$$

where

Q is the breakeven point
F is the total fixed costs, Baht
P is the price per unit, Baht
V is the variable cost per unit, Baht

Payback period

$$\text{Payback period}=\frac{Q}{N} \tag{2}$$

where

Q is the breakeven point
N is the productivity yield/year

The data on fixed costs are shown in Table 4.

Table 4. Data on fixed cost.

| Type | | Cost | Source |
|---|---|---|---|
| **Materials** | Cement | 2.5 Baht/kg | (OneStockHome Co., Ltd., 2018 : online) |
| | Sand | 0.3 Baht/kg | (CRG CEMENT, 2017 : online) |
| | Waste glass | 0 Baht/kg | Koh Sichang, Chonburi Province |
| **Machines** | Los Angeles abrasion machine | 98,000 Baht/unit | (Testmaterial Co.,Ltd., 2018 : online) |
| | Aggregate Vibration Screen | 145,000 Baht/unit | (Testmaterial Co.,Ltd., 2018 : online) |
| | Pan mixer (STARON™) | 22,000 Baht/unit | (CANTON TRADING Co., Ltd., 2017 : online) |
| | Block machine | 50,000 Baht/unit | (Fox thai, 2018 : online) |

## 3. Results and Discussion

### 3.1. Physical and Mechanical Properties of Concrete Bricks

The characteristics of concrete bricks of all series (WG0, WG10, WG20, WG30, and WG100), including the general appearance, compressive strength, water absorption, and density. Figure 3 shows that all the concrete bricks had a gray color with smooth surfaces, except WG100, which was produced from 100% of waste glass; this had a rough surface and the most porosity.

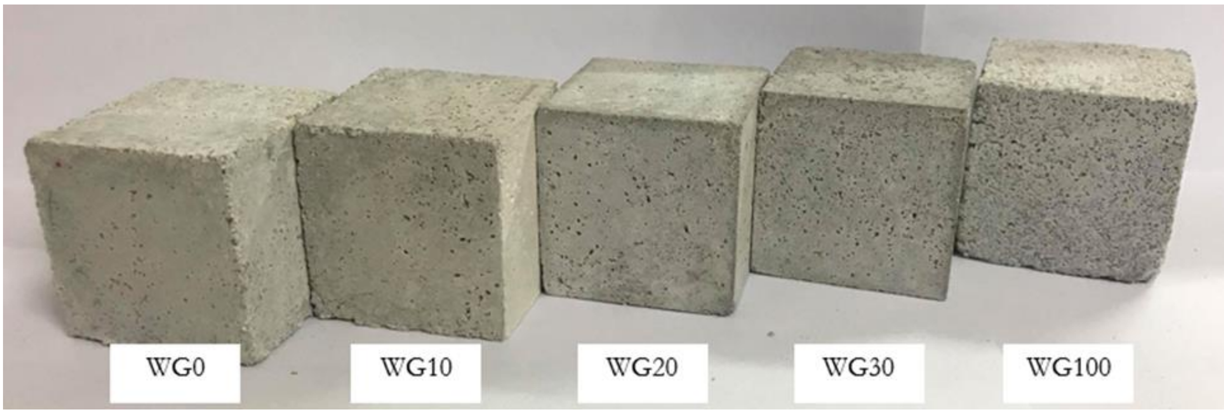


Fig. 3. General appearance of concrete bricks.

The compressive strength of concrete bricks with different replacement amounts of waste glass at 7, 14, and 28 days are presented in Fig. 4. It was found that all the samples had the same trend; as the best result, at 28 days, a compressive strength value of 48.49 MPa was obtained from concrete bricks with 20% waste glass as aggregate replacement, representing a 7.61% increase in compressive strength compared with the control mix (45.06 MPa); replacement up to 20% gave a high compressive strength value. Adaway and Wang [23] reported that the increase in compressive strength above the control mix may be attributed to the angular nature of glass aggregate, which has a greater surface area than the naturally rounded sand particles. In contrast, the compressive strength of concrete bricks decreased with the increase of waste glass up to 30%, caused by the weak bond between waste glass and cement paste due to the surface of waste glass is smoother than sand causing poorly mechanical anchorage between cement paste and waste glass [7, 24].

