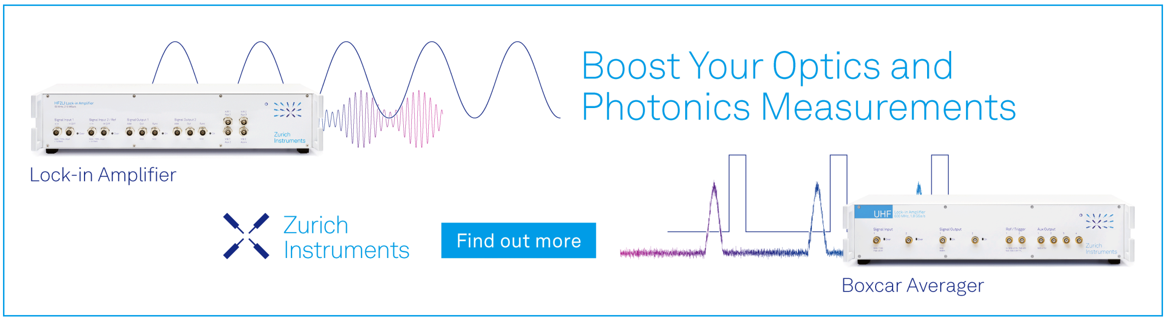
RESEARCH ARTICLE | APRIL 22 2024

Effect of ceramic tile powder as a partial cement replacement material in mortar

Alaa Tanash; Khairunisa Muthusamy; Saffuan Wan Ahmad; Fadzil Mat Yahaya; Mohamed A. Ismail

AIP Conf. Proc. 3114, 030008 (2024)
https://doi.org/10.1063/5.0201546



Effect of Ceramic Tile Powder as a Partial Cement Replacement Material in Mortar

Alaa Tanash[1], Khairunisa Muthusamy [1, a)], Saffuan Wan Ahmad[1], Fadzil Mat Yahaya[1], Mohamed A. Ismail[2]

[1]*Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Persiaran Tun Khalil Yaakob, 26300, Kuantan, Malaysia.*
[2]*Department of Civil Engineering, Miami College of Henan University, Kaifeng, China.*

[a)] *Corresponding author: khairunisa@ump.edu.my*

Abstract. Continued construction activity is increasing demand to produce cement-based composites. Meanwhile, construction and demolition activities also generate solid waste that is disposed of in landfills. The disposal of ceramic tile waste (CTW) generated from construction projects at landfill pollutes the environment. Therefore, this study explores the impact of utilizing ceramic tile powder (CTP) as a partial cement replacement on the flowability, compressive strength and water absorption of mortar. Several mortar mixes were prepared with various percentages of CTP as a partial cement replacement in the mortar. All samples were subjected to continuous water curing. The results show that the use of an appropriate percentage of CTP results in comparable compressive strength and water absorption of the mortar. However, excessive use would result in a deterioration of mortar strength. In principle, the utilize of CTP in concrete would help to save natural resources and promote a cleaner environment.

INTRODUCTION

In the last decade, the United Nations has proposed sustainable development goals (SDGs). SDGs are a global commitment to more sustainable, resilient, and inclusive development [1]. One of the seventeen goals is to combat climate change. Thus, the Secretary-General of the UN proposes a green transformation in all sectors of the economy. Meanwhile, cconcrete is the most utilized construction material in the world. It is widely used because it is easy to obtain, water resistant, and can be formed into many shapes[2]. However, the widespread use of concrete inevitably leads to increased energy consumption and pollution of the natural environment. The cement industry is the third-largest emitter of CO_2 [3]. The cement industry is produce up to 7% of global CO_2 emissions[4, 5]. Therefore, it contributes significantly to climate change [6]. Thus, the utilize of alternative cement materials can help reduce the impact of concrete on climate change, which is in line with the SDGs.

