Investigation of using granite sludge waste and silica fume in clay bricks at different firing temperatures

E.M. Abdel Hamid

Chemical Engineering Department, Egyptian Academy for Engineering & Advanced Technology, Cairo, Egypt

ABSTRACT
A large amount of granite sludge waste (GSW) is produced during the granite quarry processing that has a negative impact on the environment. The main aim of this study to investigate the possibility of partial replacement of brick clay by GSW and silica fume (SF) due to the similarity of the mineralogical composition of GSW and clay. Five different series of clay to SF to GSW proportions were tried, which were (70:5:25), (70:10:20), (70:15:15), (70:20:10), (70:25:5) by weight. These bricks were mixed and molded in the dimensions of 50 x 50 x 50 mm³ and then fired at three different temperatures (700°C, 750°C and 800°C). The properties of green and fired bricks were studied as a function of waste percent. The vitrification parameters, such as compressive strength, water absorption, saturation coefficient, apparent porosity and bulk density, were determined and compared with ASTM standards. The results showed that the water absorption and compressive strength is very sensitive to the temperature changes than waste addition. It is possible to produce bricks with the highest compressive strength of 18.5 MPa at firing temperature 700°C using 70% clay, 25% SF and 5% granite sludge waste with water absorption of 18.2% and saturation coefficient 0.9 to meet the standard specification ASTM C216 grade for moderate weathering that are recommended for environmental and economic benefits.

ARTICLE HISTORY
Received 6 October 2020; Revised 5 March 2021; Accepted 11 March 2021

KEYWORDS Silica fume; granite sludge waste; water absorption; brick clay

Introduction
A large amount of waste produced from the granite industry has a negative effect on the environment. The reusing of the waste produced by the industrial activities in building materials becomes a valuable solution for waste disposal and control of the pollution problem.

Granite is one of the most common types of rocks which is used for different purposes. It can be used in building materials due to having high strength. Granite sludge waste (GSW) is produced during the granite quarrying process...
especially in the sawing and polishing process. Water is used in a large amount in equipment for cooling and lubricating. The amount of water used differs from one factory to another according to the amount, size and types of sawed blocks per year. Slaked lime and iron powder were added by some factories to facilitate the sawing process and also to increase the service life of the sawing blade. The produced mixture of water and fine powders is known as a sludge or granite slurry [1].

Many researchers studied these wastes in different industrial applications, such as ceramics, concrete, cement and bricks manufacturing. This waste needs to be removed in an economic way to reduce its harmful effect on the environment [2].

Nagaraj et al. [3] investigated the possibility to utilize the granite sludge as a partial replacement of sand used in the production of compressed stabilized earth blocks (CSEBs) with different percentages ranging between 0% and 60% of granite sludge. Different engineering properties were evaluated such as compressive strength, durability and water absorption. They found that adding granite sludge enhances the engineering properties of the CSEBs with water absorption less than 10% and wet compressive strength ranging between 3.5 and 7.8 MPa.

While Swaminathan et al. [4] studied the possibility of using granite and marble sawing waste in the production of bricks. The characteristics of the produced bricks were evaluated, such as chemical composition, particle size, plasticity and also mineralogical and petrological analyses. They found that these wastes can be added to the raw clay material up to 50% wt. to enhance the produced bricks.

On the other hand, Salman and Vidya [5] discussed the partial replacement of the clay with rice husk ash (RHA), ceramic powder and marble dust in the production of clay bricks with different percentages 0%, 4%, 8% and 12%. Different properties such as water absorption, linear shrinkage, compressive strength, apparent porosity and bulk density were determined for the produced bricks. The results showed that RHA and ceramic waste powder can be used up to 8% replacement, while up to 12% marble dust can be used in the production of clay bricks. Also, El Mahllawy et al. [6] investigated the effect of the addition of marble cutting waste in different percentages in the production of bricks up to 25%. They used cement, hydrated lime and marble cutting waste with clay and sand to produce a cylindrical unfired brick specimen which cured in a humidity chamber for 2–4 weeks. The produced specimens were dried and tested according to ECBS. The results showed that marble cutting waste can be used up to 15% with hydrated lime.