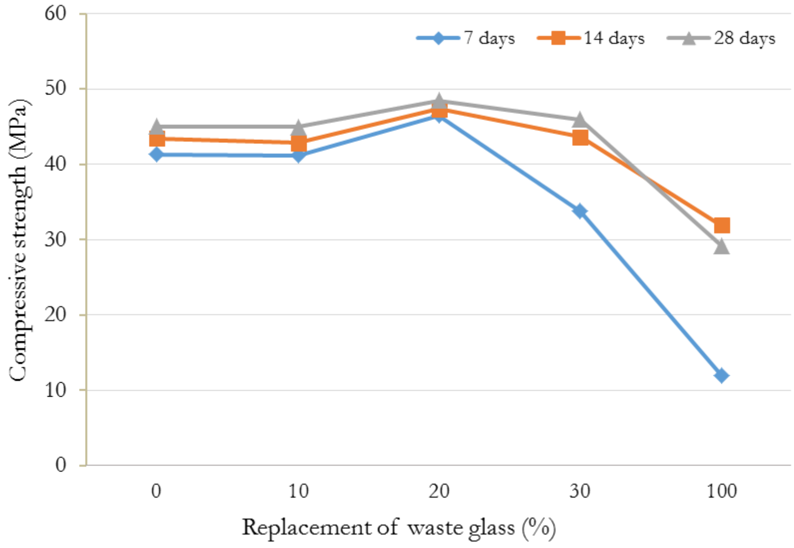


Fig. 4. Compressive strength of concrete bricks with different replacement of waste glass.

The water absorption and density of concrete bricks with different replacements of waste glass at 7, 14, and 28 days are presented in Fig. 5 and Fig. 6. The results show that all the samples exhibited the same trend. The increase of curing time decreased the water absorption and increased the density of concrete bricks as a result of the pore filling of the hydration reaction. The results showed that concrete bricks of 20% waste glass as aggregate replacement had the lowest value of water absorption at 14 and 28 days (5.91 and 5.35) and the highest compressive strength. This is consistent with Du and Tan [25], who observed compressive strength correlate well with the reduced porosity of concrete.

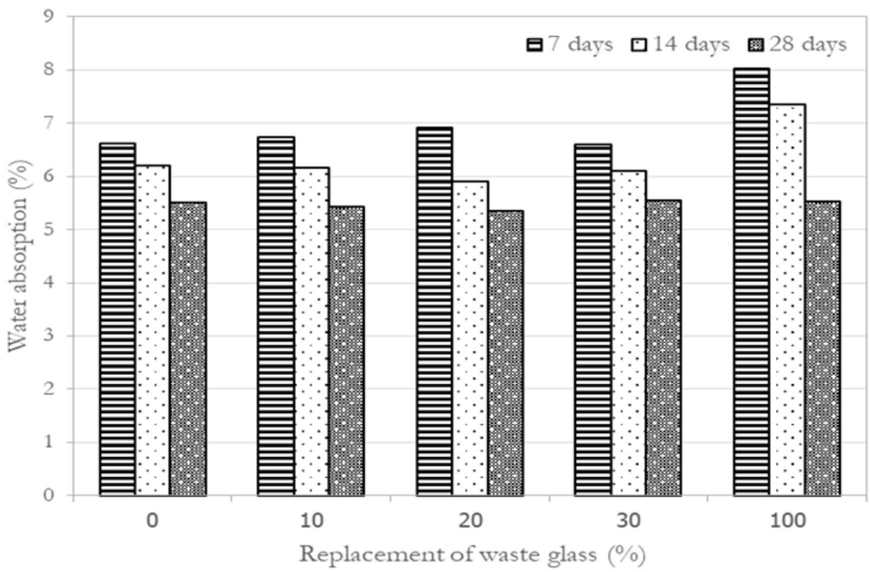


Fig. 5. Water absorption of concrete bricks with different replacement amounts of waste glass.

