Effect of Ceramic Waste Powder on Strength Development of Brick Aggregate Concrete

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Abstract. The uses of ceramic products are expanding day by day in different forms like tiles, sanitary fittings, wall linings, electrical insulations etc. Due to its brittle nature, huge number of ceramic materials turn into waste during processing, transporting and fixing. The direct dumping of these waste materials leads to environmental and dust pollution in addition to occupation of vast and useable land area. The aim of the study was to investigate the effect of ceramic waste powder (CWP) on the strength development of brick aggregate concrete (BAC). A total of 180 nos. cylindrical specimens (100mm dia. × 200mm height) were cast for compressive and split tensile strength tests and 45 nos. prism (100mm × 100mm × 500mm) for flexural strength test from concrete with mix ratio of 1:1:5:3 (by weight) using three different water-to-binder ratios (i.e., 0.40, 0.45 and 0.50 by weight). In concrete mix, cement was replaced by CWP at various replacement levels of 0, 5, 10, 15 and 20% and specimens were cured in plain water for 7, 14, 28 and 56 days. The specimens were tested for compressive, split tensile and flexural strengths at the end of different curing ages. The test results indicate that the strength of concrete decreases with the increase of CWP contents in the mix that ranges from 2 to 30%. However, the decrease in strength is observed to be lower up to 10% cement replacement levels that lies in the range of 11 to 13%. Hence CWP can be utilized as partial replacement of cement up to 10% without significantly affecting the strength performance of BAC.

Keywords: Ceramic waste powder, brick aggregate concrete, compressive strength, split tensile strength, flexural strength.

1 Introduction

Production and utilization of concrete have been increasing day by day, resulting in increased consumption of cement clinker and aggregates [1]. Cement is the main binding material in making a particular grade of concrete [2]. But there is a scarcity of sources of materials for making cement clinker [3]. Industrial waste materials may be a great source of the binding component of construction materials [4]. Most of the demolition waste in our country are not recycled but end up in landfills occupying valuable lands. For example, ceramic tiles are often discarded as waste, but it can be recycled and used as a construction material, which would be economical and

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friendly [5]. Ceramic waste can be used as a construction material without a dramatic change in the production and application process [6].

The uses of ceramic products are expanding day by day in different forms like tiles, sanitary fittings, brick walls and electrical insulators etc. For this reason, ceramic industries are increasing day by day in Bangladesh. Due to its brittle behavior, huge amounts of ceramic materials turn into waste during processing, transporting and fixing. Ceramic waste in Dhaka City reaches 1.13% of total municipal solid wastes [7]. Most of these wastes are directly dumped into the landfill increasing the burden on landfill loading. The cost of dumping of ceramic waste in the landfill will not only be saved but also raw materials and natural resources will be replaced if it can be recycled. The finest approach in the construction sector, especially the concrete sector, is using of the waste from industries as building materials [8].

Pozzolanic concrete are used extensively throughout the world where oil, gas, nuclear and power industries are among the major users. The applications of such concrete are increasing day by day due to their superior structural performance, environmental friendliness, and energy conserving implications. The search for alternative binders or cement replacement materials has been carried out for decades. Research has been conducted on the use of fly ash, volcanic ash, rice husk ash, volcanic pumice, pulverized-fuel ash, blast slag and silica fume etc. as the cement replacement material. Ceramic waste powder (CWP) is pozzolanic material because of their reaction with lime liberated during the hydration of cement. These materials can also improve the durability of concrete and the rate of gain in strength and can also reduce the rate of liberation of heat, which is beneficial for concrete. Concrete containing mineral admixtures are used extensively throughout the world for their good performance and for the ecological and economic reason [6].

The ceramic industries dump the waste in the nearby pit or vacant spaces near their unit, although notified areas are marked for dumping. This leads to serious environmental and dust pollution as well as the occupation of vast land area, especially after the powder dries up. So, it is necessary to dispose of the ceramic waste quickly. As the ceramic waste is piling up every day, there is a pressure on ceramic industries to find a solution for its disposal [6]. So, producing concrete by using ceramic waste is a better solution for ceramic industries too. This offers cost reduction, energy savings, arguably superior products, and fewer hazards in the environment.