On the other hand, silica fume (SF) waste is produced as a byproduct from the production of silicon or ferro-silicon alloys using electric arc furnaces. High-purity quartz is reduced at a temperature of 2000°C to produce silicon and vapor of silicon dioxide which oxidizes and condenses to SF at low temperature. SF particles have a spherical shape with a particles size ranging
from (0.1 to 0.3 μm). It has a high surface area and also a high content of fine amorphous silicon dioxide more than 90% of SF. SF is applied in different applications which is more efficient in cement and concrete [7].

Baspinar et al. [8] discussed the effect of different amounts of SF addition on the properties of fired clay bricks. The test samples were produced using uniaxial pressing and fired at different temperatures ranging between 800°C and 1100°C. They found that the strength of fired bricks at temperatures 1000°C and 1100°C was improved due to the addition of SF and also found that the addition of SF has a tendency to decrease the bulk density at low firing temperature and increase at high firing temperature due to better sintering action.

While Elbeyli et al. [9] investigated the possibility of partial replacement of 20% borax waste, 20% borax waste+20%fly ash and 20% borax waste+10% SF in clay bricks. These mixtures were molded under pressure 10 bar and fired at different temperatures ranging from 970°C to 1030°C. The results indicated that the amount of waste added and firing temperatures affects on the quality of the building bricks which increase the porosity, water absorption and decrease the compressive strength. It was found that the best values of the quality tests for bricks samples at temperature 1000°C. Also, Hegazy et al. [10] investigated the utilization of three different wastes water treatment plant sludge (WTPS), SF and RHA in the production of bricks as a complete substitution of clay brick. The proportional samples of WTPS, SF and RHA were (25:25:50%), (50:25:25%) and (25:50:25%), respectively, which fired at different ranges from 900°C to 1200°C. Different properties were evaluated and compared to the Egyptian Standard Specifications and the clay brick. They found that the optimum proportional material was 50% WTPS, 25% SF and 25% RHA to produce bricks.

Finally, Sankar et al. [11] investigated the possibility of partial replacement of clay with 50% of granite sawing waste and SF with different proportions at a specific temperature. They found that using granite sawing waste and SF at this percentage decreased the water absorption of these bricks.

According to the previous studies, this paper studies the effect of changing firing temperature on the different proportions of GSW and SF in the production of building bricks.

**Experimental methods**

Kaolin clay is obtained from Upper Egypt Beni-sweif that was used in the brick industry, while GSW and SF waste were kindly provided from Shaq Al-Thu’ban Cluster and Egyptian Ferro Alloys, respectively.

The clay was mixed with different percentages of GSW and silica fume waste (SFW) in the presence of 20% wt of water as a binding agent that is shown in Table 1. The homogenous mixtures were molded in (50 mm x 50 mm x 50 mm) cubic molds. Brick specimens were dried at room temperature for 72 hours.
The brick specimens were dried on three steps using a laboratory dryer. The first step was at 50°C for 3 hours and then 80°C for 3 hours, and finally at 120°C for another 3 hours. The brick specimens were fired at three different temperatures (700, 750 or 800) °C with soaking time of 1 hour. ‘Figure 1’ shows the process manufacturing of clay bricks with different percentages of waste.

**Results and discussions**

**Characterization of raw materials**

**Chemical analysis**

The chemical composition of clay, SF and GSW was determined using X-Ray Fluorescence spectrometry shown in Table 2.

**Mineralogical analysis**

XRD analysis was applied on clay, SF and GSW shown in ‘Figure 2’. The clay consists of quartz, albite, kaolinite and calcite, while quartz is the main phase of SF. On the other hand, GSW is composed of quartz and gypsum.

---

**Table 1.** Different proportional of granite sludge waste and SF waste in clay building bricks.

| Code | SF (%) | GSW (%) | Clay% |
|------|--------|---------|-------|
| Mix 1 | 0      | 0       | 100   |
| Mix 2 | 5      | 25      | 70    |
| Mix 3 | 10     | 20      | 70    |
| Mix 4 | 15     | 15      | 70    |
| Mix 5 | 20     | 10      | 70    |
| Mix 6 | 25     | 5       | 70    |

---

**Figure 1.** Process manufacturing of clay bricks.
Thermal analysis
Thermal analysis was performed for the raw materials. ‘Figure 3’ displayed the TGA of these raw materials which reveals the peaks accompanied with the weight loss. ‘Figure 3(a)’ shows 0.7% wt decrease in weight due to evaporation of physical water then followed by oxidation of organic compounds with 6.53% loss in weight and then dehydroxylation of montmorillonite with 4.43% weight loss. Above 600°C, there is a slight decrease in weight due to the decomposition of calcite.

