IJoCED

Indonesian Journal of Computing, Engineering, and Design

Journal homepage: http://ojs.sampoernauniversity.ac.id/index.php/IJOCED

The Potential of Tea Waste and Silica Fume as Partial Replacements for Cement in Bricks

Yong Tat Lim[1], Michelle Sze Hui Ting[1], Ummi Humaira Binti Bujang[1], Mastura Binti Bujang[1], Jen Hua Ling[1]*

[1]Centre for Research of Innovation and Sustainable Development, School of Engineering and Technology,

University of Technology Sarawak, 96000 Sibu, Sarawak, Malaysia

Correspondence: limyongtat@uts.edu.my

ABSTRACT

Bricks are widely used building materials made from sand, cement, and water in standard proportions. However, the increasing demand for construction materials that use sand and ordinary Portland cement is leading to the depletion of natural resources. To address this issue, researchers are exploring alternative materials, such as Tea Waste (TW) and Silica Fume (SF), as partial replacements for cement bricks. This study used a mix proportion of 1:2.5 with a certain percentage of replacement materials and 0.5 of a water/cement ratio. The experimental results indicated that when TW and SF were substituted at 5% and 10%, respectively, the compressive strength of the cement bricks was adequate and met the minimum masonry unit requirements of the British Standard. Additionally, the density of the cement bricks (with TW and SF) was lower than that of solid bricks, and the water absorption met the requirements of the British Standard. However, the cement bricks' effective strength-to-weight ratio (s-w ratio) was lower than 1.0, except for the specimens with 5% TW and 10% SF. The optimum mix proportion was the cement brick with 5% TW and 10% SF as it achieved all the industry requirements.

ARTICLE INFO

Article History:
Received 18 Jul 2024
Revised 28 Aug 2024
Accepted 26 Sep 2024
Available online 01 Oct 2024

Keywords:
Brick,
Cement,
Sand,
Silica fume,
Tea waste.

1. INTRODUCTION

Bricks have been a crucial building element for thousands of years and are widely used in civil engineering structures. Different types of bricks have been employed in construction, including cement, clay, and concrete bricks. The demand for bricks is expected to rise as developing countries like Malaysia undergo significant infrastructural changes. However, this increased production may lead to potential cement depletion. To mitigate this, research is needed to develop cement bricks using waste materials as partial substitutes (Ling et al., 2021a,b).

Throughout the years, previous research has focused on exploring the utilization of waste materials in brick manufacturing, aligning with the industrial ecology concept of repurposing waste as raw materials in other industries (Ozturk et al., 2019). Numerous waste materials have been investigated, such as tea waste (TW), silica fume (SF), ferrochrome slag, concrete waste, rice husk ash, cigarette butts, sugarcane bagasse ash, and marble powder. The aim is to identify potential ways of incorporating these waste materials into the production of bricks.

Tea is known as a famous beverage in the current era. Tea was discovered in China by Emperor Shen Nung 5000 years ago. Tea consumption has reached about five million tons annually, and the demand keeps increasing worldwide (Celik & Celik, 2014). Such TW faces disposal problems and is present in bulk quantity. Furthermore, SF is a by-product of industries such as OM Materials, Pertama Ferroalloys, and Sakura Ferroalloys (Yunus, 2015). Those industries generate a large amount of silicon and ferrosilicon alloys, created at high temperatures by reducing quartz (Mehta, 2019)—for instance, OM Materials Sdn. Bhd. generated 1369.96 mt of micro-silica each day, which harms human beings.

This study aims to use the waste and by-products from the industries, i.e., TW and SF, to reduce the environmental impact. Thus, the materials may be reused for the production of cement bricks. TW and SF are being used as a partial replacement for cement. Those waste materials could change the properties of bricks. Partly replacing TW is expected to decrease the density and compressive strength (Djamaluddin et al., 2020). The loss of compressive strength caused by TW could be compensated using SF, as it could improve the compressive strength of the brick (Ling et al., 2019). For that, the combined effects of TW and SF could develop a lightweight brick that meets the industry's requirements.

This study was carried out to validate the hypothesis by investigating (a) the performance of cement brick, (b) optimum mix proportions, and (c) the suitability of brick in the construction industry. Successful application of TW and SF into the cement brick could (a) reduce the amount of cement used in the cement brick and (b) overcome the problem of excessive tea waste and silica fumes worldwide.

