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STRENGTH, WATER ABSORPTION AND THERMAL COMFORT OF MORTAR BRICKS CONTAINING CRUSHED CERAMIC WASTE

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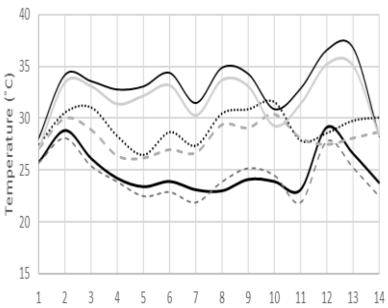
Graphical abstract



Abstract

This present study investigated the crushed ceramic waste utilisation as sand replacement in solid mortar bricks. The percentage of crushed ceramic waste used were 0% (CW0), 10% (CW10), 20% (CW20) and 30% (CW30) from the total weight of sand. The dimension prescribed of mortar bricks are 215 mm x 102.5 mm x 65 mm as followed accordance to MS 2281:2010 and BS EN 771-1:2011+A1:2015. Four (4) tests were conducted on mortar bricks namely crushing strength, water absorption, compressive strength of masonry units and thermal comfort. The incorporation of ceramic waste in all designated mortar bricks showed the increment of crushing strength between 23% and 46% at 28 days of curing and decrement water absorption between 34% and 44% was recorded corresponding to control mortar bricks. The prism test of masonry units consists of mortar bricks containing ceramic waste indicated the high increment of compressive strength at about 200% as compared to mortar brick without ceramic waste. The thermal comfort test of ceramic mortar bricks were also showed the good insulation with low interior temperature. Therefore, the ceramic waste can be utilised as a material replacement to fine aggregate in mortar brick productions due to significant outcomes performed.

Keywords: Ceramic bricks, crushing strength, water absorption, thermal comfort

Abstrak

Kajian ini dijalankan untuk mengkaji penggunaan buangan seramik yang dihancurkan sebagai menggantikan pasir di dalam batu-bata mortar. Peratus bahan hancur buangan seramik yang digunakan ialah 0% (CW0), 10% (CW10), 20% (CW20) dan 30% (CW30) daripada jumlah berat pasir. Dimensi saiz batu-bata mortar yang digunakan ialah 215 mm x 102.5 mm x 65 mm seperti yang dinyatakan di dalam MS 2281:2010 dan BS EN 771-1:2011+A1:2015. Empat (4) ujian telah dijalankan ke atas batu-bata mortar iaitu kekuatan hancur, penyerapan air, kekuatan mampatan untuk unit masonri dan keselesaan terma. Penggunaan bahan buangan seramik di dalam semua batu-bata mortar menunjukkan kenaikan kekuatan hancur di antara 23% dan 46% pada hari pengawetan ke 28 dan penurunan penyerapan air di antara 34% dan 44% telah direkodkan berbanding dengan batu-bata mortar kawalan. Untuk ujian prisma unit masonri yang terdiri dari batu-bata mortar mengandungi bahan buangan seramik mencatatkan kenaikan kekuatan mampatan setinggi 200% jika dibandingkan dengan batu-bata mortar kawalan. Keselesaan terma bagi batu-bata mortar yang mengandungi bahan buangan seramik menunjukkan penebat yang baik dengan suhu dalaman yang rendah. Oleh itu, keputusan yang ditunjukkan dalam kajian ini, menyimpulkan bahan buangan seramik boleh digunakan sebagai bahan penggantian kepada batu halus di dalam pengeluaran batu-bata mortar.

Kata kunci: Buangan seramik, kekuatan hancur, penyerapan air, keselesaan terma

1.0 INTRODUCTION

Ceramic waste or also known as ceramic dust was classified as waste generated from the clay production such as earthenware, stoneware, sanitary ware, porcelain ware, ceramic sludge and from electrical insulator industrial due to poor quality as rejected wares (Amin *et al.* 2016 [1]). This accumulation of ceramics waste increased the demand of landfilled disposal. As the alternatives to promote the green environment in order to address the problem of landfilled disposal, ceramic waste had been introduced as the potential additive in enhancing the brick properties. Generally, the usage of ceramic waste was huge used in replacing partially the coarse and fine aggregates in clay bricks (Alonso *et al.* 2012 [2]; Nirmala and Viruthagiri 2015 [3]; Tereza *et al.* 2015 [4]; Ali *et al.* 2016 [5]; Silva *et al.* 2017 [6]). The inclusion of ceramic waste contents in clay brick productions exhibited the remarkable value of compressive strength and lowest water absorption corresponding to control clay bricks without ceramic waste.