While ‘Figure 3(b)’ illustrates a slight decrease in weight due to evaporation of physical water followed by oxidation of organic compounds and finally above 580°C, there was dehydroxylation of illite. On the other hand, ‘Figure 3(c)’ shows the same behavior of clay that display an endothermic peak due to loss of physical water below 160°C and then a small exothermic peak due to oxidation of the organic compounds followed by the decomposition of calcite starts at temperature 580°C.

Screen analysis
Screen analysis of the raw materials used in this study revealed that GSW and SF waste were much finer than clay as displayed in ‘Figure 4’. The mean particle sizes (D50) were 0.06 mm, 0.06 mm and 0.068 mm for GSW, SF waste and clay, respectively.

| Constituents, Wt. (%) | Clay | Silica Fume | Granito Sludge waste |
|----------------------|------|-------------|----------------------|
| SiO₂                 | 46   | 87.7        | 71.5                 |
| Al₂O₃                | 19.9 | 2.44        | 13.6                 |
| Fe₂O₃ (tot.)         | 9.99 | 0.834       | 2.27                 |
| TiO₂                 | 1.57 | 0.161       | 0.229                |
| MgO                  | 1.75 | 0.248       | 0.179                |
| CaO                  | 0.971| 3.17        | 1.51                 |
| Na₂O                 | 1.37 | 0.331       | 2.85                 |
| K₂O                  | 1.27 | 0.597       | 5.72                 |
| P₂O₅                 | 0.162| 0.0481      | 0.0678               |
| SO₃                  | 0.82 | 0.971       | 0.0499               |
| SrO                  | 0.318| 0.0221      | 0.0227               |
| MnO                  | 0.0489| 0.0214    | 0.0571               |
| CuO                  |       |             | 0.0211               |
| ZrO₂                 | 0.0367| 0.131      | 0.0365               |
| Cl                   | 1.63 | 0.102       | 0.0259               |
| Ag₂O                 |       |             | 0.0563               |
| L.O.I                | 14.35| 3.3         | 1.8                  |
| **Total**            | 100.1866| 100.0766  | 99.9953              |

Table 2. Chemical analysis of raw materials.
Figure 2. XRD pattern of raw materials: (a) clay, (b) silica fume, (c) granite sludge waste.
Figure 3. Thermal analysis of raw materials: (a) clay, (b) silica fume waste, (c) granite sludge waste.
Assessment of green bodies

Linear dry shrinkage (LDS) and green compressive strength were determined after drying specimens as mentioned in the experimental methods and can be described in details as the following points.

**Linear dry shrinkage**

The effect of different mixtures of waste GSW and SFW on the LDS. There are two factors that affects the slight decrease in LDS: the first one is the replacement of clay with SF which consists mainly of non-plastic silica (SiO₂) and the second is due to the larger particle size of clay compared to GSW and SFW. Table 3 shows the decrease in the LDS and volume dry shrinkage at different proportions of SF and GSW.

**Green compressive strength**

The effect of the partial replacement of the two different wastes on the green compressive strength can be summarized in Table 3. On adding waste, it can be considered that the green compressive strength ranged between 0.581 and 0.816 MPa, and they were determined to avoid serious losses during the handling process.

*Figure 4.* Particle size analysis of raw materials.
Assessment of fired bodies

The produced fired bricks were tested to determine cold water absorption, boiled water absorption, saturation coefficient, apparent porosity, bulk density and finally compressive strength that will be discussed in the following points.

Cold water absorption

‘Figure 5’ illustrates the effect of waste addition on cold water absorption. The addition of waste increases slightly the water absorption as a result of the coarser particle size of clay and also due to decomposition of carbonate calcium present in GSW which leaves vacancies for the diffusion of water in pores that can be seen clearly at specimens fired at 700°C and 750°C. At high firing temperature (800°C), the SF addition clogged the open pores that was expected because of the sintering action which increased with increasing the firing temperature [8].

