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Compressive Strength and Water Absorption of Sand Cement Brick that Incorporated with Construction Tiles Waste

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Abstract: Ceramic Tiles Waste (CTW) is one of the major sources of construction and demolition (C&D). Recycling the C&D waste is one of the most effective ways to develop sustainable building elements. In this study, the CTW were used as a partial sand replacement in sand cement brick. The percentages replacement of CTW are 0%, 10%, 20%, 30%, 40% and 50% by mass of the sand with mix design ratio of 1:3 and 0.6 water cement ratio. All the bricks were curing up to 90 days. The density, compressive strength and water absorption of sand cement bricks were also determined for its mechanical and durability performance. The experimental results reveal that the optimum replacement of CTW in sand cement brick is in range of 10% to 40% that give a good performance in compressive strength. The compressive strength of sand cement bricks increases in range of 10.17% up to 30.82% for each stage of curing days from 7 days up to 90 days. Meanwhile, the percentage of water absorption of sand cement bricks at 28 days up to 90 days of curing are below 12% as per stated in ASTM C90.

Keywords: Sand cement brick, CTW, specific gravity, density, particle size, water absorption, compressive strength, durability

1. Introduction

The construction industry is crucial to any country`s economy and economic implementation in developing nations. The most significant component of building quality improvement is to enhance the accuracy of measurements of building items and concrete structures. Meanwhile, bricks are a common and vital sustainable material that is exploited in a variety of construction developments. There are two common bricks used in the construction of houses, buildings, and other structures such as clay brick and sand cement brick. The brick is well known as sand-cement brick because of the highly constituent of cement, sand and water which easily to produce on site by molding, pressing and drying process. The sand cement bricks are convenient, lower expensive, provide less maintenance and abundant (Sani & Muftah, 2012). Due to massive brick plants, natural resources are extracted from streambeds and valleys to supply the brick manufacturing, keeping mining regions un-reclaimed. Environmental destruction occurs because of such mining activities, including air pollution that persists after the mines halt operations, leaving scars on the terrain (Shakir & Mohammed, 2013).

Apparently, infrastructure and innovation funding are among the 17 Global Targets that dominate the Sustainable Development Agenda for 2030. The targets are mainly to build quality, effective, sustainable and scalable infrastructure

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to support economic growth and human well-being, including regional and transboundary infrastructure, with an emphasis on affordable and equal access for all. Recycling of waste materials as the replacement of natural sources is obviously related towards the 9th goal of Sustainable Development Agenda 2030. Green concrete supports the use of waste resources and unordinary recyclable materials in concrete in a sustainable and innovative manner. It has several environmental, technological, and economic advantages, including high strength, greater durability, better workability, decreased permeability and higher acid resistance (Liew et al., 2017). The current high demand for natural resources to satisfy infrastructure demands has provided enormous prospects for the use of waste materials in the development of green building. An increase in social awareness about waste disposal, particularly waste from the building sector, which includes demolition waste, broken tiles, hygienic appliance waste and ceramic tile waste (CTW). These wastes are simply disposed of in landfills, but studies have shown that they may be utilized to produce concrete by replacing a specific amount of the building elements with ceramic waste. Consequently, the usage of ceramic waste in concrete reduces costs while simultaneously resolving disposal difficulties. In associated with environmental conservation, the use of these ceramic waste offers several benefits, such as a decrease in the use of raw materials, which leads to the improvement of natural resources (Agrawal, 2017).

A preliminary bibliometric analysis was carried out using the scientific journal repository Scopus from Elsevier. The keyword use for this preliminary research was “ceramic waste replacement”. To narrow the scope of research, specific criteria were applied such as sort out the publication in time range of year 2008 to 2022. Some of the documents were filtered according to source type, document type and English language. This search generated 161 documents. Figure 1 shows the total number of publications in time range of year 2008 to 2022 regarding to ceramic waste replacement which is related to this field of study. The highest publication in year 2021. Meanwhile in year 2022 might increase due to the period.