However, limited studies were disclosed in replacing the ceramic waste as fine aggregate in mortar bricks (Jiménez *et al.* 2013 [7]; Fernando *et al.* 2017 [8]); Haiying *et al.* 2011 [9]), therefore the investigation on influence of ceramic waste addition in mortar bricks to their mechanical and physical properties was performed by conducting the laboratory tests as accordance to MS 327: Part 3-1997 [10] and ASTM C1314-16 [11]. Prior to testing, the specimens of mortar bricks were prepared with size of 215 mm x 102.5 mm x 65 mm that conforming in MS 2281:2010 [12] and BS 3921:1985 [13]. In testing the thermal comfort of bricks, only model of masonry unit consists of 30% replacement of ceramic waste was calibrated in order to measure the temperature of interior and exterior of building model and compared to control masonry unit. The purpose was to establish the influence of ceramic waste contents which was achieved the optimum crushing strength value. Hopefully, the outcome of the investigation conducted was able to propose the ceramic waste as sustainable materials in minimizing the wastage from rejected to valuable materials.

2.0 METHODOLOGY

Four (4) different percentages of ceramic waste replacement were prepared with 10% (CW10), 20% (CW20) and 30% (CW30) from the total weight of sand. It was also included the control mortar bricks without ceramic waste (CW0). The purpose of introducing different percentages of ceramic waste contents was to investigate the effect of ceramic waste replacement to crushing strength, water absorption, compressive strength of masonry units and thermal comfort followed as stipulated in MS 2281:2010, MS 327-Part 3: 1997 and ASTM C1314-16. The following outline describes the procedure performed in preparing the ceramic waste and mortar bricks.

2.1 Preparation of Ceramic Waste

The ceramic waste was collected from Guocera Industries Sdn. Bhd. which was located in Kluang, Johor, Malaysia. The sacks of ceramic waste collected was cleaned and crushed using tap water and Los Angeles abrasion machine, respectively. Then, it was sieved to obtain the size of 5 mm which was the same size of sand used in this present study.

2.2 Preparation of Mortar Bricks

The size of mortar brick specimens used was 215mm x 102.5mm x 65mm which is classified as cuboid bricks (ASTM C1314-16) with proportion of 1:6 which is ratio of Portland cement to sand. The wood mould was assembled as shown in
Figure **1** with thickness of 4 mm. Then, the mix were poured into the mortar bricks mould and pressed using low pressure hydraulic hand pump. After the mix hardened for 24 hours, the hardened specimens were cured in room temperature prior to testing.

Figure 1 Wood mould used to cast brick specimens

2.3 Mix Proportion of Materials

Table 1 shows the mix proportion used of cement, sand and ceramic waste including the total of specimens prepared subjected to crushing strength, water absorption, compressive strength of masonry prism and thermal comfort. Total of specimens required for all testing were 184 specimens of mortar bricks.

Table 1 Proportion of sand and ceramic waste with total number of specimens prepared

Symbol	Fine Sand (%)	Ceramic Waste (%)	Total Specimen				
			Crushing Strength		Water Absorption	Compressive Strength Masonry Prism	Thermal Comfort
			7 days	28 days	28 days	28 days	28 days
CW0	100	0	3	3	5	15	40
CW10	90	10	3	3	5	15	-
CW20	80	20	3	3	5	15	-
CW30	70	30	3	3	5	15	40

2.4 Crushing Strength of Mortar Bricks

MS 327-Part 3:1997 outlined the crushing strength was calculated with total maximum load, W divided with average of the gross areas, A. The test of crushing strength or also known as compressive strength was conducted at the age of 7 and 28 days of curing using compression machine as shown in Figure 2.