Table 3. Assessment of unfired bricks.

| Code | Silica Fume (%) | Granite Sludge Waste (%) | Clay (%) | LDS (%) | VDS (%) | Green Compressive Strength, (MPa) |
|------|----------------|--------------------------|----------|---------|---------|-----------------------------------|
| Mix 1 | 0              | 0                        | 100      | 5.075   | 16.650  | 0.816                             |
| Mix 2 | 5              | 25                       | 70       | 2.597   | 8.395   | 0.824                             |
| Mix 3 | 10             | 20                       | 70       | 3.968   | 13.360  | 0.581                             |
| Mix 4 | 15             | 15                       | 70       | 3.197   | 10.002  | 0.663                             |
| Mix 5 | 20             | 10                       | 70       | 2.076   | 6.640   | 0.802                             |
| Mix 6 | 25             | 5                        | 70       | 2.945   | 8.735   | 0.709                             |

Figure 5. Effect of different waste addition on cold water absorption.
The water absorption is comparable to firing at 700°C, 750°C and 800°C. At a temperature of 700°C, there is a little shrinkage compared to the higher temperatures. The cold-water absorption ranging between 10% and 13% at 800°C, 12% and 14.5% at 750°C and finally 15% and 16.8% at 700 °C.

**Boiled water absorption**

‘Figure 6’ shows the effect of waste addition on the boiled water absorption. The increase in SF addition increases the percent of water absorption. At low firing temperature, the addition of SF increases the porosity which is responsible for the water absorption, since SF particles act as an inert and decrease the sintering process by preventing the contact between clay particles during sintering [8].

**Saturation coefficient**

Saturation coefficient is used to indicate the bricks durability to which it becomes saturated with water. Saturated coefficient is the ratio between cold water absorption after 24 hours submersion to boiling water absorption after 5 hours. It ranges usually from 0.4 to 0.95 [12]. The lower values indicate high durability, while the higher values indicate low durability. ‘Figure 7’ shows the effect of temperature on the different proportion of bricks on the saturation coefficient. As expected, the lowest firing temperature the highest saturation coefficient due to the presence of unclogged pores while at highest temperature the lowest saturation coefficient due to absence of

![Boiled Water Absorption](image)

**Figure 6.** Effect of different waste addition on boiling water absorption.
The saturation coefficient due to the addition of waste ranged between 0.8 and 0.9.

**Apparent porosity**
The apparent porosity is directly proportional to the water absorption that was plotted against different mixtures of bricks shown in **Figure 8**. It was
found that the behaviors of these curves are similar to the boiling water absorption. This result is expected as a result of increasing the SF addition that is responsible of the presence of pores which range between 30.29% and 31.67% at 700°C and 26.5% and 29% at 750°C, while at higher temperatures 800°C, the addition of SF decreases slightly the apparent porosity which shown in ‘Figure 8’.

**Bulk density**
The slight increase in pores caused a decrease in the bulk density which shown in ‘Figure 9’. The bulk density decreases due to increasing of SF. SF has a lower density compared to clay and GSW. Table 4 shows the true densities of the raw materials.

**Compressive strength**
The effect of adding waste on the compressive strength of the produced bricks at different temperatures can be shown in Table 5. As a result of decomposition of calcite present in clay with appreciable amounts, the compressive strength of the blank brick (Mix 1) fired at 800°C is lower than the other firing temperatures which is below the minimum prerequisite. It can be noted that the addition of waste increases the compressive strength. It is observed that only one mixture satisfied the minimum compressive strength 15.2 N.mm⁻² according to ASTM C 216 [13] for Grade MW (Moderate

![Figure 9](image-url)  
**Figure 9.** Effect of different waste addition on bulk density.

| Table 4. True densities of different raw materials. |
|---------------------------------------------------|
| **Raw Materials** | **Clay** | **Silica Fume** | **Granite Sludge Waste** |
| True Density (g.cm⁻³) | 2.38     | 2.2             | 2.59              |
Weathering) when using proportion 25:5:70 SF, GSW and clay, respectively, at firing temperature 700°C.

The relative effect of firing temperature and waste addition on both water absorption and compressive strength was determined using the correlation coefficient function with the help of EXCEL program. The results are shown in Table 6. It can be seen that both water absorption and compressive strength are more sensitive to temperature than adding waste. Increasing temperature has a negative effect on water absorption and compressive strength, while the addition of waste compared to the change temperature has a positive effect on both parameters.