In this sense, ceramic products are an essential part of the standard tool for the construction of any building. Commonly manufactured ceramic products include wall and floor tiles, sanitary ware, and household ceramics [7]. In 2019, over 12.6 billion square meters of ceramic tiles were produced worldwide[8]. Up to 30% of global ceramic production is disposed to landfills each year[9]. In addition, 45% of construction and demolition waste (CDW) consists of ceramic waste from the construction sector [10]. A significant amount of CTW is generated each year from demolition debris and production defects [11]. The potential for environmental damage from careless ceramic disposal makes it imperative to develop efficient ceramic waste management strategies. In recent years, it has been discovered that broken ceramic tiles can be used as suitable substitutes for certain cement [12-15]. Using CTP in concrete improves waste management and reduces the burden on finite resources.

The 3rd International Conference on Science, Engineering, and Technology 2023 (ICSET2023)
AIP Conf. Proc. 3114, 030008-1–030008-6; https://doi.org/10.1063/5.0201546

EXPERIMENTAL PROGRAMME

Materials

Ordinary Portland cement (OPC) of grade 52.5 N, prepared according to ASTM C 150 [16], was used for the study. Broken ceramic tile pieces were collected as waste by local tile companies. The discarded ceramic particles were then dried in an oven at 110 °C for 24 hours. The incoming ceramic tile waste was crushed using a crushing machine and then screened through a 4.75-m sieve to remove the larger particles. To meet ASTM 618 [17] particle size requirements (66% pass 45 um), the screened ceramic was again ground for 7.5 h using a modified Los Angeles machine. The powder was then collected and used for the blending process (As shown in Fig. 1). A natural sand with a maximum grain size of 2.36 was utilized in this study. In addition, clean tap water was utilized for mixing and curing.

FIGURE 1. Ceramic Tile Powder.

Specimen Preparation

In accordance with ASTM C109 [18], six samples were prepared and their compositions are listed in Table 1. The above mixes included a control sample (CTP0) and five other samples (CTP10 to CTP50) containing 10%, 20%, 30%, 40%, and 50% CTP in place of cement, respectively. Table 1 shows that the weight ratio of cement to sand in the composite samples must be one part cement to 2.75 parts sand. The average W/C ratio for all samples was 0.485. To mix all materials evenly, a clean mortar mixer was used. The dry mixing of sand, CTP, and cement took three minutes. Water was then added to the mortar and mixing continued for an additional 5 minutes to ensure complete homogeneity. A vibrating table was utilized to compact the mortar mixture. The mortar had to be removed from the mould and cured in water for 7, 14, and 28 days.

TABLE 1. Mixture proportions for mortars (kg/m^3).

CTP%	OPC	Sand	CTP	Water
0%	657	1810	-	318
10%	591.3	1810	65.7	318
20%	525.6	1810	131.4	318
30%	459.9	1810	197.1	318
40%	394	1810	262.8	318
50%	328.5	1810	328.5	318

Testing

The workability of the mortar' was evaluated utilizing a flow table test in adherence with ASTM C1437-15[19]. The surface of the round table and mold was moistened and scrubbed. The mold was placed in the center of the round surface and filled with three layers of new mortar. Between each layer, the mortar was compacted with 20 strokes per layer with the tamping rod. To obtain a flat surface, the top layer was scraped off with a trowel. After removing the mold, 25 drops with a drop height of 12.5 mm were placed within 15 seconds. Compressive strength was measured 7, 14, and 28 days after fabrication according to ASTM C109-11[18]. The average result for each test condition was determined by testing three samples. Water absorption testing was conducted on 28-day water-cured samples in adherence with the procedure reported in BS 1881-122 [20].

RESULTS AND DISCUSSION

Workability

Figure 2 shows the changes in flow behavior when CTP is used as a partial cement substitution in mortar mixes. The flow behaviors of the mortars decrease with the increasing proportion of CTP as a partial cement substitution. For mortars with proportions of 0%, 10%, 20%, 30%, 40%, and 50%, the corresponding flow diameters were 180mm, 175 mm, 165 mm, 160 mm, 155 mm, and 150 mm. The workability of the mortars containing CTP is lower than that of the control mortars. It is obvious that the flowability of the mortar mixture is affected by the addition of CTP, which has different properties than cement. This could be due to the non-uniform morphology of CTP, which could increase interlocking and thus friction between particles, as well as the energy required to start the mixture to flow. A similar behavior has also been reported by previous researchers for various types of cement-based composite[12, 21-23].

