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Utilization of Tea Waste and Silico Manganese Slag in Cement Brick

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ABSTRACT

Bricks are commonly utilized construction materials composed of sand, cement, and water in standardized ratios. Such demand of construction materials could result in the exhaustion of natural resources. In order to tackle this problem, researchers are investigating the utilization of alternate substances including tea waste and silico manganese slag as partial replacement for sand and cement respectively in bricks. The study utilized a sand/cement ratio of 1:2.5 and a water/cement ratio of 0.5, along with the inclusion of 5-15% tea waste and 10-20% silico manganese slag in the mix percentage. The experimental findings demonstrated that by substituting tea waste and silico manganese slag into the cement brick, the brick exhibited sufficient compressive strength and water absorption properties, satisfying the minimum masonry unit requirements specified in the British Standard of 1985. Furthermore, the density of the cement brick with tea waste and silico manganese slag was found to be lower than the solid bricks, classifying it as a lightweight brick. All of the cement bricks containing tea waste and silico manganese slag met the criterion for the effective strength to weight ratio, except for the bricks made with 15% tea waste and 10% silico manganese slag. Based on the results, it was determined that the proposed mix proportion for the cement brick was the brick consists of 15% tea waste and 20% silico manganese slag. Such brick with the highest effective strength to weight ratio of 1.16 was suitable to be used in the construction industry.

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1. INTRODUCTION

Bricks, a widely used building material, have evolved over time and become a crucial component in civil engineering structures (Murmu and Patel, 2018). The construction industry uses various brick types, including cement bricks, burnt clay bricks, concrete bricks, fly ash clay bricks, sand lime bricks, and engineering bricks, to construct various structures (Raju and Ravindhar, 2020).

Malaysia, a developing country, faces a growing demand for cement bricks, which could lead to a potential resource shortage. To address this issue, research has been conducted to explore alternative materials as partial replacements in cement bricks. Waste materials can be utilized in recycling and reusing in the construction industry. A wide range of waste materials has been studied, including tea waste, silico manganese slag, silica fume, concrete waste, waste glass, expanded polystyrene beads, oil palm empty fruit bunches fibres and reclaimed paving materials (Ling et al., 2019; Priyadarshini, Giri and Patnaik, 2021; Ling et al., 2021a,b; Lim et al., 2023; Hussien et al. 2024).

Tea waste, produced by steeping young Camellia sinensis leaf buds, has become a primary concern due to its longer decomposition time. Additionally, silico manganese slag, produced as a byproduct of making silico-manganese alloy, contributes to environmental pollution due to its lack of established recycling mechanisms (Zhou et al., 2021; Cota et al., 2023).

This research aims to use tea waste and silico manganese slag as partial replacements for sand and cement, reducing compressive strength and density (Ibrahim et al., 2023). The loss of compressive strength due to tea waste can be compensated using silico manganese slag, resulting in a lighter and more compressive-strengthening cement brick that meets industry requirements.

The hypothesis can be verified by conducting experiments to investigate the properties of the cement brick. With the successful incorporation of tea waste and silico manganese slag into cement bricks, it may be possible to (a) lower the amount of sand and cement utilised in the cement brick and (b) solve the global issue regarding the disposal problems of tea waste and silico manganese slag.

2. MATERIALS AND PROCEDURES

2.1. MATERIALS

Tables 1 and **2** present an overview of the physical properties and chemical composition of the materials, respectively. The data indicate that the density of tea waste (196 kg/m³) and silico manganese slag (610 kg/m³) is significantly lower than that of sand (1284 kg/m³). This lower density suggests that incorporating these materials could lead to the production of lightweight cement bricks, potentially enhancing their effectiveness.

Table 1. Physical Properties of Materials

Materials	Descriptions
Fine aggregates	Sand with a density of 1284 kg/m^3 90% passing through a 600 µm sieve
Ordinary portland cement	Size within 7 µm to 200 µm Density of 1222 kg/m^3 Strength class 42.5 N/mm^2 (complied with MS EN 197-1:2014)
Tea waste	Size can pass through the 5 mm sieve Density of 196 kg/m^3
Silico manganese slag	Size can pass through the 5 mm sieve Density of 610 kg/m^3

Silico manganese slag shares similarities with cement in its chemical composition, containing compounds such as silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), iron (III) oxide (Fe_2O_3), magnesium oxide (MgO), and calcium oxide (CaO). These compounds can function as binding agents in construction materials, thereby enhancing their compressive strength.