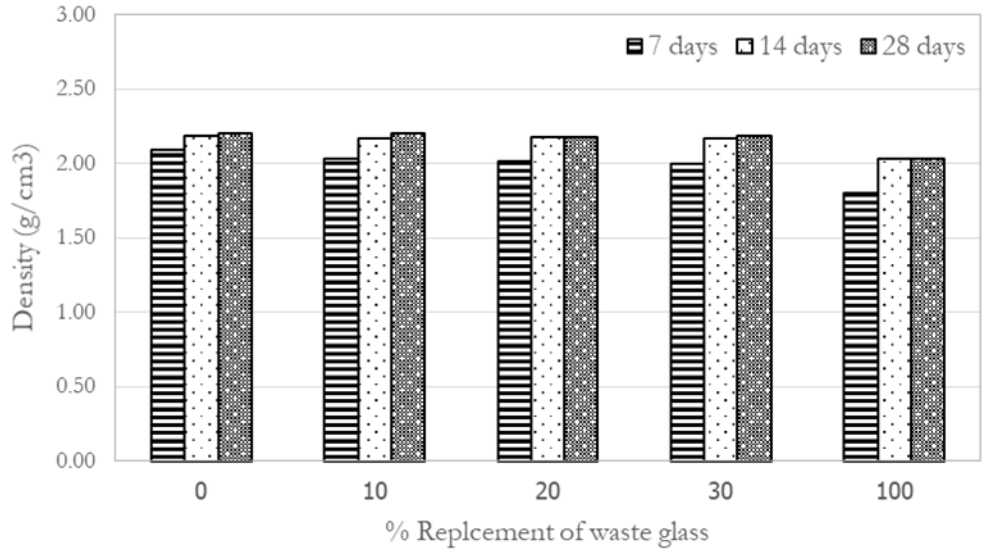


Fig. 6. Density of concrete bricks with different replacement amounts of waste glass.

The microstructure characterization of concrete bricks was observed using SEM (JEOL, JSM-IT300), as shown in Fig. 7 and Fig. 8. A good bond between the cement paste and aggregate was obtained, with high density and lower porosity, as shown in Fig. 7a and b; moreover, as illustrated in Fig. 7c, there was high porosity between the cement paste and aggregate. Figures 8a, b, c, d, and e show the SEM-EDS images of concrete brick sections, with 0, 10, 20, 30, and 100% waste glass as aggregate replacement at 28 days. The findings showed that increments of waste glass had more voids and were looser, and Si was found in all concrete bricks with 0, 10, 20, 30, and 100% waste glass as aggregate replacement.