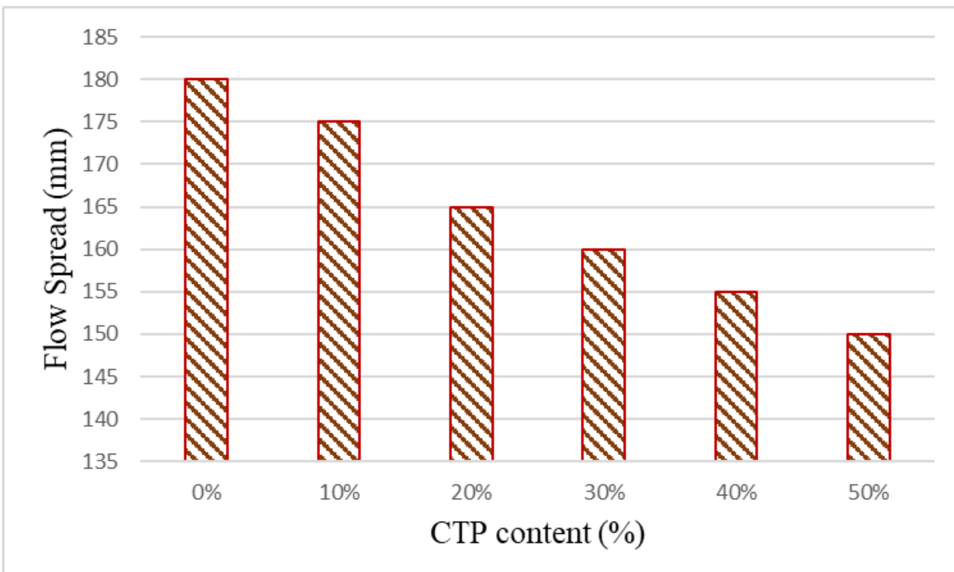


FIGURE 2. Effect of CTP content as a cement substitute on flowability of mortar.

Compressive Strength

The compressive strength of the mortar is influenced by the CTP content, as shown in the Fig.3. Mortars containing CTP has lower compressive strength than the control mortar at all test ages, and this trend worsens as more CTP is added to the mix. The compressive strengths of the control mortars are 41, 48.79, and 52.5 MPa after 7, 14, and 28 days, respectively. After 7 days, the compressive strength of the specimens at 10%, 20%, 30%, 40%, and 50% were 32.7, 29.8, 25, 21, and 16 .5MPa, respectively. Due to the CTP effect on the development rate of the CSH gel and the immature pozzolanic reaction of the mortar, the early compressive strength decreases drastically[23]. After 28 days, mortar mixes with 10% and 20% CTP as cement replacement showed a lower strength loss relative to the control samples. The compressive strength of 10 %CTP, 20% CTP, 30%CTP, 40%CTP, and 50%CTP mortars after 28 days are 48.69, 46.33, 39.1, 33.1, and 29.37 MPa, respectively, corresponding to a decrease of 8%, 12%, 26%, 37%, and 45%. The different strength development of the test specimens is due to the pozzolanic reaction. Blending high quantity of CTP results in significant strength declination. A similar trend has also been noticed by past researchers for various types of cement-based composite [12, 21, 24].