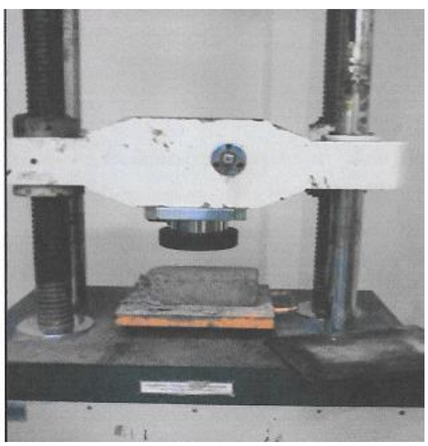


Figure 2 The mortar bricks was crushed to obtain crushing strength

2.5 Water Absorption of Mortar Bricks

MS 327-Part 3:1997 stated the specimens of mortar bricks was dried at six (6) hours and weighed as specimen's weight before immersion (W_d). Then, the specimens was immersed in distilled water and boiled for two (2) hours before it was remained immersed in water for twenty (20) hours. Eventually, the mortar bricks surface was wiped using the damp cloths and weighed as specimens after immersion (W_w). The water absorption was calculated based on Equation 1;

$$\text{Water absorption} = W_d - W_w \quad \text{(Equation 1)}$$

2.6 Compressive Strength of Masonry Prism

In the prism test method, five (5) specimens of mortar bricks was assembled as masonry unit and tested their compressive strength. The prism of mortar bricks was stacked altogether and grouted as shown in Figure 3 was used the mixture of cement and sand with proportion of 1:3. After grouting, the prism was cured in room temperature for 48 hours prior to testing. During the test, the capping plate with dimension of 400mm and 194mm was placed on the top and bottom of prism set as shown in Figure 4 in accordance with ASTM C1314-16.

Figure 3 The arrangement of bricks made on one set of masonry prism

Figure 4 The arrangement of capping plate prior to testing

2.7 Thermal Comfort of Masonry Units

The temperature of interior and exterior in model prototype was taken for 14 days using Rotronic Instrument. The readings were recorded at three (3) different durations comprises of morning, afternoon and night which was measured at 7am, 12pm and 5pm. The interior and exterior temperatures were measured by constructing the model prototype consists of 40 specimens of mortar bricks for control and same model for ceramic mortar bricks as shown in Figure 5.

Figure 5 Model prototype of masonry unit consist of mortar bricks

3.0 RESULTS AND DISCUSSION

The section describes the result obtained from the laboratory test with the discussion based on the figure illustration and previous studies.

3.1 Crushing Strength of Mortar Bricks

The results explained the crushing strength was increased with the increase of ceramic waste contents. The mortar bricks contains CW10, CW20 and CW30 indicated high increment of crushing strength at about 23%, 37% and 46% respectively corresponding to the control mortar bricks as shown in Figure 6. Previously, the similar pattern was observed that inclusion of ceramic waste in clay bricks contribute the high crushing strength (Nirmala and Viruthagiri 2015, Ali *et al.* 2016, Silva *et al.* 2017). While, Hanifi 2007 [14] and Jiménez *et al.* 2013 [7] found the increment of crushing strength was at about 14% in mortar bricks and 40% in mortar specimens, respectively containing ceramic waste at the age of 28 days curing. Similar pattern was also reported in Fernando and Said 2010 [15] which was replaced the ceramic waste to aggregate in concrete specimens with increment of 13%. However the study of Abdul Rahman *et al.* 2015 [16] reported the low increment at about 2% of crushing strength between mortar specimens with and without ceramic waste.