A large quantity of ceramic waste is generated at the production stage. Senthamarai & Devadas [9] have estimated that about 30% of the daily manufacturing volume in the ceramic industry goes to waste. In Europe, according to Fernandes et al. [10], the amount of waste in the production stages of ceramic industry reaches 3% to 7% of its global production. Cement and concrete production can consume a substantial percentage of the total generated waste materials. Consumption of waste in concrete production can alleviate the acute environmental impact of these materials and also partly help to achieve the much-needed sustainability in cement and concrete production [11].

Ceramic waste can be used in concrete to improve its strength and durability. It can be used as a partial replacement of cement, fine aggregate or coarse aggregate to improve different properties of concrete. The utilization of ceramic waste powder as a cementitious material in cement and concrete depends on the pozzolanic property of its powder. The pozzolanic reactivity of the powder is closely related to the form of silica present. The physio-chemical properties of silica in ceramic waste powder are strongly influenced by the temperature and the duration of thermal treatment. It has been shown that ceramic powder contains more than 60% silica [4, 12].

Several studies were performed on the utilization of ceramic tiles waste as aggregates and ceramic waste powder (CWP) as partial replacement of cement [1, 3-4, 13]. In addition, several researches have been carried out to confirm the pozzolanic reactivity of CWP [1, 14-15]. But all these studies investigated the properties of either stone aggregate concrete or ceramic tiles aggregate concrete. In Bangladesh, brick chips are widely used as coarse aggregates because of its cost and availability. Therefore, this study was intended to investigate the effect of CWP on the mechanical properties of brick aggregate concrete (BAC) using ceramic powder as partial replacement of cement. The utilization of waste tiles powder as CWP in BAC is expected to prevent environmental pollution, reduce consumption of natural resources and thus contribute to the sustainable development of the country. Please note that the first paragraph of a section or subsection is not indented. The first paragraphs that follows a table, figure, equation etc. does not have an indent, either.

2 Materials and Methodology

2.1 Ceramic Waste Powder (CWP)

Locally available ceramic wall tiles were used in this study. Fig. 1 shows the selected ceramic wall tiles after crushing by hammer and ceramic waste powder after grounding and sieving. CWP passed more than 85% through 75 μm sieve.

2.2 Cement

Ordinary Portland cement (OPC Type-1) was used as binding materials. The cement satisfied the requirements of American Society for Testing and Materials (ASTM) C150 standard [16].

2.3 Coarse Aggregate

Locally available first-class bricks were broken manually for making coarse aggregate. Brick chips passing through 19 mm sieve was used as coarse aggregate. The properties of coarse aggregate are shown in Table 1.

Fig. 1. Broken ceramic tiles and ceramic waste powder

2.4 Fine Aggregate

Locally available coarse sand was used as fine aggregate. Table 1 shows its physical properties.

2.5 Water

In this study, drinking water was used for making concrete. Water was clean and free from injurious components.

Table 1. Physical properties of coarse and fine aggregates

Property	Coarse Aggregate (Brick chips)	Fine Aggregate
Fineness Modulus	6.94	3.04
Specific Gravity (dry)	2.03	2.65
Water Absorption (%)	15.56	0.93
Unit weight (kg/m^3)	1070	1387

2.6 Mixing of Concrete Ingredients

The ingredient materials were measured according to the concrete mix ratio of 1:1.5:3 (Binder : FA : CA). To fulfil the objective of the study five different cement replacement levels (i.e., 0, 5, 10, 15 and 20%) and three different water-to-binder (w/b) ratios (i.e., 0.40, 0.45 and 0.50 by weight) were used. As per replacement level, required amount of CWP was mixed with the measured amount of OPC. The sand and cement with or without CWP were mixed in the mixer machine till getting uniform color. Then the required amount of CA was added. Initially half of the required water was added in the mixture followed by adding of the rest amount at the later stages. The mixing process took 2 to 3 minutes. Cement, CWP and water were added to maintain the required w/b ratio. After mixing, workability for each batch of cement was determined using slump test as per ASTM standard. Fig. 2 shows the details of slump test.

Fig. 2. Slump test of fresh concrete

2.7 Casting of Specimens

A total of 180 nos. cylindrical specimens (100 mm dia x 200 mm height) for compressive and split tensile strength tests and 45 nos. prism (100 mm x100 mm x 500 mm) for flexural strength test were used to investigate the strength properties. The cylindrical and prism steel molds were lubricated at their inner faces before use. The fresh concrete was placed in three layers in the molds and compacted by tamping rod as per ASTM C31 [17]. The specimens were demolded after 24 hours and placed in the curing tank for the desired curing periods of 7, 14, 28 and 56 days.