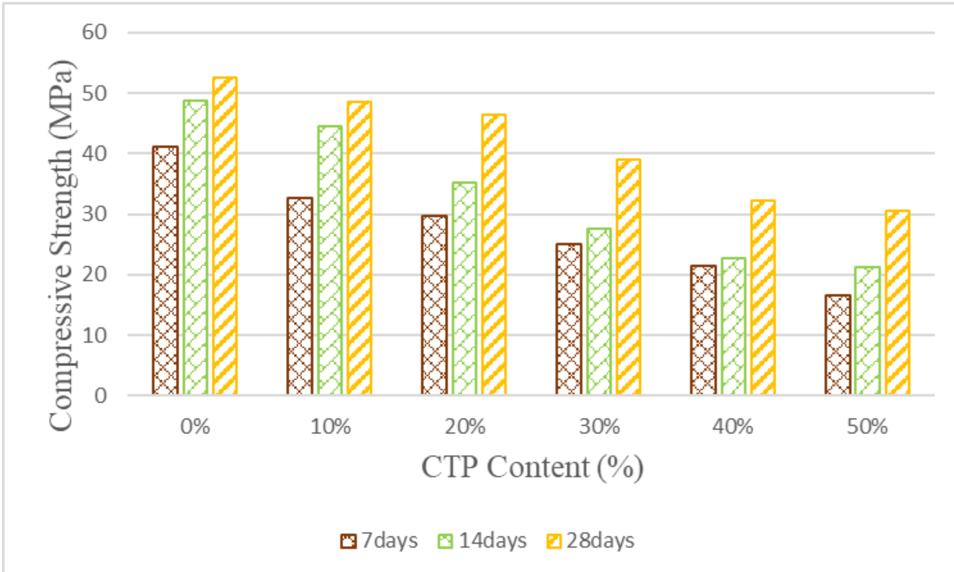


FIGURE 3. Effect of CTP content as a cement substitute on compressive strength of mortar.

Strength Activity Index

Figure 4 displays the strength activity index (SAI) for the compressive strength of CTP mortar. The test outcomes show that the addition of CTP affects the compressive strength of the mortar at an early age (7 days), with the loss proportional to the amount of CTP. At a CTP content of up to 10%, the SAI of the mortar with CTP is still more than 75% according to the requirements of ASTM C618. However, with a proportion of up to 50% CTP, the SAI drops to 40%. The lower development of the primary calcium silicate hydrate structure in the matrix is held responsible for this performance. Mortars containing up to 10% CTP had a compressive SAI 92% at 28 days. The SAI of 20% CTP mortar increases to 88%, which well above the minimum requirement of ASTM C618 (75%)[17]. Nevertheless, if the CTP content exceeds 20%, the SAI of the mortar is below 75% and does not meet the standards of ASTM C618[17]. The compressive strength of the mortar reduced by 8%,12%, 26%, 37% and 45% for CTP replacement of 10%,20%, 30%, 40% and 50%, respectively. It can be concluded that the CTP used in this study has good reactivity.

Figure 5 shows the results of the water absorption test for all the blends used in this study. The results show that the mixes with 10 and 20% CTP have comparable water absorption relative to the control samples. However, the mixes with a cement replacement content of more than 30% showed increased water absorption than the control samples. The absorption rates were 3.31 to 3.93% compared to 3% for the control mixture at a replacement ratio greater than 30%. This rise in the water absorption capacity of the waste mixes is due to the increase in the pore volume of the mortar mixes. The resistance of the mortar to water absorption is comparable or higher at suitable CTP concentration, which is mainly owing to the pozzolanic reactivity and the filling effect of CTP. CTP increases mortar porosity by reducing the amount of hydration products in cementitious materials, so a mortar with a high CTP content can absorb more water than a mortar with a lower CTP concentration. The water absorption of the mortar is negatively affected by the lower hydration products, and the positive pozzolanic activity and the filling effect cannot compensate for this[25].