2. RESEARCH METHODOLOGY

2.1. MATERIALS

Table 1. Physical properties of materials

Materials	Descriptions
Fine aggregates	- Natural sand that can pass through the 600 µm sieve - Density of 1526 kg/m^3
Ordinary Portland cement	- Dimension between 7 µm to 200 µm - Density of 1376 kg/m^3
TW	- Passing through the 5 mm sieve - Density of 243 kg/m^3
SF	- Passing through the 600 µm - Density of 662 kg/m^3

Table 2. Chemical composition of materials

Composition	Cement (%)	TW (%)	SF (%)
SiO_2	19.34	0.83	85.45
Al_2O_3	5.20	0.79	-
Fe_2O_3	3.41	0.37	-
CaO	64.75	11.14	0.16
MgO	1.44	2.15	4.43
SiO_3	2.85	-	0.69
K_2O	0.47	4.21	0.15
Na_2O	0.10		0.14
P_2O_5	-	2.37	-
MnO	-	0.44	-
SO_3	-	2.02	-
Cl^-	-	0.47	0.02
Na_2O	-	-	0.24
Loss on ignition	3.42	75.02	1.91

Table 1 and **Table 2** summarize the materials' physical properties and chemical composition, respectively. It seems that the density of the tea waste (243 kg/m^3) was lower than that of the fine aggregates (1526 kg/m^3), thus reducing the density of the cement brick. The density reduction could lead to lower strength but could be

compensated with silica fume due to the high percentage of SiO_2 (85.45%), improving the bonding between particles.

2.2. MIX PROPORTION

All cement bricks (215 mm x 102.5 mm x 65 mm) were cast with the (a) 1:2.5 cement-to-sand ratio and (b) 0.5 water-to-cement ratio for all compositions (Ling et al., 2019). The TW and SF were the materials of partial replacement for the cement, and the percentages of substitution range from (a) 5% to 15% for TW and (b) 10% to 15% for SF (**Table 3**).

Each mixture comprises nine specimens: 6 for compressive strength tests on days 7 and 28 (with three specimens per day) and 3 for density and water absorption tests on day 28. The average values of three specimens will be taken for all the results.