Table 2. Chemical Composition of Materials

Composition	Cement (%)	Tea Waste (%)	Silico Manganese Slag (%)
SiO_2	19.34	-	32.00
Al_2O_3	5.20	-	25.87
Fe_2O_3	3.41	-	1.54
CaO	64.75	-	18.17
MgO	1.44	-	4.11
SiO_3	2.85	-	-
K_2O	0.47	-	-
Na_2O	0.10	-	-
MnO	-	-	10.95
C	-	49.34	-
O	-	39.60	-
N	-	7.89	-
Ca	-	1.31	-
Loss on ignition	3.42	-	-

2.2. MIX PROPORTION

This study examined the use of tea waste and silico manganese slag in cement bricks, replacing sand and cement in a mixture. The sand/cement ratio was established, and 120 cement brick samples were tested for dimensions, compressive strength, density, and water absorption.

In this study, a water/cement ratio of 0.5 and a sand/cement ratio of 1:2.5 were used. **Table 3** lists the number of specimens needed for each mixing proportion.

2.3. TEST PROCEDURES

The specimens with the size of 215 mm x 102.5 mm x 65 mm were produced using the brick mould depicted in **Figure 1**. The mixture underwent 25 cycles of compaction, with each cycle consisting of 3 layers using a rod compactor. The specimens were removed from the moulds after one day of being cast and left to cure for days 3, 7, and 28.

Table 3. Specimens Details

Mix	Tea Waste (%)	Silico Manganese Slag (%)	Compressive Strength (N/mm^2)			Dimension (mm), Density (kg/m^3) and Water Absorption (%)	Total
			Day 3	Day 7	Day 28		
Solid Brick	-	-	3	3	3	3	12
S1	5	10	3	3	3	3	12
S2	5	15	3	3	3	3	12
S3	5	20	3	3	3	3	12
S4	10	10	3	3	3	3	12
S5	10	15	3	3	3	3	12
S6	10	20	3	3	3	3	12
S7	15	10	3	3	3	3	12
S8	15	15	3	3	3	3	12
S9	15	20	3	3	3	3	12
						Total brick	120

The specimens' dimensions were acceptable as their size was within the specified limits outlined in BS 3921:1985 (1985), as indicated in **Table 4**. The ELE International compression machine with a capacity of 3000 kN and an electronic balance with a capacity of 30 kg were used to test the compressive strength, density (ρ), and water absorption (WA). The calculations were performed using equations from ASTM C140-11a AS, 2012.

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

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

Where: W_i = weight of the immersed, kg
W_s = weight of the saturated, kg
W_d = weight of the oven-dry, kg

(a) Mixing Material (b) Compacted Layer (c) Demould (d) Curing Brick
(e) Dimension Test (f) Weighing Brick (g) Dry the Specimen (h) Compressive Test

Figure 1. Preparation and Testing

Table 4. Limit Size of Bricks

Work 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

Table 5 presents a summary of the results obtained from the specimens. The compressive strength, density, and water absorption on day 28 range from 7.6 N/mm^2 to 10.3 N/mm^2, 1526.25 kg/m^3 to 2022.67 kg/m^3, and 16.88% to 19.98%, respectively.

The evaluation of cement bricks were done according to the performance criteria outlined below:

(a) **Compressive Strength (British Standards Institution, 1985)**: The compressive strength of a cement brick is important in assessing its ability to withstand external loads. As specified in BS 3921:1985, bricks must have a minimum compressive strength of 7 N/mm^2. This value serves as a vital benchmark for evaluating their structural reliability.

(b) **Density (ASTM C140-11a AS, 2012)**: Lightweight bricks are preferred in construction due to their ease of handling and reduced transportation costs. According to ASTM guidelines, a brick is classified as lightweight if its density does not exceed 1680 kg/m^3.

(c) **Water Absorption (ASTM C140-11a AS, 2012)**: Excessive water absorption in cement bricks can lead to reduced durability and weaker bonding with mortar or plaster. To maintain structural integrity and ensure longevity, ASTM standards specify that brick water absorption should not exceed 20%.

The effective strength-to-weight ratio (*s-w* ratio) must be at least 1, as recommended by Lim and Ling (2019), to ensure better performance compared to control bricks.