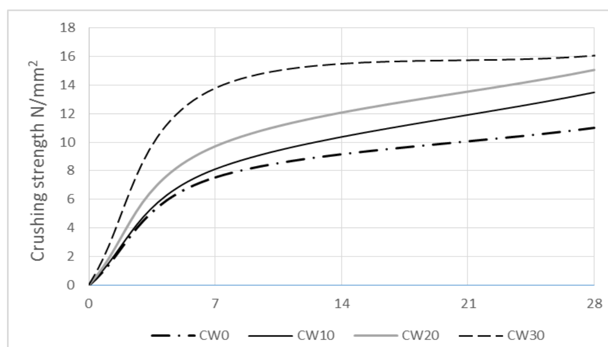


Figure 6 Effect of ceramic waste inclusion to the crushing strength of mortar bricks at the age of 7 and 28 days of curing

3.2 Water Absorption of Mortar Bricks

At the age of 28 days after curing, the ceramic mortar bricks of CW20 and CW30 indicated low water absorption with 3.6% and 4.2%, respectively with respect to control mortar bricks without ceramic waste as illustrated in
Figure 7. However, specimens of CW10 denoted high water absorption at 7.3% while control specimens was 6.4%. Clearly seen that the high contents of ceramic waste decreased the water absorption of ceramic mortar bricks.

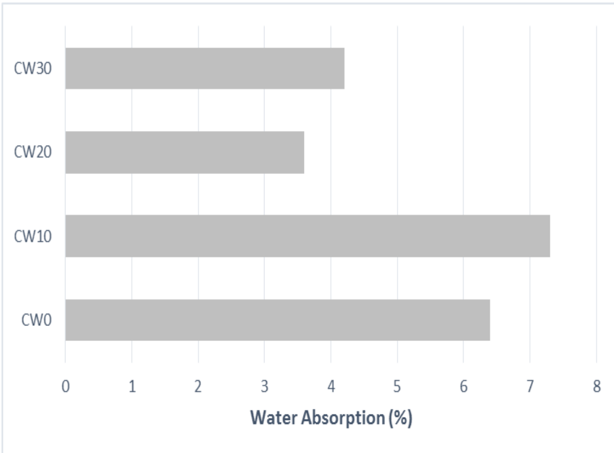


Figure 7 Water absorption of mortar bricks containing with and without ceramic waste

Contradictory from the previous outcome in Ghafour *et al.* 2010 [17] which was recorded high water absorption in fired clay bricks containing ceramic sludge. Similar result was observed in ceramic concrete specimens which was recorded high water absorption compared to control specimens without ceramic waste (Sudarsana *et al.* 2013 [18]). High water absorption can be due to physical conditions of ceramic waste which was consists of crystalline structure on the surface. However, this result obtained in this present study agree with study of Dina *et al.* 2013 [19] and Niyazi 2015 [20] which was concluded the increment of ceramic waste contents decreased the water absorption of mortar bricks. Low water absorption was confirmed with the evidence obtained in micrograph image which was showed the microstructure of ceramic mortar brick specimens presented the sintering heat treatment (Nirmala and Viruthagiri, 2015). In this process, the big pores in the mortar bricks containing ceramic waste was removed. Therefore, minimal amount of water was able to penetrate into the internal structure of mortar bricks containing ceramic waste.

3.3 Compressive Strength of Masonry Prism

The increased of ceramic waste contents shows the huge increment of compressive strength of masonry units. It can be up to 200% of compressive strength with respect to control mortar brick as shown in Figure 8. This outcome confirms the potential of ceramic waste as the replacement to fine aggregate. Conversely, on the previous study (Ghafour *et al.* 2010) concluded the replacement of ceramic sludge in clay bricks was not contributed high compressive strength. The decrement of compressive strength recorded was more than 10%. However, similar pattern was observed in masonry mortar units containing more than 50% ceramic waste with increment up to 50% compressive strength (Fernando *et al.* 2017).