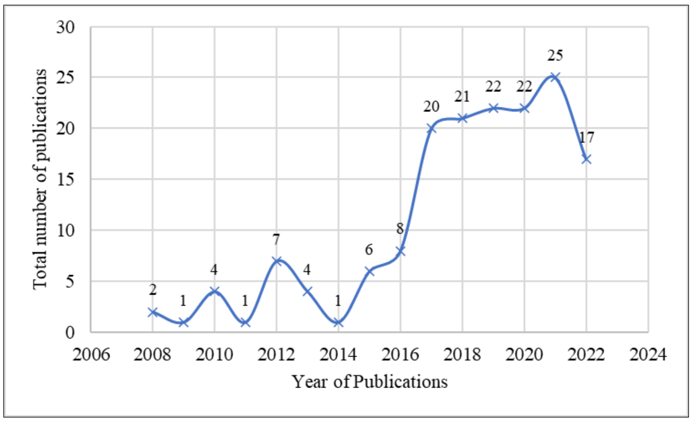

Fig. 1 - Total number of publications in time range of 2008 to 2022

Senthamarai & Manoharan found that around 30% of the ceramic industry's daily production goes to waste. Ceramic waste, on the other hand, is long-lasting, hard and extremely resistant to biological, chemical and physical degrading processes. As ceramic waste accumulates daily, the ceramic industries are under pressure to find a solution for its disposal. Nevertheless, standard crushed stone aggregate resources are rapidly diminishing, especially in some arid parts of the world. The use of inorganic industrial leftover materials in the production of concrete will result in a more sustainable concrete design and a greener environment (Senthamarai & Manoharan, 2005).

Hasanah et al. found that at 90 days of curing, water absorption rates for control specimens and ceramic mortars were 2.11% and 1.32%, respectively which ceramic mortar exhibits 37% less water absorption than control specimens. This performance was most likely caused by a decrease in mortar porosity caused by the production of calcium silicate hydrate gel from the pozzolanic reaction, which eventually plugs the pore (Hasanah et al., 2017).

Kapok et al. found that the compressive strength of the brick sample with 10% replacement of CTW exhibits the highest percentage for 7 days curing from 7.8MPa and the number had increased to 13.2 MPa at 28 days. This is exacerbated by the pozzolanic element in the ceramic that lessens the concrete density (Kapok et al., 2020). While Covarrubias et al. has revealed that the replacement of 20% of ceramic waste with 90 days of curing exhibit the highest compressive strength which is 30.54 MPa compared to the other specimens. The resistance loss characteristics associated with an increase in the content of the ceramic aggregate may be due to the physical characteristics of the ceramic aggregates, such as lower densities and higher absorption ratios than those of the natural aggregate (Covarrubias et al., 2015).

Hence this study analyzes the impact of Construction Tiles Waste (CTW) on Mechanical and Durability Properties of Sand Cement Brick.

2. Experimental Program

This study consisted of three parts of experimental program which are determination of physical properties of materials (Ordinary Portland Cement, Sand and Construction Tile Waste), sand cement brick preparation and mechanical testing of sand cement brick.

2.1 Raw Material

Materials selected for the load-bearing brick are Ordinary Portland Cement (OPC), Sand, Construction Tile Waste (CTW) and water. The OPC used in this experimental work is compliant with the Malaysian Standard Specification MS 522: Part 1:2003 while water was obtained from tap within the University Tun Hussein Onn Malaysia of Advance Material Laboratory. The fineness of OPC has been tested by particle size analyzer CILAS 1180 liquid which is 483.33 m^2/kg, greater than $225m^3/kg$ as required by MS 522: Part 1:2003.

2.1.1 Sand and Construction Tile Waste (CTW) Characterizations

Natural sand used in this study is complying to Standard Specification for Aggregate for Masonry Mortar (ASTM C144-11). While the Construction Tile Waste (CTW) were collected at the dumping site around Batu Pahat, Johor. Figure 2 shows the CTW preparation to produce an exact size of CTW which is similar to the sand. The CTW were smash by hammer into small pieces before the process of grinding. The CTW were grind by using Los Angeles Abrasion Machine. Half of the machine was fill with CTW and grind for 30 minutes for each period. The grinding time and quantity of CTW inside the machine affect the particle size of the CTW. If the machine was fully loaded with the CTW, the particle size of the CTW will become coarser. The grinding process shall follow the ASTM C 131 – 03. After the grinding process, the CTW were sieved using sieve shaker with the opening size of 0.15mm, 0.3mm, 0.6mm, 1.18mm, 2.36mm and 4.75mm.