$$\rho = \frac{w_d}{w_s - w_i} \times 100\% \quad (1)$$

$$WA = \frac{w_s - w_i}{w_d} \times 100\% \quad (2)$$

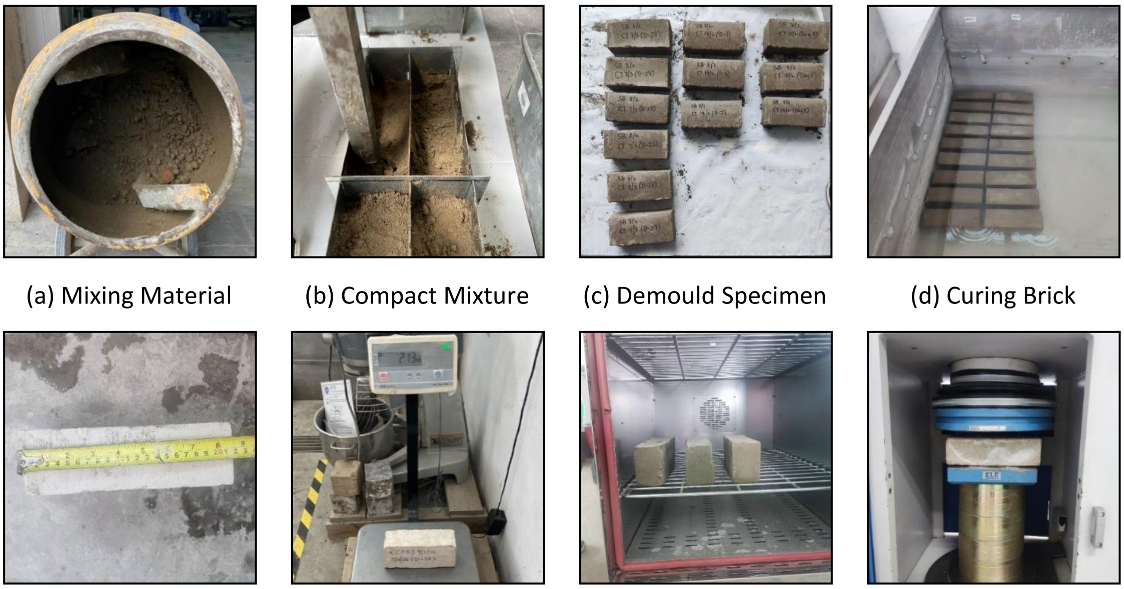
2.3. TEST PROCEDURES

All the specimens were prepared using the brick mold (215 mm x 102.5 mm x 65 mm), as shown in **Figure 1**. All specimens were mixed for 25 minutes at 30 ± 5°C, respectively. The specimen was poured into the mold in three layers and compacted 25 times with a rod compactor for each layer. The specimens were de-molded after 24 hours of casting and curing for days 7 and 28.

Table 3. Specimens' details

Mix	TW (%)	SF	Number of specimens
C1	0	0	9
S1	5	10	9
S2	5	12.5	9
S3	5	15	9
S4	10	10	9
S5	10	12.5	9
S6	10	15	9
S7	15	10	9
S8	15	12.5	9
S9	15	15	9
		Total	90

The dimensions of the specimens were acceptable, as the size was within the limits specified in BS EN 771-5: 2011 (British Standard Institution, 2011). The allowable range for length, height, and width is 211.8 mm to 218.1 mm, 100.6 mm to 104.3 mm, and 63.1 mm to 66.8 mm, respectively (**Table 4**).



(a) Mixing Material (b) Compact Mixture (c) Demould Specimen (d) Curing Brick

(e) Dimension Test (f) Weighing Brick (g) Dry the Specimen (h) Compressive Test

Figure 1. Preparation and testing

The compressive strength, f_c, density ρ, and water absorption, WA were tested using the compressive test machine (3000 kN capacity) and electronic weighing machine (60 kg capacity). The results were calculated using the ASTM International (ASTM International, 2011) standard. From the equations, W_i, W_s, and W_d represents the weight of the immersed, saturated, and oven-dry specimens, respectively.

Table 4. Allowable size for bricks

Size (mm)	Dimension of 1 brick	
	Minimum (mm)	Maximum (mm)
215.0	211.8	218.1
102.5	100.6	104.3
65.0	63.1	66.8

3. RESULT AND DISCUSSION

3.1. TEST RESULTS

Table 5 summarizes the specimen results. The results of compressive strength, density, and water absorption on day 28 were between 3.20 $\mathrm{N/mm^2}$ to 11.90 $\mathrm{N/mm^2}$, 1566.43 $\mathrm{kg/m^3}$ to 2052.45 $\mathrm{kg/m^3}$, and 17.23% to 20.96%, respectively.

The mixes were evaluated according to the following criteria:

(a) The brick can sustain loads and self-weight. Hence, compressive strength should be at least equal to 5 $\mathrm{N/mm^2}$, as stated by BS EN 771-5: 2011 (British Standard Institution, 2011).

(b) It is preferable to use lightweight brick. Therefore, the density should not exceed 1680 $\mathrm{kg/m^3}$ as stated by ASTM International (2012).

(c) Good bonding can be archived if optimum moisture is extracted from the mortar plaster. Water absorption should be lower than 20%, as stated by the Bureau of Indian Standards (Bureau of Indian Standards, 1992).

From **Table 5**, it can be observed that:

(a) 70% of the specimens achieved 5 $\mathrm{N/mm^2}$as specified by BS 3921. The specimens failed to meet 5 $\mathrm{N/mm^2}$ as the substitution of TW reached 10%.

(b) All the specimens were considered lightweight with densities less than 1680 $\mathrm{kg/m^3}$.

(c) Most of the specimens (70%) met the requirement of water absorption below 20%.

(d) Specimens S1, S2, S3, and S4 reached the industry standard regarding compressive strength, density, and water absorption.