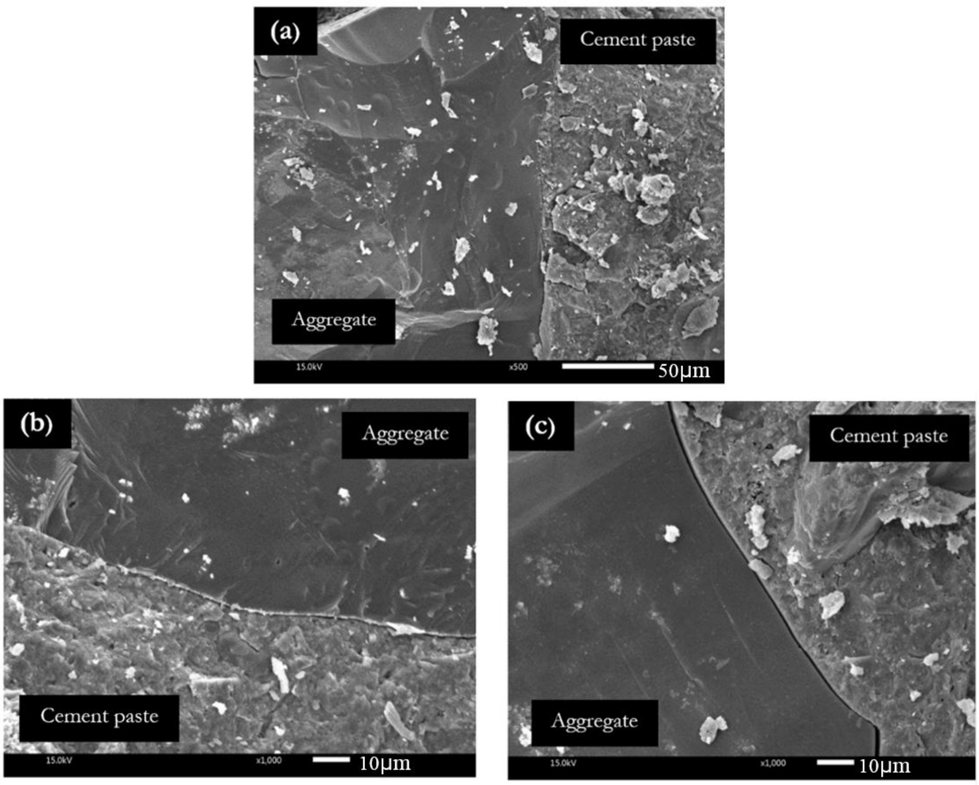


Fig. 7. SEM images between cement paste and aggregate: (a) WG0 (x500), (b) WG20 (x1000), and (e) WG100 (x1000).