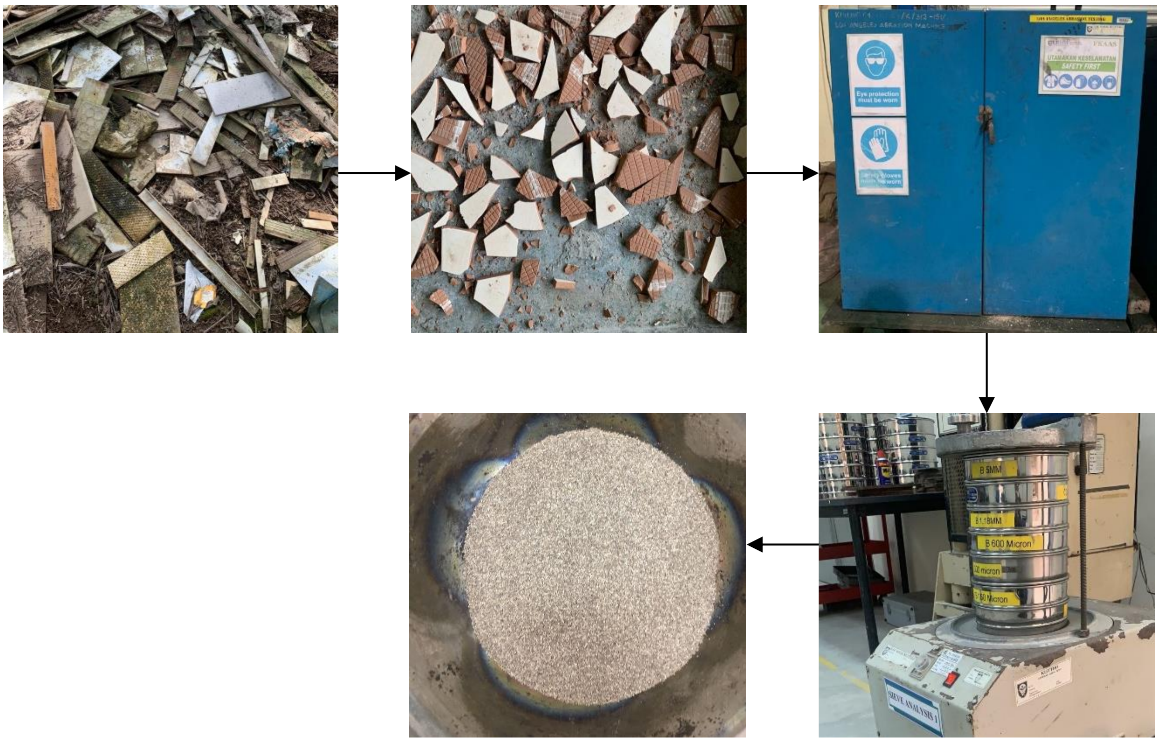

Fig. 2 - Process of grinding construction tiles waste (CTW)

Sieve analysis test results of sand and CTW were shown in Figure 3. According to Standard Specification for Aggregate for Masonry Mortar (ASTM C144-11), the sand should not have more than 50% retained between any two consecutive sieves nor more than 25% between 300µm and the 150µm sieve. The dotted lines with square and round marker show the upper limit and lower limit of the fine aggregate sieve analysis. The solid lines with diamond and triangular marker show the percentage passing of sand and CTW. The percentage passing of the sand and CTW were in range between upper and lower limit which are acceptable to be used as fine aggregate in load bearing brick. As shown in the red circle, the percentage passing of sand and CTW through opening 0.3mm are 16.5% and 20% which mean that the particle size of CTW is 17.5% smaller compared to the sand.