Table 5. Test results of specimens

Specimen	Results				Evaluation criteria		
	Compressive strength, f_c ($\mathrm{N/mm^2}$)		Density, ρ ($\mathrm{kg/m^3}$)	Water absorption, WA (%)	Compressive strength, f_c ($\mathrm{N/mm^2}$)	Density, ρ ($\mathrm{kg/m^3}$)	Water absorption, WA (%)
	Day 7	Day 28	Day 28	Day 28	$f_c \geq 5\ \mathrm{N/mm^2}$	$\rho \leq 1690\ \mathrm{kg/m^3}$	$WA \leq 20\%$
C1	8.22	11.90	2052.45	17.91	√	X	√
S1	6.33	9.80	1671.33	17.82	√	√	√
S2	5.30	8.27	1664.34	17.23	√	√	√
S3	4.57	7.10	1636.36	16.67	√	√	√
S4	4.60	7.27	1629.37	19.31	√	√	√
S5	3.30	5.33	1615.38	19.05	√	√	√
S6	2.87	4.57	1608.39	18.26	X	√	√
S7	3.27	5.23	1594.41	20.96	√	√	X
S8	2.23	3.70	1576.92	20.62	X	√	X
S9	1.93	3.20	1566.43	20.04	X	√	X

3.2. COMPRESSIVE STRENGTH

The cement bricks show an increase in compressive strength by age due to the cementitious mix. They achieved about 60% on day 7 of full strength, f_c.

TW influences the compressive strength of the specimens. As shown in **Figure 2**, the compressive strength decreases as the percentage of TW increases. This is due to TW's porosity and coarser particle sizes, which could reduce the strength.

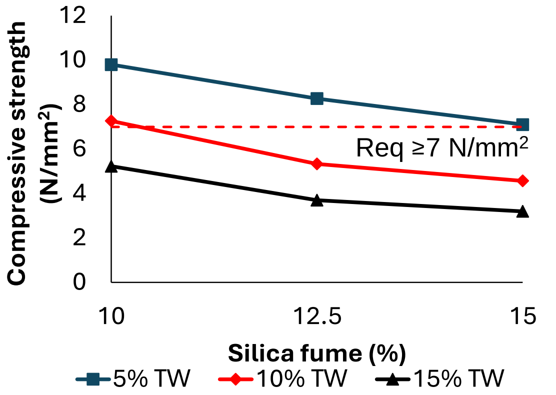


Figure 2. Compressive strength of specimens

However, the loss caused by TW can be compensated by SF, as the substitution of SF improves the compressive strength of the cement brick, thus making it harder (Lim et al., 2022; Hoque et al., 2014). However, an excessive amount of SF (more than 10%) in the cement brick decreased the compressive strength due to the high-water requirement of SF for small particles.

3.3. DENSITY

The density decreased as TW increased (**Figure 3**). Specimen S1 had the highest density of 1671.33 kg/m^3. Meanwhile, specimen S3 had the lowest density of 1636.36 kg/m^3 when 10% SF was mixed. These results show 18.57% and 20.27% lower than the control brick. Such observation aligned with Djamaluddin's analysis (Djamaluddin et al., 2020). This was due to the characteristic of TW, which has a higher porosity content and traps the water bubble inside the cement brick.

SF theoretically does not affect the density of the mixture as long as the mixture is compacted uniformly, according to ACI Committee 234 (2006). The decrease in density was probably caused by significant SF water absorption, which led to a decrease in free water in the mixture (Ling *et al.*, 2019). This would result in a cement mixture with low compatibility and compaction issues.

From the results, all the cement bricks had a density lower than 1680 kg/m^3, considered lightweight bricks (**Table 5**). Thus, the bricks are preferred due to their lower self-weight, which makes them easy to handle during construction.

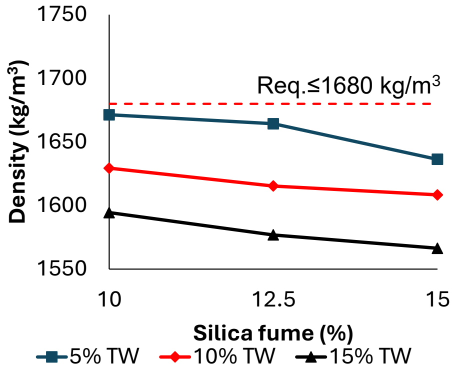


Figure 3. Density of specimens

3.4. WATER ABSORPTION

The water absorption of specimens increased as the TW increased (**Figure 4**). This was probably due to the increased porous structure, thus creating more gaps within the cement brick, offering high water absorption (Ismail, 2006).