2.8 Testing of Specimens

At the end of the specific curing periods, the specimens were subject to three different types of strength tests namely compressive, split tensile and flexural strength tests. Average of three strength values was reported as representative data for each case. The compressive strength test was determined as per ASTM C39 [18]. Unbounded metal cap with neoprene elastomeric pads were used to ensure uniaxial loading. Fig. 3 shows the compression test set up and failed specimens under compression. The split tensile strength test was carried out as per ASTM C496 [19]. Fig. 4 shows the split tensile strength test setup and the failure of specimens. On the other hand, the flexural strength test was carried out on prism specimens as per ASTM C293 [20]. The detail of test setup and the failure pattern of specimens are shown in Fig. 5.

Fig. 3. Compressive strength test during loading and specimen after failure

Fig. 4. Split tensile test during loading and specimen after failure

Fig. 5. Flexural strength test during loading and specimen after failure

3 Results and Discussions

3.1 Workability

Workability is one of the major issues for cement-based products to ensure the proper flowability. It was determined using slump test as per ASTM standard and the results are presented in Fig. 6. It is seen that the slump of CWP concrete gradually increases with the increase of CWP contents irrespective of w/b ratios. This is due to reduction of friction between aggregate and paste interface due to low specific gravity of CWP as demonstrated by Aly et al. [12].

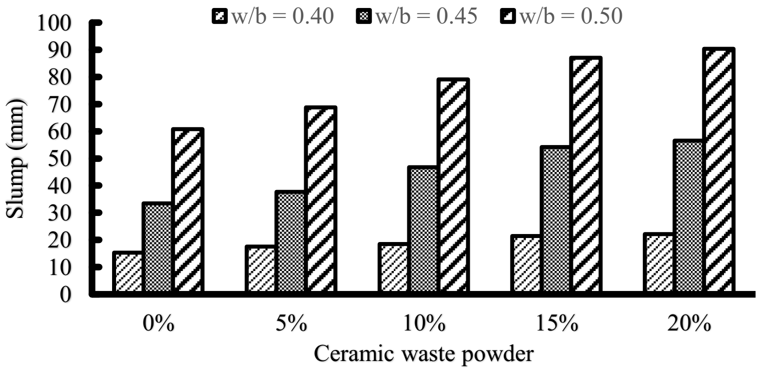

Fig. 6. Slump of control and CWP blended BAC

3.2 Compressive Strength

The compressive strength development of BAC specimens cast from control (0% CWP) as well as CWP blended at various replacement levels over the curing periods of 7, 14, 28 and 56 days is presented in Figs. 7, 8 and 9. Fig. 7 shows the compressive strength of CWP blended BAC cast with w/b = 0.40. Similarly, Fig. 8 and Fig. 9 show the compressive strength of CWP blended BAC having w/b = 0.45 and w/b = 0.50, respectively.

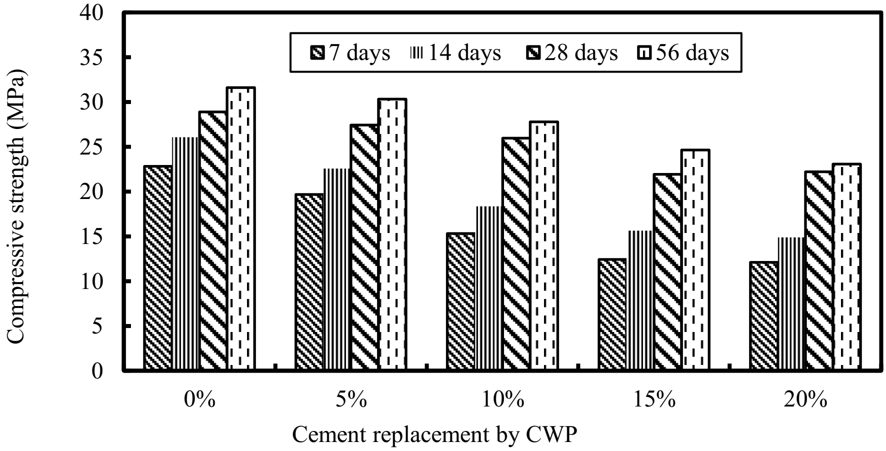

Fig. 7. Compressive strength of control and CWP blended BAC (w/b = 0.40)