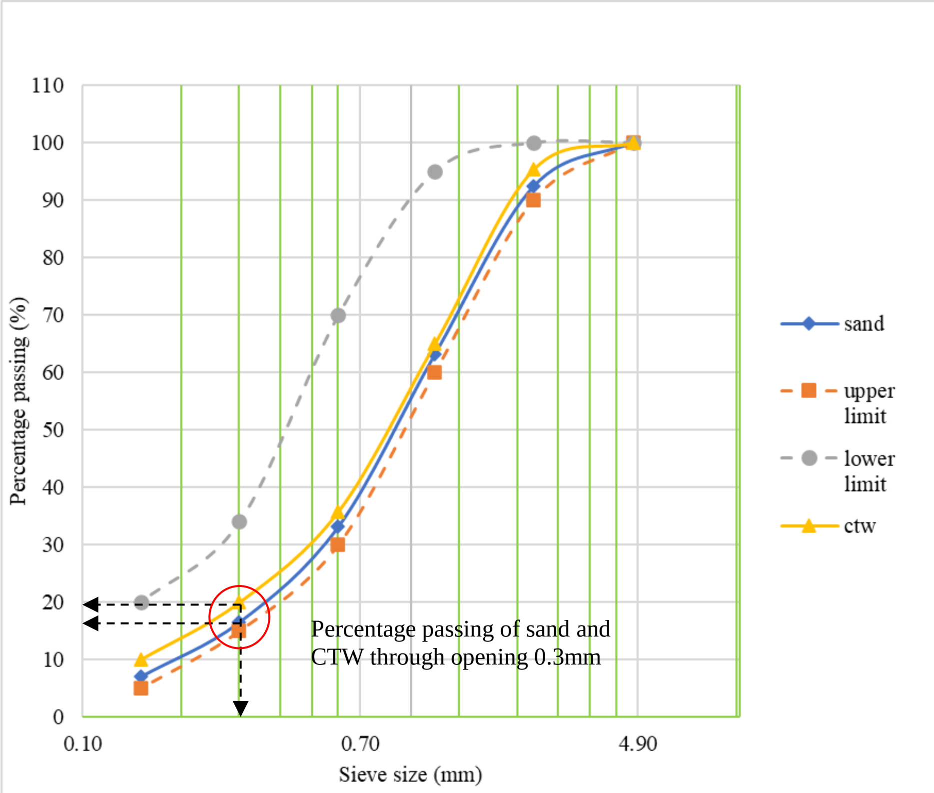

Fig. 3 - Sieve analysis result of sand and construction tiles waste (CTW)

Specific Gravity (SG) test of sand and CTW was carried out in compliance to ASTM C778 – 17 as shown in Figure 4. The SG of sand and CTW obtained from the SG test are 2.69 and 2.7 respectively. The SG of CTW is 0.37% higher than the SG of sand. The percentage different of SG between sand and CTW is below than 10% which is acceptable. Therefore, when the SG is lower, the density of materials also decreases which can minimize the weight of sample.

Fig. 4 - Specific gravity test of sand and construction tiles waste (CTW)

Water absorption test of sand and CTW was carried out in compliance BS 812: Part 2: 1995 as shown in Figure 5. The water absorption test of material is important because it determines the water demand of the material in the mortar or concrete mixture which affect their workability. Workability will affect the appearance, quality and strength of samples. Lack of water will affect the hydration process of the find aggregate and OPC to bind well. Therefore, the water absorption test of material is important to determine the water/cement ratio.

Fig. 5 - Water absorption test of sand and construction tiles waste (CTW)

Table 1 shows the water absorption result of sand and CTW. The water absorption of sand and CTW are 37% and 38% respectively. It shows that the CTW absorb 1% higher than CTW. The higher water absorption of CTW is due to surface area and compacted pore structure.

Table 1 - Water absorption results

Items	Sand	CTW
Wet (kg)	0.73	0.74
Oven dried for 24 hours (kg)	0.47	0.46
Water absorption (%)	37	38

2.2 Experimental Procedure

The experimental procedure of producing the sand cement brick is analyzing the brick mix design, sample preparation and brick testing.

2.2.1 Sand Cement Brick Mix Design

The size of sand cement brick is 215 mm x 103 mm x 65 mm in compliance to Jabatan Kerja Raya (JKR) Standard Specifications for Building Works. The mix design was calculated according to the target density of brick about 1800 kg/m3 and the design mix ratio of cement and sand is 1:3 as shown in Table 2.

Table 2 - Sand cement brick mix design

Design mix ratio	Water cement ratio (w/c)	Volume of brick (m^3)	Target density of brick (kg/m^3)
1:3	0.6	1.439×10^{-3}	1800

2.2.2 Sample Preparation

The samples preparation consisted of two groups which are control bricks and Sand+CTW bricks as shown in Table 3. The control bricks were consisted of 100% sand. The sand+CTW bricks were partially replaced sand with CTW from 10% up to 50% which are associated with CTW-10 to CTW-50. The bricks were curing at 7days up to 90 days to reveal the pozzolanic reaction occurred amongst the reactive silicon oxide (SiO_2) from lower to the higher percentage of CTW with the OPC hydration elements such as calcium hydroxide ($Ca(OH)_2$).

Table 3 - Percentage of sand replacement

Group	Sample ID	Sand (%)	CTW (%)
Control	Control	100	0

Sand+CTW	CTW-10	90	10
	CTW-20	80	20
	CTW -30	70	30
	CTW -40	60	40
	CTW -50	50	50

2.2.3 Sand Cement Brick Testing Method

There were three testing were carried out towards the bricks which are density, compressive strength and water absorption test. Table 4 shows the details information of testing method which described by the method of testing, standard, testing equipment and the expected outcomes.