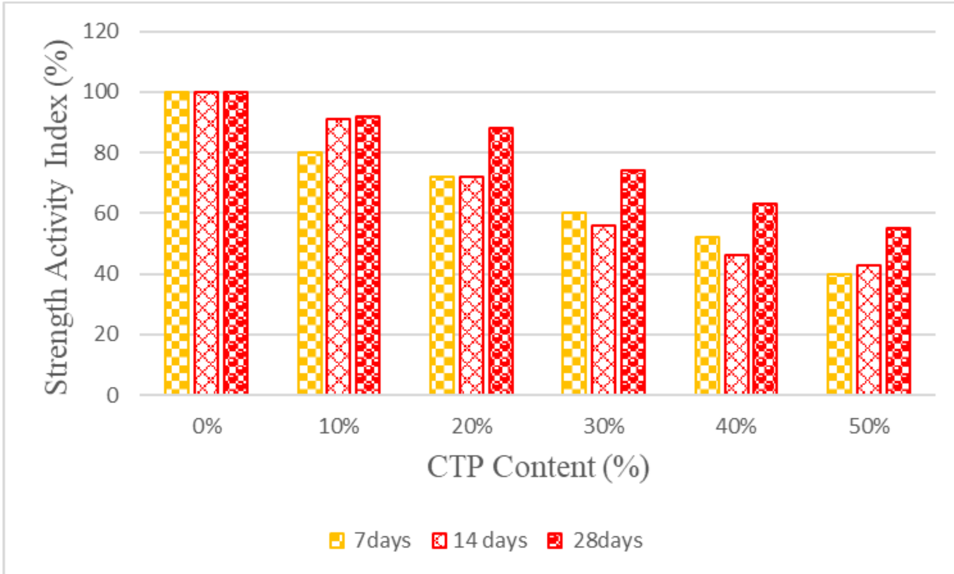


FIGURE 4. Effect of CTP content as a cement substitute on SAI of mortar.

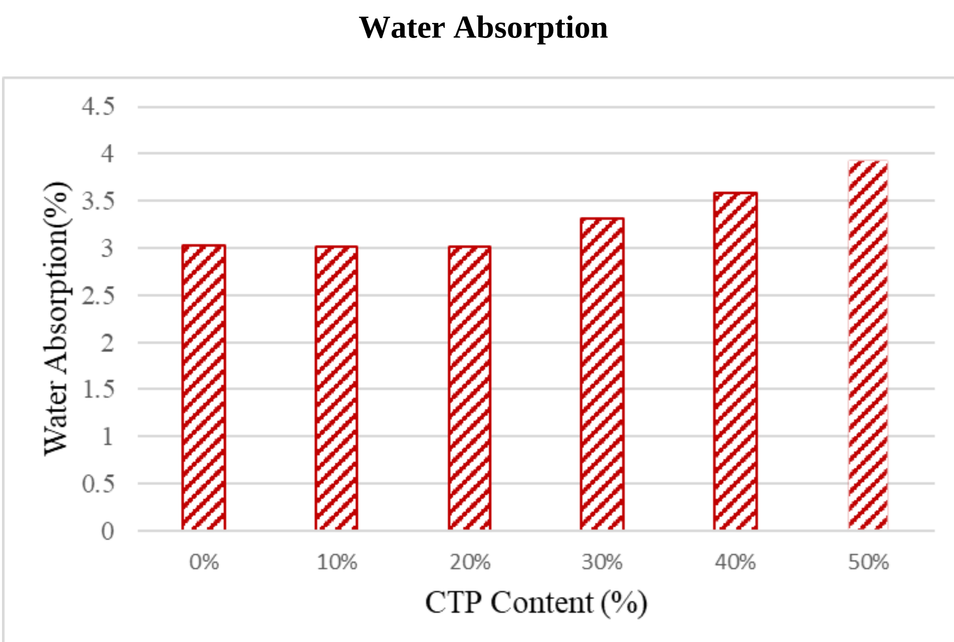


FIGURE 5. Effect of CTP content as a cement substitute on water absorption of mortar.

CONCLUSION

The results show using an appropriate amount of CTP (Up 20%) as a cement replacement, mortars with comparable strength compared to control mortars can be produced. Excessive use of CTP for mortar production should be avoided as it results in a drastic strength decline. Success in integrating CTP as partial cement replacement for construction material production would save the use of cement and reduce ceramic tile waste ending at landfill.

ACKNOWLEDGMENTS

The authors would like to thank Universiti Malaysia Pahang for supporting the study through the internal research grant PGRS220345.