### Table 5. Compressive strength of the produced bricks at different temperatures.

| Code | SF (%) | GSW (%) | Clay (%) | Comp. Strength MPa, 700°C | Comp. Strength MPa, 750°C | Comp. Strength MPa, 800°C |
|------|--------|---------|----------|---------------------------|---------------------------|---------------------------|
| Mix 1 | 0      | 0       | 100      | 11.3                      | 10.6                      | 5.7                       |
| Mix 2 | 5      | 25      | 70       | 12.9                      | 11.5                      | 13.8                      |
| Mix 3 | 10     | 20      | 70       | 12.9                      | 12.1                      | 10.1                      |
| Mix 4 | 15     | 15      | 70       | 12.4                      | 9.6                       | 11.9                      |
| Mix 5 | 20     | 10      | 70       | 15.1                      | 10.5                      | 10.2                      |
| Mix 6 | 25     | 5       | 70       | 18.5                      | 8.9                       | 8.6                       |

### Table 6. Correlation of fired bricks.

| Waste (%) | Temperature | Water Absorption | Compressive Strength |
|-----------|-------------|------------------|----------------------|
| Waste (%) | 1           | 0                | 0.056226             |
| Temperature | 0           | 1                | −0.91904             |
| Water Absorption | 0.056226   | −0.91904         | 1                    |
| Compressive Strength | 0.200226   | −0.57623         | 0                    |

### Conclusion

Granite sludge waste was mixed with SF with different percentages in the presence of clay to produce building bricks reaching to 30% partial replacements. The produced bricks were molded and fired at different temperatures ranging between 700°C and 800°C with a soaking time of 1 hr. It is possible to use 25% SF, 5% GSW and 70% clay to produce a building brick fired at 700°C with a compressive strength of 18.5 MPa, boiled water absorption 18.2% and 0.9 saturation coefficient to meet the specifications of ASTM C216 Grade MW.

### Disclosure statement

The author declares that there is no conflict of interests regarding the publication of this paper.
ORCID

E.M. Abdel Hamid http://orcid.org/0000-0002-1390-3773

References

1. Allam ME, Bakhoum ES, Garas GL. Re-use of granite sludge in producing green concrete. ARPN J Eng Appl Sci. 2014 December;9(12):2731–2737.
2. Agrawal Y, Saxena R, Varma M. Impact assessment of waste granite slurry in construction industries application. National Conference on Road Map for Smart Cities of Rajasthan, April 2017, Udaipur, Rajasthan.
3. Nagaraj H, Anand K, Devaraj N. Utilization of granite sludge in the preparation of durable compressed stabilized earth blocks. Moj Civil Eng. 2018;4(4):237–243.
4. Dhanapandian S, Gnanavel B, Ramkumar T. Utilization of granite and marble sawing powder wastes as brick materials. Carpathian J Earth Environ Sci. 2009 Oct;4(2):147–160.
5. Salman Shah S, Jose V. Ecofriendly brick construction using waste materials. Int Res J Eng Technol(Irjet). 2018 March;5(3):2147–2153.
6. El-Mahlawy MS, Kandeel AM, Mahmoud L, et al. The feasibility of using marble cutting waste in a sustainable building clay industry. Recycling. 2018;3:39.
7. Panesar DK. Developments in the formulation and reinforcement of concrete. 2nd ed. Chapter 3; 2019, Woodhead Publishing.
8. Serhat Baspinar M, Demir I, Orhan M. Utilization potential of silica fume in fired clay bricks. Waste Manage Res. 2010 Feb;28(2):149–157.
9. Elbeyli Y, Kalpakl YK, Gülen J, et al. Utilization of borax waste, fly ash and silica fume in manufacturing of building brick. Uluslararası Bor Sempozyumu, 2004, Uluslararası Bor Sempozyumu:449–454.
10. Hegazy B, Fouad H, Hassanan A. Incorporation of water sludge, silica fume, and rice husk ash in brick making. Adv Environ Res. 2012;1(1):83–96.
11. Sankar GME, Shalini V, Shanthosh J, et al. Experimental investigation on clay bricks by using granite saw dust. Int J Curr Eng Sci Res. 2019;6(3):297–323.
12. Khalaf FM, Devenny AS. New tests for porosity and water absorption of fired clay bricks. J Mater Civ Eng. 2002 August;14(4):334–337.
13. ASTM C216-10 (Approved 2010). Standard specifications for facing bricks (solid masonry units made from clay or shale). Annual book of American Society for Testing of Material (ASTM). USA.