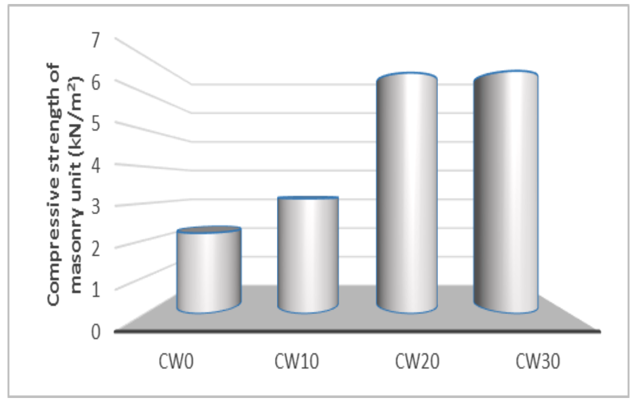


Figure 8 Compressive strength of masonry units containing with and without ceramic waste at the age of 28 days after curing

3.4 Thermal Comfort of Masonry Units

The outdoor temperature of the masonry units containing ceramic waste did not show any significant values due to similar temperature recorded compared to control masonry units. While, the ceramic mortar bricks indicated the low temperature of interior as shown in Figure 9. The fluctuations temperature was detected in unit model of control and ceramic masonry unit during morning and afternoon within 14 days. The lowest temperature was recorded in the evening for both units prototype model. The range of temperature recorded in mortar and control masonry units was between 22˚C and 36˚C and from 23˚C to 38˚C, respectively. While the unit model of ceramic mortar bricks indicated lowest temperature in the evening with range between 22˚C and 28˚C than control unit. For Malaysia climate, Department of Standards Malaysia, 2007 [21] recommended the range of indoor temperature was between 23˚C and 26˚C. Study of Sabarinah and Steven, 2007 [22] proposed the comfort temperature of all building should be below 28.6˚C. Therefore, the prototype model of ceramic masonry units responded better thermal comfort than control mortar bricks.

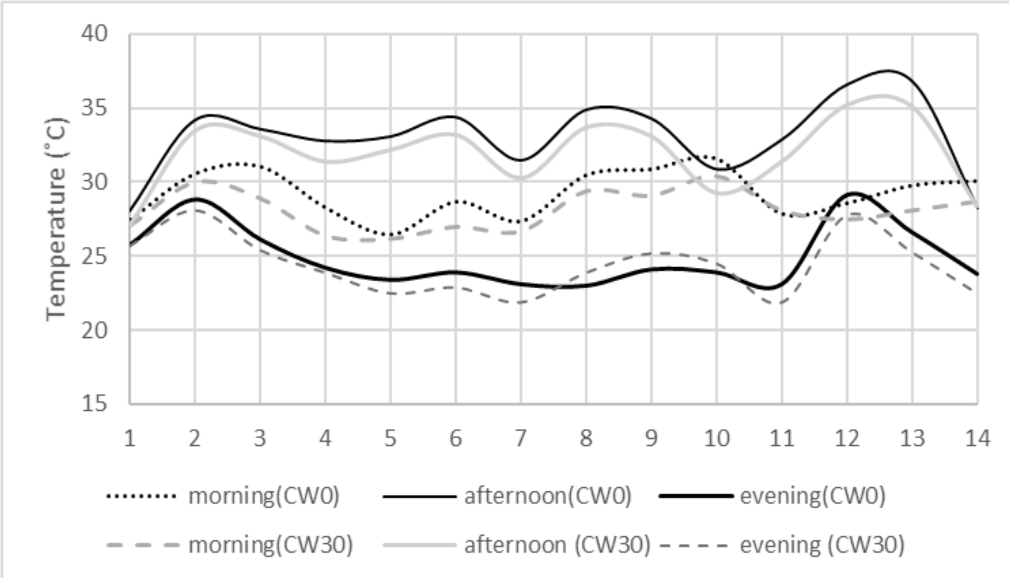


Figure 9 Measurement of interior temperatures in prototype model of control (CW0) and ceramic masonry units (CW30) within fourteen days

4.0 CONCLUSION

The incorporation of ceramic waste in mortar bricks as sand replacement with 10%, 20% and 30% increased the crushing strength with increment of 23%, 37% and 46% with the low water absorption corresponding to mortar bricks without ceramic waste. While, compressive strength of masonry units was increased up to 200%. Subsequently, the thermal comfort in masonry units of ceramic mortar bricks recorded the low interior temperature. Therefore, the replacement of ceramic waste to fine aggregate proven significantly enhance the brick properties and their performance performed the potential in replacing fine aggregate in brick productions.

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