For the SF, the water absorption decreased as the SF increased. This could be due to the addition of silica fume in the cement brick, reducing the pores' size and connectivity and thus limiting water ingress (Almeida et al., 2018).

Based on **Table 5**, 70% of the specimens achieved the minimum requirement for water absorption, which was less than 20.0% (British Standard Institution, 1985). Such specimens can prevent excessive water extraction from mortar during the wall-laying. In addition, the specimens (with water absorption less than 20.0%) could prevent fungal growth and long-term degradation.

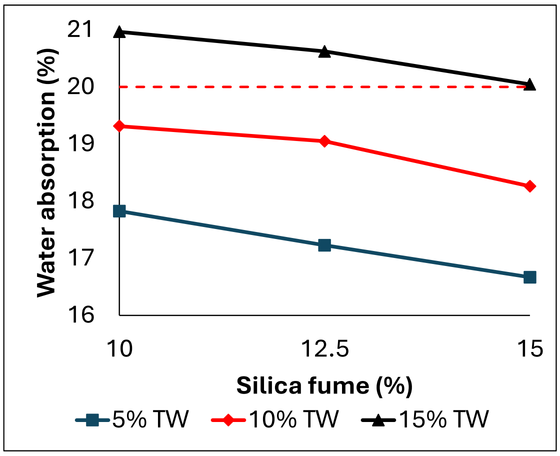


Figure 4. Water absorption of specimens

3.5. STRENGTH TO WEIGHT RATIO

The overall performance of the cement brick is evaluated using the effective strength-to-weight ratio (*s-w* ratio) equation (Lim & Ling, 2019). *S* and *W* indicate the strength and weight reduction compared to the control brick. Meanwhile, W_C and W_L represent the weight of the control brick and the lightweight brick. S_C and S_L represent the strength of the control and lightweight brick.

$$s - w \text{ ratio} = \frac{100 - S}{100 - W} \quad (3)$$

where:

$$W = \frac{W_C - W_L}{W_C} \times 100\% \quad (4)$$

$$S = \frac{S_C - S_L}{S_C} \times 100\% \quad (5)$$

From **Table 6**, specimen S1 had the highest $s - w$ ratio of 1.02. Meanwhile, the other specimens were lower than 1.0, which was not recommended. Although brick (S1) might not be stronger than the control brick, the weight reduction exceeds the strength reduction. Thus, the brick (S1) was more effective than the control brick in strength-to-weight ratio.

For the application, the raw materials replaced with TW and SF must be significant, so the initiative of reducing the weight of the brick is meaningful. For that, S1 specimen replacement was acceptable.

Table 6. Specimens' details

Specimens	Reduction of strength, *S* (%)	Reduction of weight, *W* (%)	Strength to weight ratio, (*s-w* ratio)	Remark (A/NA) *1
Equation	4	5	3	-
C1	-	-	1.00	A
S1	80.74	82.35	1.02	A
S2	80.41	69.50	0.86	NA
S3	79.05	59.66	0.75	NA
S4	78.72	61.09	0.78	NA
S5	78.04	44.79	0.57	NA
S6	77.70	38.40	0.49	NA
S7	77.03	43.95	0.57	NA
S8	76.18	31.09	0.41	NA
S9	75.68	26.89	0.36	NA

Notes: *1A = Adequate ($s - w$ ratio ≥ 1.0), NA = non-adequate ($s - w$ ratio < 1.0)

4. CONCLUSION

This study was conducted to (a) investigate the physical and mechanical properties, (b) identify an optimum mix proportion, and (c) determine the suitability of brick in the construction industry. Based on the results, it was found that (a) the compressive strength decreased as the TW and SF increased, (b) the density decreased as the TW and SF increased, and (c) the water absorption increased as the TW increased. However, the water absorption decreased as SF increased. Specimen S1 (5% TW and 10% SF) fulfilled all the industry criteria. Less cement was required to obtain an equivalent performance to that of the control brick. For that, it is possible to reduce the weight of the cement brick up to 18.40% without affecting its effectiveness. This can be achieved by partially replacing sand and cement with 5% of TW and 10% of SF, respectively.