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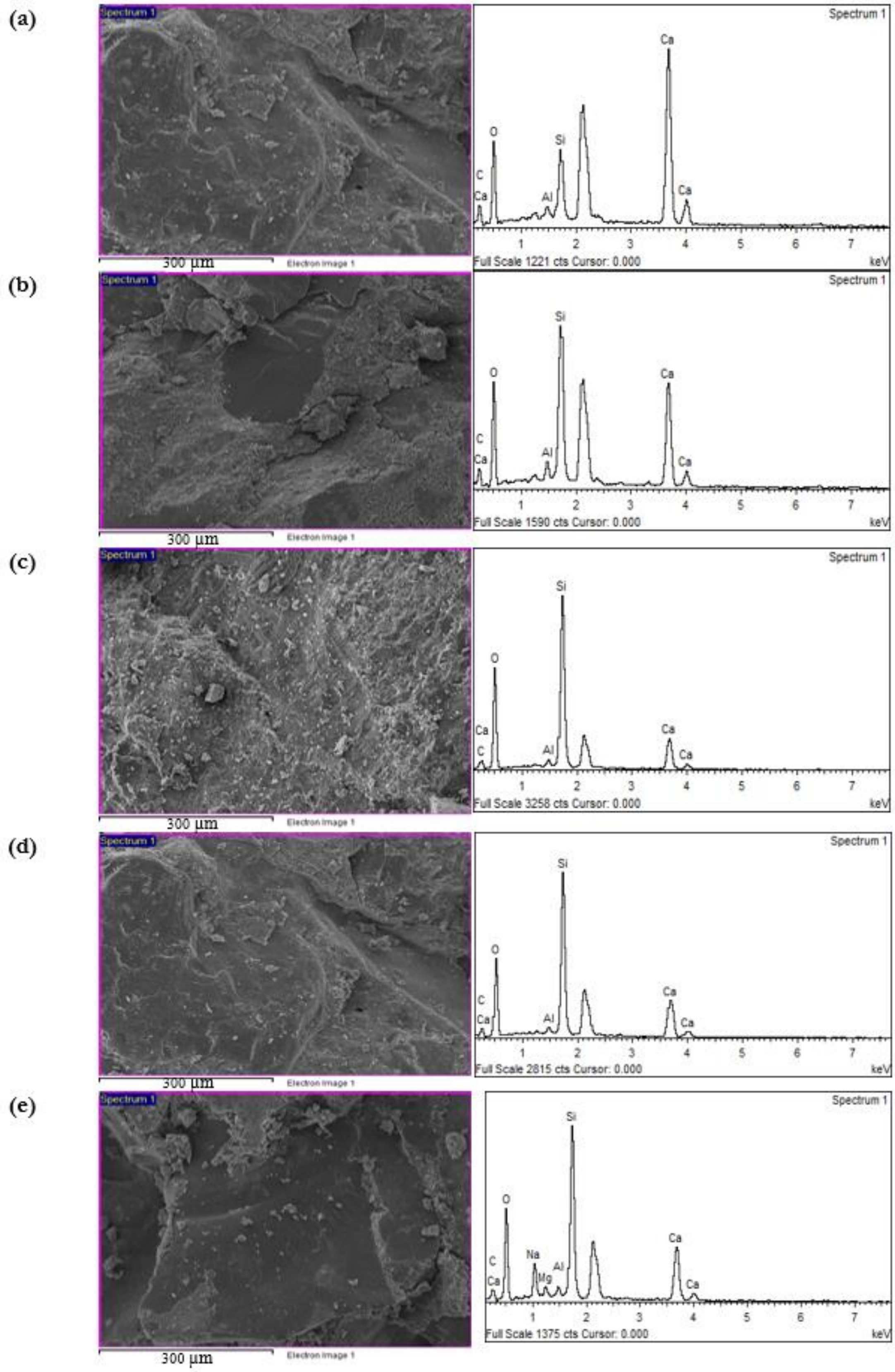
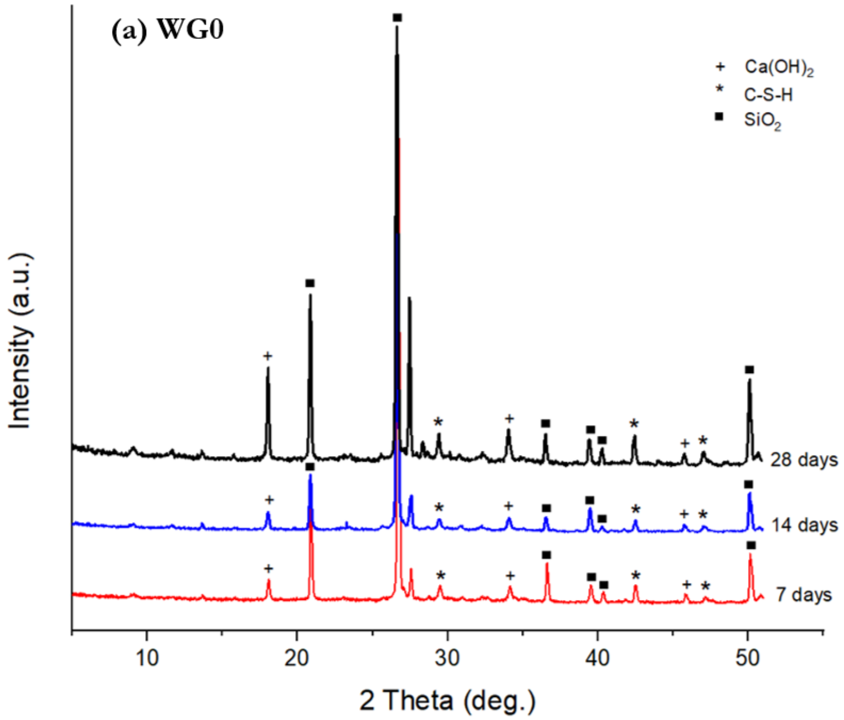
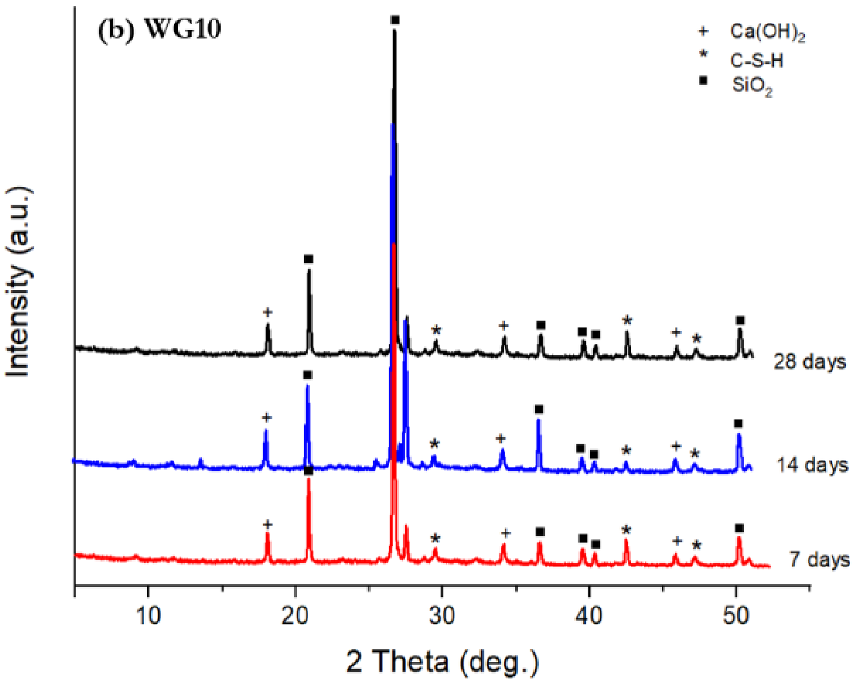