REFERENCES

1. Neshovski, r. *United Nations Sustainable Development*. 2018 [cited 2021 20/12].
2. Xu, Q., et al., *Characteristics and applications of sugar cane bagasse ash waste in cementitious materials.* Materials, 2018. **12**(1): p. 39.
3. Andrew, R.M., *Global CO 2 emissions from cement production, 1928–2017.* Earth System Science Data, 2018. **10**(4): p. 2213-2239.
4. Ahmed, M., et al., *An overview of Asian cement industry: Environmental impacts, research methodologies and mitigation measures.* Sustainable Production and Consumption, 2021. **28**: p. 1018-1039.
5. TANASH, A.O.A.A.R. and K. Muthusamy, *Concrete Industry, Environment Issue, and Green Concrete: A Review.* Construction, 2022. **2**(1): p. 01-09.
6. Tun, T.Z., S. Bonnet, and S.H. Gheewala, *Emission reduction pathways for a sustainable cement industry in Myanmar.* Sustainable Production and Consumption, 2021. **27**: p. 449-461.
7. Awoyera, P.O., et al., *Characterization of ceramic waste aggregate concrete.* HBRC journal, 2018. **14**(3): p. 282-287.
8. insights, f.b. *Ceramics Market Size, Share, Growth | Industry Statistics, 2028*. 2021 [cited 2021 27/12].
9. Agrawal, A., A. Singh, and A. Imam, *Utilization of Ceramic Waste as a Sustainable Building Material*. 2020.
10. Reig, L., et al., *Alkaline activation of ceramic waste materials.* Waste and Biomass Valorization, 2013. **4**(4): p. 729-736.
11. Pitarch, et al., *Pozzolanic activity of tiles, bricks and ceramic sanitary-ware in eco-friendly Portland blended cements.* Journal of Cleaner Production, 2021. **279**: p. 123713.
12. Mas, M.A., et al., *Ceramic tiles waste as replacement material in Portland cement.* Advances in Cement Research, 2016. **28**(4): p. 221-232.
13. Xu, K., et al., *Mechanical properties of low-carbon ultrahigh-performance concrete with ceramic tile waste powder.* Construction and Building Materials, 2021. **287**: p. 123036.
14. Ay, N. and M. Ünal, *The use of waste ceramic tile in cement production.* Cement and Concrete Research, 2000. **30**(3): p. 497-499.
15. Pitarch, et al., *Pozzolanic activity of tiles, bricks and ceramic sanitary-ware in eco-friendly Portland blended cements.* Journal of Cleaner Production, 2021. **279**: p. 123713.
16. C150, A., *ASTM C150 / C150M - 20 Standard Specification for Portland Cement.* www.astm.org.
17. 618, A., *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.* www.astm.org.
18. C109, A., *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50 mm] Cube Specimens).* www.astm.org.
19. C1437-15, A., *Standard Test Method for Slump of Hydraulic-Cement Concrete.* www.astm.org.
20. 1881-122, B., *Concrete Testing Water Absorbtion.* 2009.
21. Pereira-de-Oliveira, L.A., J.P. Castro-Gomes, and P.M.S. Santos, *The potential pozzolanic activity of glass and red-clay ceramic waste as cement mortars components.* Construction and Building Materials, 2012. **31**: p. 197-203.
22. Mohammadhosseini, H., et al., *Enhanced performance of green mortar comprising high volume of ceramic waste in aggressive environments.* Construction and Building Materials, 2019. **212**: p. 607-617.
23. Heidari, A. and D. Tavakoli, *A study of the mechanical properties of ground ceramic powder concrete incorporating nano-SiO2 particles.* Construction and Building Materials, 2013. **38**: p. 255-264.
24. Pitarch, A.M., et al., *Pozzolanic activity of tiles, bricks and ceramic sanitary-ware in eco-friendly Portland blended cements.* Journal of Cleaner Production, 2021. **279**: p. 123713.
25. Ma, Z., et al., *Mechanical properties and water absorption of cement composites with various fineness and contents of waste brick powder from C&D waste.* Cement and Concrete Composites, 2020. **114**: p. 103758.