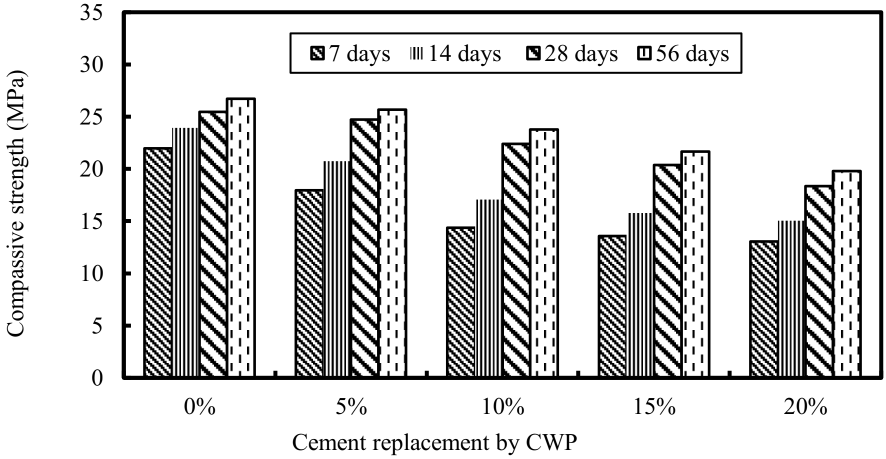

Fig. 8. Compressive strength of control and CWP blended BAC (w/b = 0.45)

From the figures, it is seen that as usual the strength of control as well as CWP blended concrete increases with the increase of curing age for all replacement levels and w/b ratios. But the rate of strength development for control concrete at early ages is relatively higher than the CWP blended concrete; although the strength of control concrete is higher than the CWP blended specimens at any curing age and w/b ratio. After 7 days of curing, the strength of concrete specimens at cement replacement levels of 5%, 10%, 15% and 20% are 86%, 67%, 55% and 53% respectively in comparison to control concrete and for w/b = 0.40. After 28 days the corresponding strengths are 95%, 90%, 76%, 70%, and after 56 days, the relevant strengths are 96%, 88%, 76% and 73% respectively. From the figures, it is clear that as the cement replacement levels increase, the strengths decrease. Similar trends are also observed in case of concretes with w/b ratios of 0.45 and 0.50. The decrease in strength due to incorporation of CWP in concrete as partial replacement of cement is supported by other investigators [21-22]. It is also noticed that up to 10% cement replacement levels, the decrease in strength is relatively lower than that for higher replacement levels. Irrespective of w/b ratio, after 28 days curing, the overall decrease in strength lies in the range of 5 to 30% as compared to control concrete (0% CWP). Whereas for CWP contents up to 10%, the decrease in strength is found to be marginal that lies in the range of 3 to 13%. Cement replacement levels beyond 10% (i.e., for 15 & 20%), the strength decrease lies in the range of 20 to 30%.

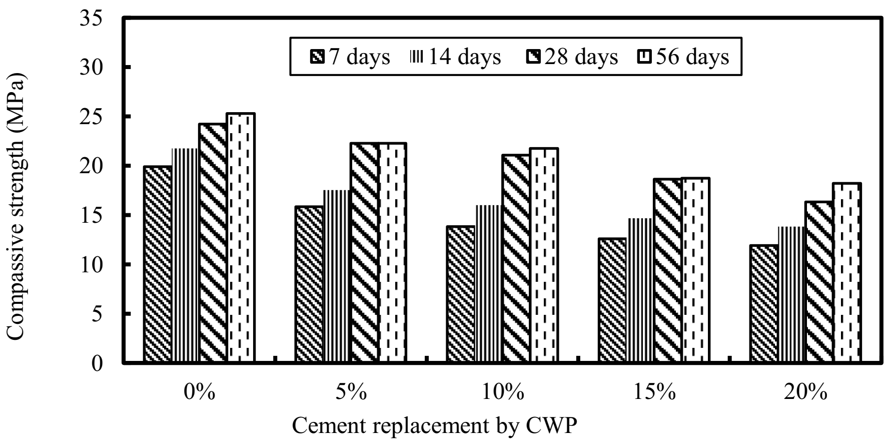

Fig. 9. Compressive strength of control and CWP blended BAC (w/b = 0.50)