Fig. 8. SEM-EDS images of concrete bricks at 28 days (x500): (a) 0WG, (b) 10WG, (c) 20WG, (d) 30WG, and (e) 100WG.

The mineralogical phases of concrete bricks were identified by using XRD (D8-Discover); as shown in Fig. 9a–d, the major mineral phase was quartz ($SiO_2$) caused by sand (aggregate). Calcium hydroxide ($Ca(OH)_2$) and calcium silicate hydrate (or C-S-H) results from the hydration reaction. C-S-H is the main product of the hydration of Portland cement, and it is like a glue that provides strength and holds concrete together [26]. The main peaks of C-S-H were found at 29.3°, 30.9°, and 47.7° [27] in all samples. According to El-Mahllawy and Kandeel [28], these represent the XRD patterns of C-S-H and quartz peaks. Figure 9e shows the peak of concrete brick with 100% waste glass as an aggregate replacement, which exhibits a clear difference from the other samples because glass is an amorphous structure.



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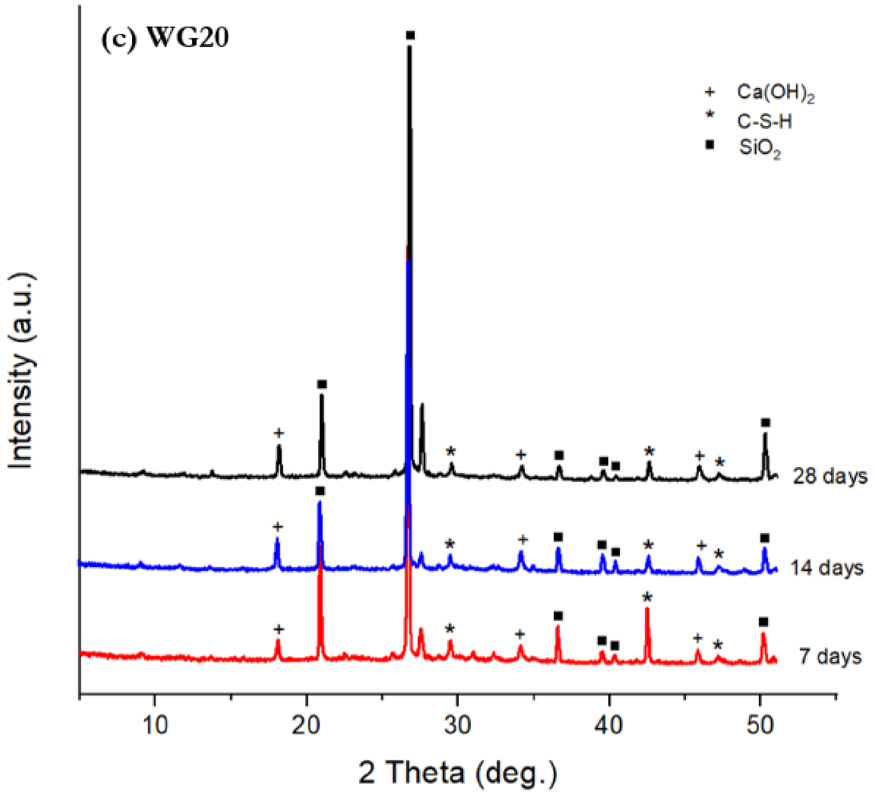