ACKNOWLEDGEMENT

This work was supported by the Research Grants of the University of Technology Sarawak, UTS/RESEARCH/1/2022/06.

SYMBOLS

f_c	Compressive strength of brick (N/mm^2)
S	Reduction of strength (%)
S_C	Strength of control brick (N)
S_L	Strength of lightweight brick (N)
$s-w$ ratio	Effective strength-to-weight ratio
W	Reduction of weight (%)
WA	Water absorption of brick (%)
W_C	Weight of control brick (kg)
W_d	Weight of the oven-dry specimen (kg)
W_i	Weight of the immersed specimen (kg)
W_L	Weight of lightweight brick (kg)
W_s	Weight of the saturated specimen (kg)
ρ	Density of brick ($\mathrm{kgm^{-3}}$)

REFERENCES

Almeida, L., Ribeiro, J., & Barbosa, V. (2018). Performance of concrete made with fine recycled concrete aggregates and silica fume in aggressive environments. *Journal of Cleaner Production*, 1(202), 530–540.

ASTM International. (2011). *Standard specification for concrete-facing brick* (ASTM C1634-11).

ASTM International. (2012). *Standard test methods for sampling and testing concrete masonry units and related units* (ASTM C140-11a).

British Standard Institution. (1985). *British Standard Specification for Clay Bricks* (BS 3921:1985).

British Standards Institution. (2011). *Specification for masonry units* (BS EN 771-5: 2011).

Bureau of Indian Standards. (1992). *Common burnt clay building bricks - Specification* (IS 1077: 1992).

Celik, M. Y., & Celik, F. (2014). Turkish tea: The only tea washed with snow that snow falls on. *International Journal of Basic and Clinical Studies*, 3(2), 1–15.

Djamaluddin, A. R., Caronge, M. A., Tjaronge, M. W., Lando, A. T., & Irmawaty, R. (2020). Evaluation of sustainable concrete paving blocks incorporating processed waste tea ash. *Case Studies in Construction Materials*, 12, 325.

Hoque, M. M., Rahman, M. M., & Islam, M. N. (2014). Study on the effect of silica fume on the properties of brick aggregate concrete. *International Journal of Engineering Research and Technology*, 3(5), 2436–2442.

Ismail, D. (2006). An investigation on the production of construction brick with processed waste tea. *Building and Environment*, 41(9), 1274–1278.

Lim, Y. T., Chong, C. H., Ling, J. H., Mohamad, M. E. B., Sia, H. T., & Leong, W. K. (2022). Experimental study of sand-cement brick with expanded polystyrene beads and silica fume as partial replacement materials. *Journal of the Civil Engineering Forum*, 9(1), 101–108.

Lim, Y. T., & Ling, J. H. (2019). Incorporating lightweight materials in reinforced concrete beams and slabs – A review. *Borneo Journal of Sciences and Technology*, 1(2), 16–26.

Ling, J. H., Lim, Y. T., Leong, W. K., Jusli, E., & Sia, H. T. (2019). Properties of cement brick with partial replacement of sand and cement with oil palm empty fruit bunches and silica fume. *Journal of the Civil Engineering Forum*, 5(3), 289–300.

Ling, J. H., Lim, Y. T., Leong, W. K., & Sia, H. T. (2021a). Effects of adding silica fume and empty fruit bunch to the mix of cement brick. *Indonesian Journal of Computing, Engineering and Design*, 3(1), 19–30.

Ling, J. H., Lim, Y. T., Leong, W. K., & Sia, H. T. (2021b). Utilization of oil palm empty fruit bunch in cement bricks. *Journal of Advanced Civil and Environmental Engineering*, 4(1), 1–10.

Mehta, A., & Ashish, D. K. (2020). Silica fume and waste glass in cement concrete production: A review. *Journal of Building Engineering*, 29, 1–18.

Ozturk, S., Sutcu, M., Erdogmus, E., & Gencel, O. (2019). Influence of tea waste concentration in the physical, mechanical and thermal properties of brick clay mixtures. *Construction and Building Materials*, 217, 592–599.

Yunus, Y. (2015, November 18). Power from dams gives a big advantage. *Borneo Post Online*. https://www.theborneopost.com/2015/11/18/power-from-dams-gives-a-big-advantage/