Table 4 - Brick testing method

Items	Density (kg/m^3)	Compressive strength (MPa)	Water absorption (%)
Method	The density of bricks was measured by dividing the weight of brick by the volume of brick which is 1.439 x 10^{-3} m^3.	The testing machine for the compression test has been attached with spherical upper platen at the center of the upper head of the machine to ensure the gap from the plane surfaces by not more than 0.025 mm.	The bricks were immersed in water for 24 hours such that the top surfaces of the bricks are at least 150 mm below the surface of the water while 3 mm separated from the bottom of the curing tank by using wire mesh. The oven dried weight of bricks was recorded after 26 hours.
Standard	ASTM C55	ASTM C55	ASTM C140/C140M-17a
Testing Equipment			
Expected result	It is expected that the density of brick is in range of 1680 to 2000 kg/m^3 which is considered as medium to normal weight.	It is expected that the compressive strength of brick is greater than 17.3 MPa for the average of 3-unit bricks.	It is expected that the percentage of water absorption is in range of 13 to 15%.

3. Test Results and Discussion on Sand Cement Brick

The performance of sand cement brick containing different percentages of CTW was analyzed and discussed.

3.1 Density

Table 5 shows the density of control and sand+CTW bricks at 7 days up to 90 days of curing. The density of control bricks was increased at the end of 28 days and merely same until the end of 90 days which is 0.31% denser compared to control bricks at 7 days. The density of CTW-10 to CTW-50 were increased linearly since day 7 up to 90 days. The density of the CTW-10, CTW-20, CTW-30, CTW-40 and CTW-50 increased in the range of 2.45% - 8.04%, 4.18% - 7.42%, 2.26% - 7.42%, 2.45% - 6.19% and 4.17% - 6.46% respectively. The increased in the density of sand+CTW bricks is due to the higher specific gravity of the CTW. However, the percentage increment of the sand-CTW bricks compared to control bricks is still below 10% which is acceptable, and the bricks were categorized as normal weight brick.

Table 5 - Density of control and sand+CTW bricks (kg/m^3)

Curing (days)	7	28	56	90
Control	1904	1910	1910	1910
CTW-10	1952	2001	2029	2077
CTW-20	1987	2015	2056	2063
CTW-30	1948	1952	2056	2063
CTW-40	1952	1958	1973	2036
CTW-50	1987	2008	2029	2042

3.2 Compressive Strength

The compressive strength of control bricks compared to CTW-10, CTW-20, CTW-30, CTW-40 and CTW-50 bricks were illustrated in bar graph as shown in Figures 6, 7, 8, 9 and 10. The compressive strength obtained for control bricks are 36.4MPa, 43.7MPa, 44.75MPa and 51.5MPa at 7 days up to 90 days of curing. The percentage increment for each period is 16.7%, 2.4% and 13.1%.

The compressive strength of CTW-10, CTW-20, CTW-30, CTW-40 and CTW-50 bricks continuously increased along the time period up to 90 days. The compressive strength of CTW-10, CTW-20, CTW-30 and CTW-40 bricks increased in range of 15.35% - 29.45%, 25.71% - 33.03%, 21.72 – 34.48% and 6.9% - 27.26% compared to control bricks. The compressive strength of CTW-30 at 90 days of curing shows the highest increment which is 34.48% compared to control brick.

The CTW-10, CTW-20, CTW-30, CTW-40 and CTW-50 bricks are categorized as loadbearing brick due to the compressive strength greater than 13.1 MPa in compliance to ASTM C90. The bricks with all level replacement of sand with CTW show a good performance of the compressive strength. This is because of the pozzolanic reaction occurred amongst the reactive silicon oxide (SiO_2) at high percentage in CTW. Furthermore, during the hydration process of OPC, calcium hydroxide ($Ca(OH)_2$) was released. As a result, the chemical interactions between SiO_2 and ($Ca(OH)_2$) resulted in the development of CSH gels in the brick mixture. The development of extra CSH gels decreased porosity, resulting in enhanced brick strength at a prolonged curing interval.