From the result, it can be observed that:

(a) All tested specimens satisfied the minimum compressive strength requirement of 7 N/mm² as specified by BS 3921:1985. However, as the proportion of tea waste increased, the compressive strength of the cement bricks decreased. Conversely, the compressive strength improved with a higher replacement of silico manganese slag.

(b) All specimens were classified as lightweight, with densities below the ASTM International threshold of 1680 kg/m³. This compliance highlights benefits such as reduced dead loads of cement bricks.

(c) The water absorption levels of all specimens remained below the 20% limit set by ASTM International. Maintaining low moisture absorption is important for ensuring the long-term durability of cement bricks.

(d) All specimens met the essential criteria for compressive strength, density, and water absorption.

Table 5. Test Results of Specimens

Specimen	Results*[1]					Evaluation criteria		
	Compressive strength (N/mm^2)			Density (kg/m^3)	Water absorption (%)	Compressive strength (N/mm^2)	Density (kg/m^3)	Water absorption, (%)
	Day 3	Day 7	Day 28	Day 28	Day 28	$\geq 7\ N/mm^2$	$\leq 1680\ kg/m^3$	$\leq 20\%$
Solid brick	5.6	8.5	9.4	2022.67	16.88	√	X	√
S1	5.3	6.9	9.2	1568.43	16.93	√	√	√
S2	4.5	5.7	10.1	1583.38	16.68	√	√	√
S3	5.2	8.1	10.3	1595.92	16.82	√	√	√
S4	4.8	6.3	8.2	1538.35	18.86	√	√	√
S5	5.2	5.6	8.9	1552.75	17.31	√	√	√
S6	5.2	6.4	9.4	1576.09	17.05	√	√	√
S7	5.5	7.4	7.6	1526.25	19.98	√	√	√
S8	5.4	4.2	8.2	1541.38	19.27	√	√	√
S9	5.3	5.9	9.7	1557.46	19.02	√	√	√

Note: *[1]Dimensions of the cement bricks obtained were taking the average value of three specimens.

3.1. COMPRESSIVE STRENGTH

The experiment demonstrated that replacing sand with tea waste in cement bricks caused a reduction in compressive strength up to 19.15%, as the proportion of tea waste increased (**Figure 2**). This reduction aligns with previous studies and is attributed to the higher porosity and larger particle size of tea waste compared to sand (Ozturk et al., 2019; Djamaluddin et al., 2020). Despite this decrease, all cement bricks maintained compressive strengths above 7.0 N/mm², meeting the required standards for construction.

Conversely, the partial replacement of cement with silico manganese slag resulted in a significant improvement in compressive strength as the proportion of silico manganese slag increased (**Figure 3**). This improvement is attributed to the smaller particle size and lower porosity of silico manganese slag compared to cement (Srikavya, Rajesh, and Harshavardhan, 2021).

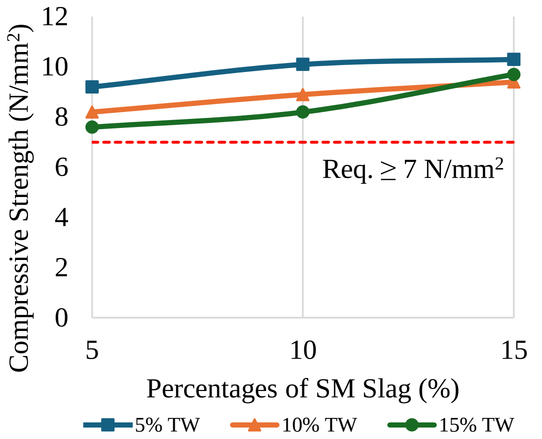

Figure 2. Compressive Strength of Specimens (TW)

Note: *[1]Tea Waste = TW, Silico Manganese Slag = SM Slag

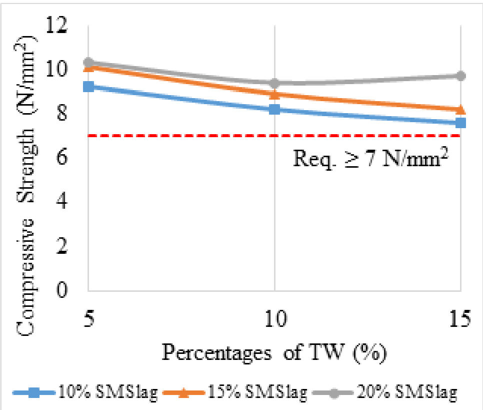

Figure 3. Compressive Strength of Specimens (SM Slag)

Note: *[1]Tea Waste = TW, Silico Manganese Slag = SM Slag

3.2. DENSITY

Specimen S3 has the highest density, measured at 1595.92 kg/m³, while specimen S7 has the lowest density at 1526.25 kg/m³. Compared to a solid brick, these densities represent reductions of 21.1% and 24.54%, respectively. This indicates that increasing the amount of tea waste results in lower brick density (**Figure 4**), consistent with findings by Caronge et al. (2022), which highlight the lower density of tea waste compared to sand.