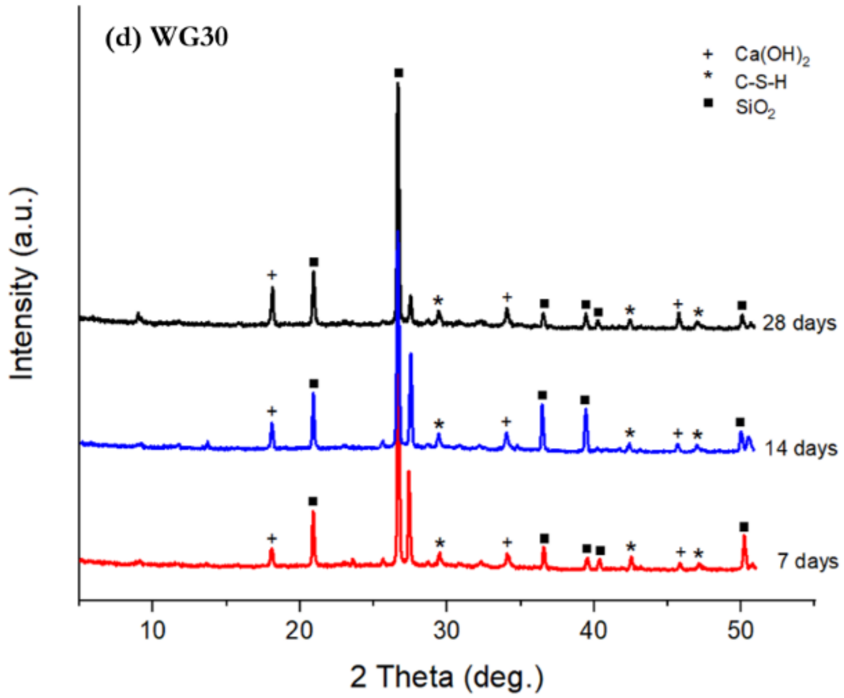

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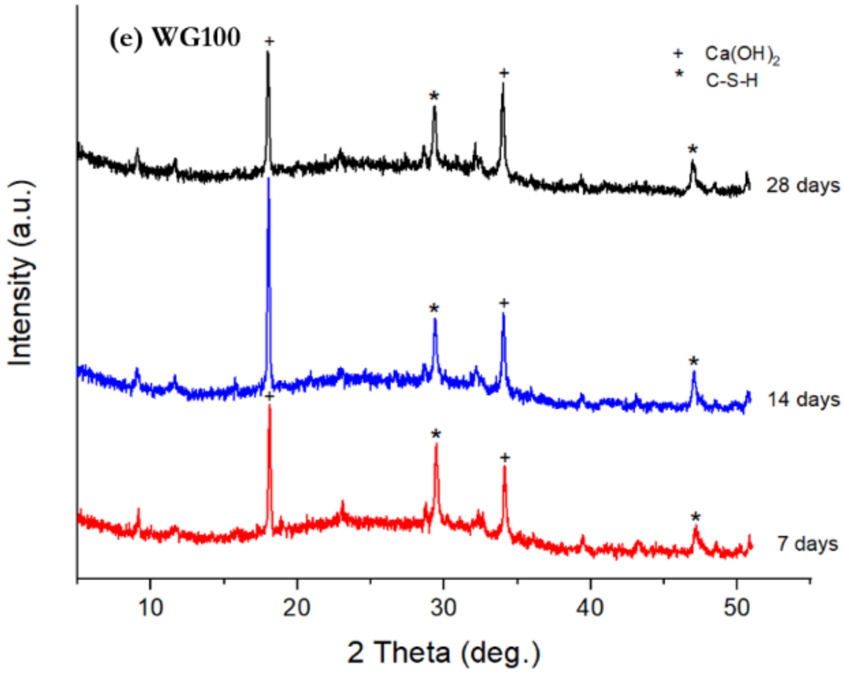


Fig. 9. XRD patterns of concrete bricks: (a) 0WG, (b) 10WG, (c) 20WG, (d) 30WG, and (e) 100WG.