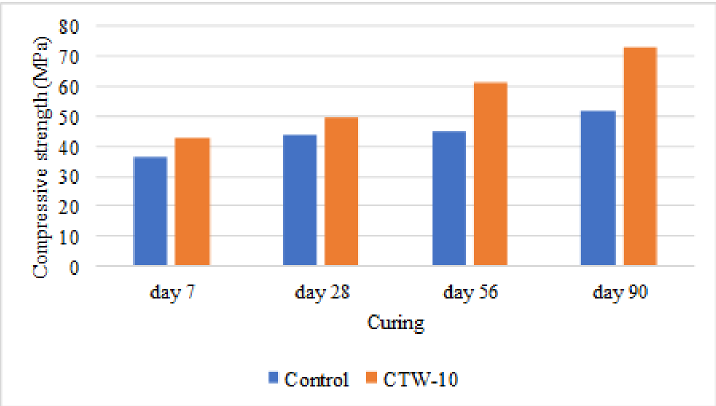

Fig. 6 - Compressive strength of control and CTW-10

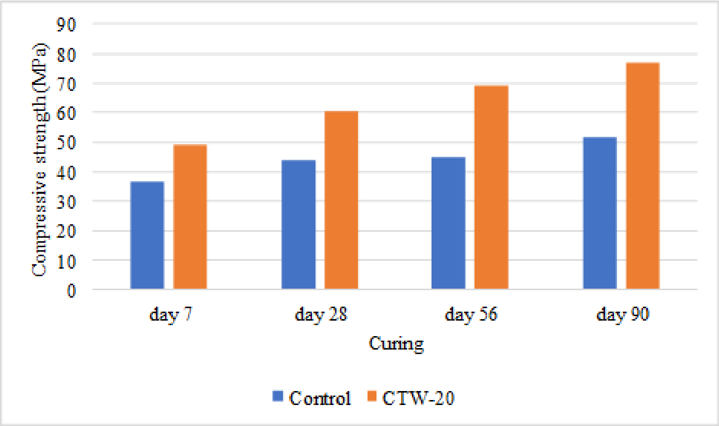

Fig. 7 - Compressive strength of control and CTW-20

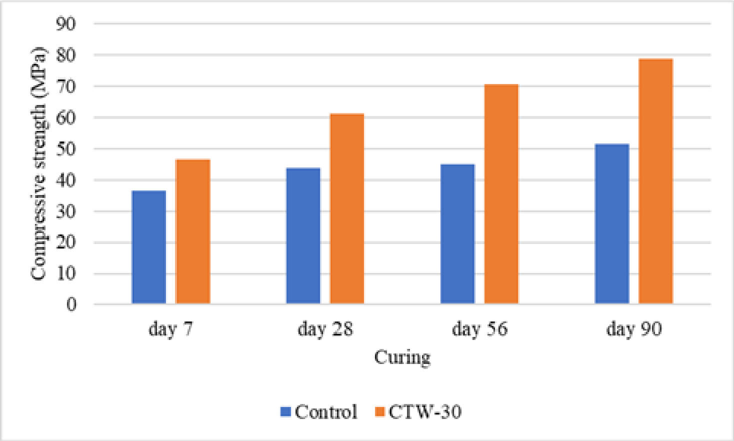

Fig. 8 - Compressive strength of control and CTW-30

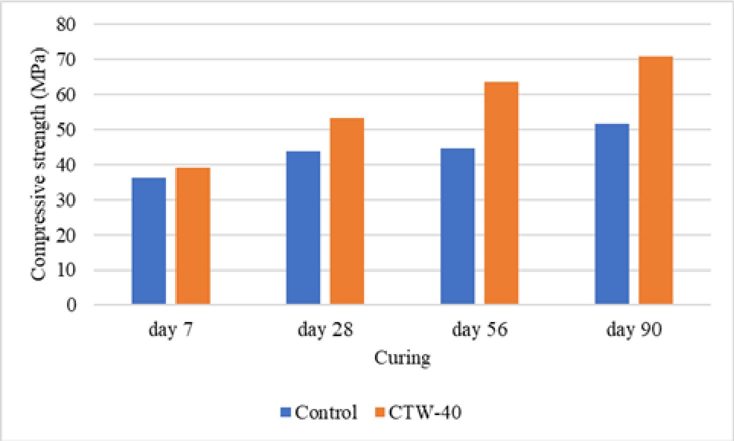

Fig. 9 - Compressive strength of control and CTW-40

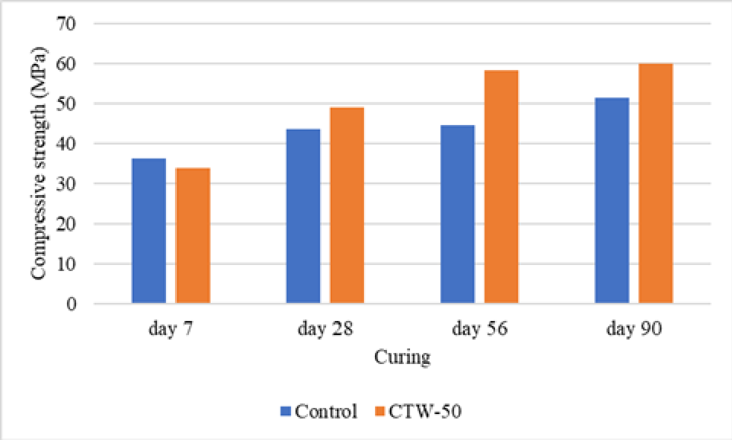

Fig. 10 - Compressive strength of control and CTW-50

3.3 Water Absorption

Figures 11, 12, 13 and 14 show the percentage of water absorption of the sand cement bricks with 0% to 50% replacement of CTW at 7, 28, 56 and 90 days of curing respectively. The water absorption of control bricks is decreased along the time range of 7 – 28 days, 28 – 56 days and 56 – 90 days which is 25.02%, 2.56% and 10.13% respectively. The red dashed line represents the percentage of water absorption of control bricks at 28 day which is 8.21% as a benchmark for the CTW-10, CTW-20, CTW-30, CTW-40 and CTW-50 bricks.