3.3 Split Tensile Strength

The 28 days split tensile strength of BAC cast with 0% (control), 5%, 10%, 15% and 20% of CWP and using three w/b ratios (0.40, 0.45 and 0.50) are presented graphically in Fig. 10. Due to some constraints, only 28 days strength tests were conducted. From the figure, it is observed that the tensile strength development follows the similar pattern as that for compressive strength. As the CWP content increases, the strength decreases. As usual, as the w/b ratio increases, the strength decreases. For w/b = 0.40, the recorded decrease in strengths is observed to lie in the range of 2 to 17%. The corresponding strength decrease values range from 4 to 20% and 7 to 20% for concrete with w/b = 0.45 and w/b = 0.50, respectively. Again, irrespective of w/b ratios, the concrete with CWP content up to 10% suffers decrease in strength in the range of 1 to 11%. The maximum strength attainment of 84% for 10% CWP content as compared to control concrete [1]. However, the strength increases up to 30% CWP content with admixture [23].

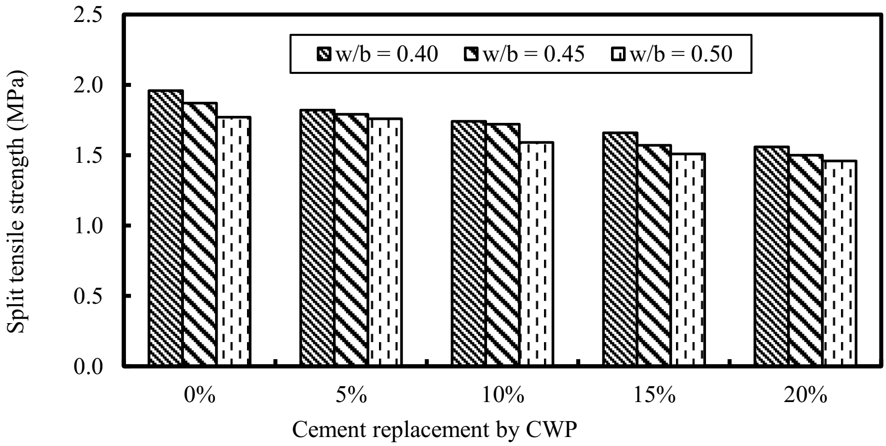

Fig. 10. Split tensile strength of control and CWP blended BAC after 28 days

3.4 Flexural Strength

The test result for flexural strength of BAC cast with different cement replacement levels and using different w/b ratios are presented in Fig. 11. Here also, only the 28 days flexural strength test has been conducted. The effect of CWP on the strength development of BAC follows the same trend as that for compressive and split tensile strengths. With the addition of CWP in the concrete mix, the strength decreases as compared to control concrete. Also, the decrease in strength is observed to be lower for cement replacement levels up to 10%. The relative strength attainment of BAC specimen at cement replacement levels of 5, 10, 15 and 20% are recorded as 98%, 88%, 79% and 76% for w/b ratio of 0.40. However, the corresponding values for w/b ratio of 0.45 are 98%, 92%, 78% and 77% respectively. Again, for w/b ratio of 0.50, the relative strengths are found as 96%, 90%, 82% and 75% respectively. In other words, the overall strength reduction is recorded as to vary in the range of 1 to 25%. For lower replacement levels i.e., up to 10%, the strength reduction lies in the range of 1 to 12%.