As shown in **Table 5**, all cement bricks have densities below 1680 kg/m³, classifying them as lightweight. This lightweight characteristic can reduce construction costs by requiring less structural reinforcement, making it a practical choice for various building applications.

Figure 5 illustrates that higher percentages of silico manganese slag led to higher density. This trend is consistent with the research by Allahverdi and Ahmadnezhad (2014), which confirms that incorporating silico manganese slag increases the density of bricks. This can be occurred due to the finely ground silico manganese slag acts as a micro-filler, thus providing lower porosity and eventually increasing the density of cement bricks.

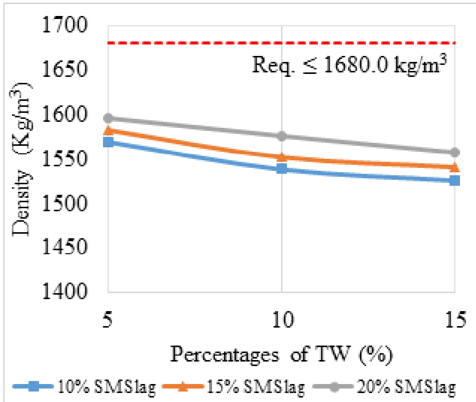

Figure 4. Density of Specimens (TW)

Note: *[1]Tea Waste = TW, Silico Manganese Slag = SM Slag

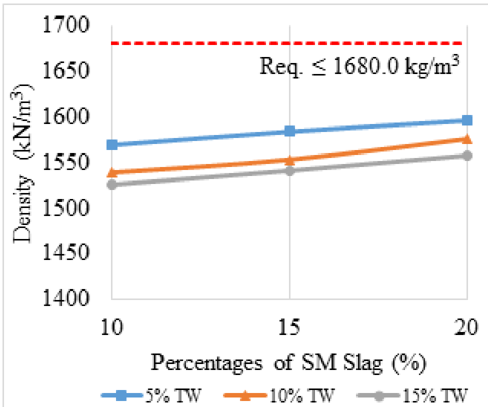

Figure 5. Density of Specimens (SM Slag)

Note: *[1]Tea Waste = TW, Silico Manganese Slag = SM Slag

3.3. WATER ABSORPTION

The influence of tea waste and silico manganese slag on the water absorption of bricks can be summarized as follows:

(a) The addition of tea waste and silico manganese slag significantly affects the water absorption properties of bricks.

(b) The water absorption rate increases as the proportion of tea waste used to replace sand rises.

(c) In contrast, increasing the percentage of silico manganese slag as a cement replacement reduces water absorption in the bricks.

(d) For instance, specimen S2 exhibited the lowest water absorption rate at 16.68%, while specimen S7 showed the highest rate at 19.98%. However, this is still acceptable as it is below 20%.

The results depicted in **Figure 6** align with previous research by Rasool, Abdulkarem, and Jasem (2022), which found that higher percentages of tea waste led to increased water absorption due to its porous structure (Ismail, 2006). This occurs because greater amounts of tea waste create more porous voids, capable of retaining larger volumes of water.

Conversely, **Figure 7** indicates that increasing the percentage of silico manganese slag decreases water absorption in the cement bricks. This is attributed to the lower porosity of silico manganese slag, which reduces pore size and connectivity. These findings are supported by the analysis conducted by Ting et al. (2020).