The water absorption of CTW-10, CTW-20, CTW-30 and CTW-40 bricks are lower than the red dashed line. The percentage of water absorption of CTW-10, CTW-20, CTW-30 and CTW-40 bricks are decreased in range of 9.01% - 53.11%, 19.12% - 65.65%, 0.97% - 77.71% and 26.31% - 85.36%. The minimum percentage of water absorption of CTW-40 at 90 days was decreased 85.36% from the control brick at 28 days. While the CTW-50 bricks resulted in higher water absorption at the end of 7 and 28 days which are 49.21% and 16.2% greater than the red dashed lines. However, the percentage of water absorption of CTW-50 bricks at the end of 56 and 90 days were decreased at 70.16% and 84.9% below the red dashed lines. According to the ASTM C90, the maximum water absorption allowed for average of 3-unit bricks is 13%. Therefore, the CTW-10, CTW-20, CTW-30, CTW-40 and CTW-50 bricks are acceptable to be used as building elements.

It can be observed that, the longer the curing period, the lower the percentage of water absorption at high level replacement of CTW. It can be due to the reduction in the pore radius of brick mixture with creations of CSH gels by the pozzolanic reaction that fill the voids. The fineness of the particles also plays important role as the finer particles help to fill in the voids resulted in lower water absorption.