### 3.2. Economic Feasibility

Economic feasibility analysis, also known as cost analysis, is the most commonly used method for analyzing the efficiency of a new project. The breakeven volume is the point at which the total cost and total revenue are equal. The payback period is the length of time required to recover the initial cost in the investment. The calculation results are presented in Table 5.

Table 5. The cost of concrete brick from waste glass.

| **The costs** | **Baht** |
|---|---|
| **Fixed cost (F)** | |
| Los Angeles abrasion machine | 98,000 Baht |
| Aggregate Vibration Screen | 145,000 Baht |
| Pan mixer | 22,000 Baht |
| Block machine | 50,000 Baht |
| Total fixed cost | 315,000 Baht |
| **Raw material capital** | |
| Cement | 360 kg |
| Sand | 840 kg |
| Waste glass | 240 kg |
| Total | |
| Weight of concrete brick | 2 kg/piece |
| Amount of concrete brick | 600 pieces/day |

Table 5. (Continued).

| The costs | Baht |
|---|---|
| **Variable costs** | |
| Material costs | |
| Cement | 2.5 Baht/kg |
| Sand | 0.3 Baht/kg |
| Waste glass | 0 Baht/kg |
| Raw materials cost | 1,150 Baht/day |
| Amount of concrete brick | 600 pieces/day |
| Total Raw materials cost/piece | 1.92 Baht/piece |
| Human labor | 300 Baht/day/person |
| Human labor 3 people | 900 Baht/day/person |
| Amount of concrete brick | 600 pieces/day |
| Total human labor cost/piece | 1.5 Baht/piece |
| **Transportation capital** | |
| Transportation costs | 50 Baht/day |
| Amount of concrete brick | 600 pieces/day |
| Total transportation cost/piece | 0.083 Baht/piece |
| **Other expenses** | |
| Electricity cost | 47.04 Baht/day |
| Amount of concrete brick | 600 pieces/day |
| Total electricity cost/piece | 0.078 Baht/piece |
| Tap water cost | 40 Baht/day |
| Amount of concrete brick | 600 pieces/day |
| Total tap water cost/piece | 0.067 Baht/piece |
| **Variable costs (V)** | |
| Raw material cost/piece | 1.92 Baht/piece |
| Transportation cost/piece | 0.083 Baht/piece |
| Human labor cost/piece | 1.5 Baht/piece |
| Electricity cost/piece | 0.078 Baht/piece |
| Tap water cost/piece | 0.067 Baht/piece |
| Total | 3.65 Baht/piece |

Table 5. (Continued).

| The costs | Baht |
|---|---|
| **Productivity yield/ year (N)** | |
| Working day | 288 days/year |
| Productivity | 600 pieces/day |
| Productivity/ year | 172,800 pieces/year |
| **Price/ unit (P)** | |
| Concrete brick cost | 5 Baht |
| **The breakeven point (Q)** | |
| $Q = \frac{F}{P - V}$ | 233,333 pieces |
| **The payback period** | |
| $\frac{Q}{N}$ | 1.35 years (17 months) |

The results showed that the optimum percentage of concrete brick was 20% waste glass as an aggregate replacement. The breakeven volume was 233,333 pieces, and the payback period was 1.35 years (17 months).

## 4. Conclusions

This research focused on waste glass management in Koh Sichang, Chonburi province, via aggregate replacement in concrete brick production. Based on the experimental investigation, the following conclusions can be drawn:

1. Waste glass can be used as an aggregate for concrete brick production, replacing up to 20% by weight of the total aggregates to increase the compressive strength value;
2. The optimum percentage replacement was 20% at 28 days (48.49 MPa), representing an increase in compressive strength of up to 7.61% compared with the control mix (45.06 MPa);
3. Increasing the waste glass more than 20% led to a high porosity of the concrete bricks, increased water absorption, and reduced compressive strength;
4. The breakeven volume was 233,333 pieces, and the payback period was 1.35 years (17 months).

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