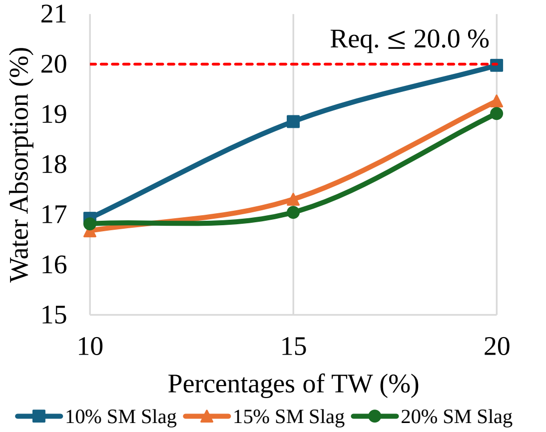

Figure 6. Water Absorption of Specimens (TW)

Note: *[1]Tea Waste = TW, Silico Manganese Slag = SM Slag

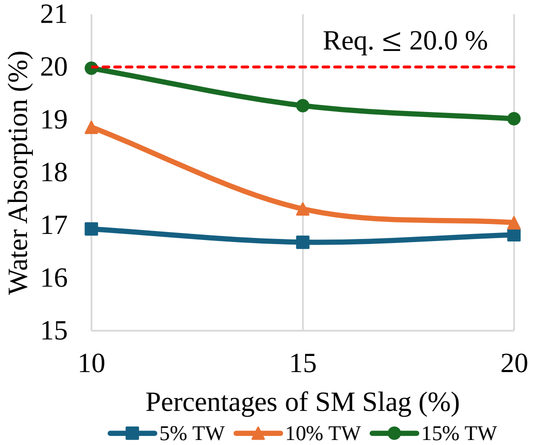

Figure 7. Water Absorption of Specimens (SM Slag)

Note: *[1]Tea Waste = TW, Silico Manganese Slag = SM Slag

3.4. STRENGTH TO WEIGHT RATIO

The performance of the cement bricks was evaluated using the effective strength-to-weight ratio (*s-w* ratio) equation proposed by Lim and Ling in 2019 (Ling et al., 2019). An efficient lightweight brick should focus on reducing weight while maintaining adequate strength, ideally achieving an *s-w* ratio greater than 1. The *s-w* ratio was calculated using Equation 3:

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

where:

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

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

W_C = weight of solid brick

W_L = weight of lightweight brick

S_C = ultimate strength of solid brick

S_L = ultimate strength of lightweight brick

Table 6 shows that S9 demonstrated the highest effective strength-to-weight ratio of 1.16. Notably, only one brick, S7, had a ratio below 1.0. Therefore, the brick containing 15% tea waste and 20% silico manganese slag was identified as the best balance between compressive strength and density compared to all other compositions.

Table 6. Strength to Weight Ratio of Specimens

Specimens	Weight Reduction /Increment *2	Strength Reduction/ Increment *2	Strength to Weight Ratio, (*s-w* ratio)	Remarks (A/NA)*1
Equation	5	6	4	-
Solid Brick	-	-	1.00	A
S1	11.33	2.13	1.10	A
S2	4.69	-7.45	1.13	A
S3	3.91	-9.57	1.14	A
S4	14.84	12.77	1.02	A
S5	8.20	5.32	1.03	A
S6	7.42	0	1.08	A
S7	15.63	19.15	0.96	NA
S8	13.28	12.77	1.01	A
S9	10.94	-3.19	1.16	A

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

*2 Positive values indicate the weight and strength reduction meanwhile negative show the increase of the weight and strength.

4. CONCLUSIONS

This study investigated the use of tea waste and silico manganese slag as partial replacements for cement and sand in cement brick production. The findings revealed that increasing the proportion of tea waste decreased compressive strength and density while raising water absorption, whereas higher proportions of silico manganese slag increased compressive strength and density while reducing water absorption. The proposed mix, comprising 15% tea waste and 20% silico manganese slag, met all the requirements for lightweight bricks, offering an innovative approach to eco-friendly construction. Although these cement bricks exhibited lower compressive strength compared to solid bricks, they were classified as lightweight due to their reduced density and were deemed suitable for construction purposes. This sustainable method not only facilitates easier handling of lightweight bricks but also promotes environmental conservation by reducing dependence on primary resources.

DISCLAIMER

The authors declare no conflict of interest.

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SYMBOLS

S	Reduction of strength (%)
S_C	Cement brick strength (N)
S_S	Solid brick strength (N)
s-w ratio	Effective strength to weight ratio
W	Reduction of weight (%)
WA	Water absorption of brick (%)
W_C	Cement brick weight (kg)
W_d	Oven-dry weight (kg)
W_i	Immersed weight (kg)
W_S	Solid brick weight (kg)
W_s	Saturated weight (kg)
ρ	Density of brick ($\mathrm{kgm^{-3}}$)

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