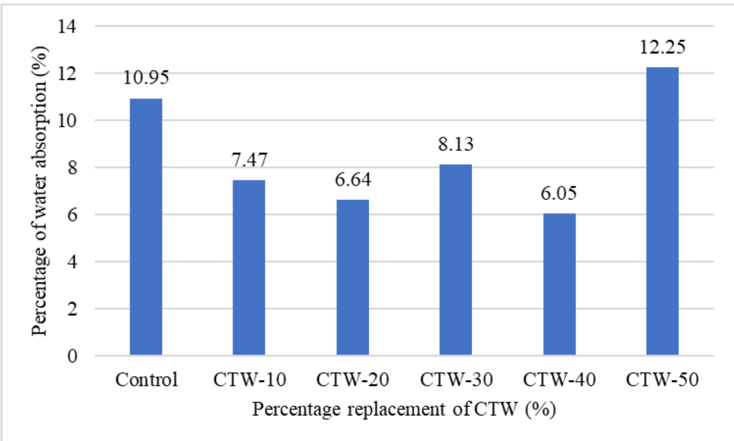

Fig. 11 - Percentage water absorption of control at 7 days of curing

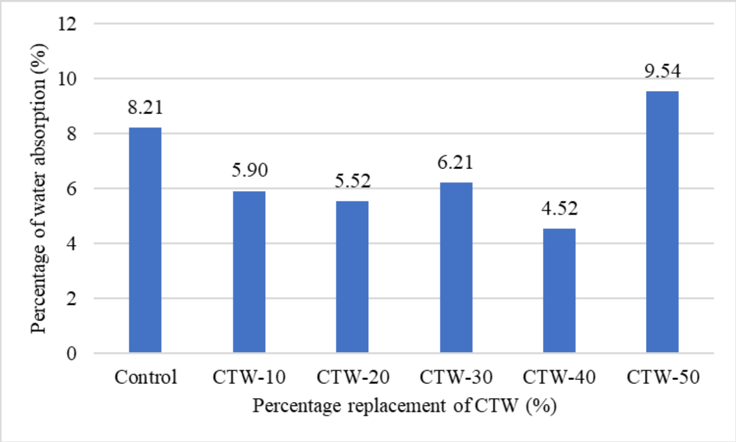

Fig. 12 - Percentage water absorption of control at 28 days of curing

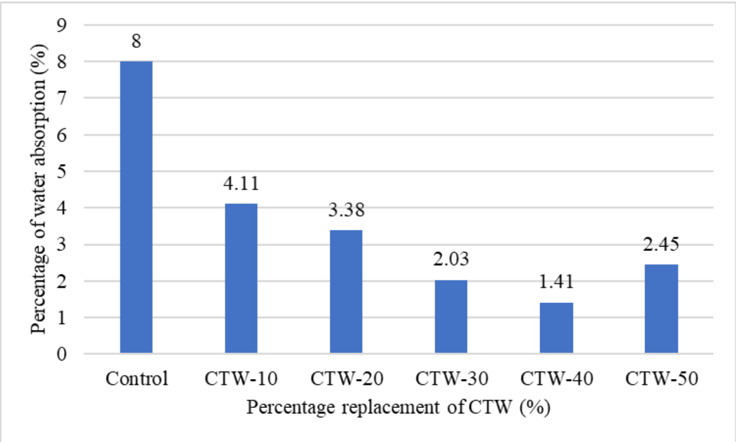

Fig. 13 - Percentage water absorption of control at 56 days of curing

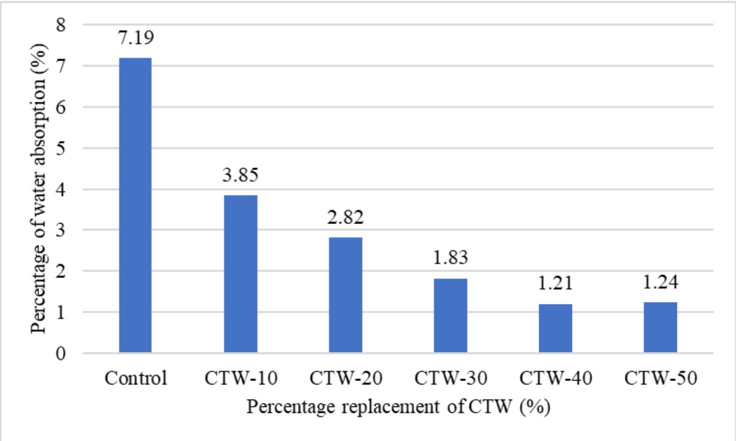

Fig. 14 - Percentage water absorption of control at 90 days of curing

4. Conclusion

- According to the physical testing of sand and CTW, it indicates that CTW is suitable material replacement of sand in sand cement brick. The percentage difference of specific gravity of sand and CTW is only 0.37% which 2.69 and 2.7. Apart from that, the particle size of CTW is 17.5% finer compared to the particle size of sand. The fineness of particle size can fill in the void in the brick mixture as resulted in high strength.
- The density of control brick is in range 1904-1910kg/m^3 while the density of sand+CTW bricks fall in range of 1948-2077kg/m^3. The bricks were considered as the normal weight brick which is applicable to be used as the construction parts of buildings.
- The CTW-10 up to CTW-50 bricks show the good performance in compressive strength in each curing time. It can be observed that the compressive strength of the CTW-10 up to CTW-50 bricks at later age gain higher strength due to the pozzolanic reaction made up of reactive silicon oxide (SiO_2) at high percentage in CTW. The CSH gels appeared amongst the calcium hydroxide ($Ca(OH)_2$) released from the hydration of OPC.
- In addition, the percentage absorption of water for all unit bricks of CTW-10 up to CTW-50 is below 13% in compliance with ASTM C90. Due to finer particle size of CTW, it tends to absorb less water which significantly improve the workability and contributes considerably to the higher durability of sand cement brick.
- Therefore, the optimum percentage replacement of sand with CTW are 10% to 40%.

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