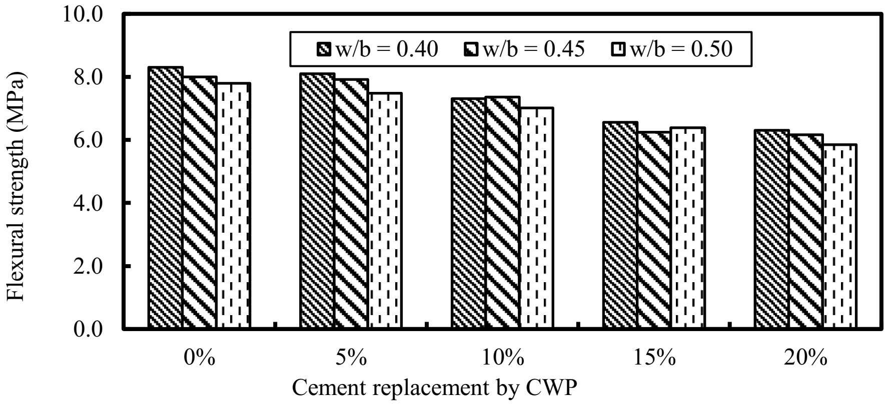

Fig. 11. Flexural strength of control and CWP blended BAC after 28 days

4 Conclusions

The effect of CWP as partial replacement of cement in BAC on its strength development has been studied. Five cement replacement levels (0%, 5%, 10%, 15% and 20%) have been considered in making the BAC test specimens that were cured up to 56 days for compressive strength and 28 days for split tensile and flexural strength tests. Based on the limited number of variables studied, the following conclusions are drawn:

1. The slump values of CWP blended BAC increase gradually with the increase of cement replacement levels.
2. The compressive strength of CWP blended BAC decreases with the increase of cement replacement levels. The overall decrease in strength is found to lie in the range of 3 to 30%. Up to 10% replacement levels, the strength reduction lies within 13%.
3. The split tensile strength of CWP blended BAC is found to decrease with the increase in cement replacement levels. The overall decrease in strength lies in the range of 2 to 20%. However, the strength reduction lies within 11% for cement replacement levels up to 10%.
4. The flexural strength of CWP blended BAC is also found to decrease with the increase of cement replacement levels in the mix. Overall, the flexural strength reduction lies in the range of 2 to 25% and up to 10% replacement levels, the strength reduction values lie within 12%.

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References

1. Kironkumer, R., Raju, K., Ramji, B. S., Sarma, V. V. S.: Exposure effect of $MgSO_4$ and HCl on strength properties of ceramic waste powder by partial replacement with cement. International Journal for Innovative Research in Science & Technology (IJIRST), **3**(9), 9-16 (2017)
2. Daniyal, M., Ahmad, S.: Application of waste ceramic tile aggregates in concrete. International Journal of Innovative Research in Science Engineering and Technology, **4**(12), 12808-1281 (2015)
3. Shuying, Q., Bin, Z., Chen, S., Jin, L.: Application of ceramic wastes in concrete. The Open Civil Engineering Journal, **8**, 368-372 (2014)
4. Raval, A. D., Patel, I. N., Pitroda, J.: Ceramic waste: effective replacement of cement for establishing sustainable concrete. International Journal of Engineering Trends and Technology, **4**(6), 2324-2329 (2013)
5. Asrul, M. F. B.: Ceramic tiles waste as coarse aggregates partial replacement for concrete production. Undergraduate Project Report, Civil Engineering Department, University of Malaysia, Pahang, Malaysia (2016)
6. Patel, J., Shah, B. K., Patel, P. J.: Ceramic powder in concrete by partial replacement of cement- A literature analysis. Journal of International Academic Research for Multidisciplinary, **2**(3), 712-727 (2014)
7. Islam, M. T., Rashid, M. H.: Municipal solid waste (MSW) management in Dhaka, Bangladesh. https://www.researchgate.net/publication/280042156, last accessed 2015/01/01.
8. Meyer, C.: The greening of the concrete industry. Cement and Concrete Composites, **31**(8), 601–605 (2009)
9. Senthamarai, R. M., Devadas, M. P.: Concrete with ceramic waste aggregate. Cement and Concrete Composites, **27**(9-10), 910-913 (2005)
10. Fernandes, M., Sousa, A., Dias, A.: Environmental impact and emissions trade ceramic industry: A case study. Proc., Portuguese Association of Ceramic Industry, APICER, Portugal (2004)
11. Cristiano, M.: The use of ceramic waste aggregates in concrete: a literary review. Proc., Progetto E Tecnologia Per Il Costruito Tra XX E XXI Secolo, Concrete-2014, Termoli, Italy. (2014)
12. Aly, S. T., Dieb, A. S. E., Taha, M. R.: Effect of high-volume ceramic waste powder as partial cement replacement on fresh and compressive strength of self-compacting concrete. ASCE Journal of Materials in Civil Engineering, **31**(2), 1-11 (2018)
13. Torgal, F. P., Jalali, S.: Compressive strength and durability properties of ceramic wastes-based concrete. Materials and Structures, **44**(1), 155-167 (2010)
14. Puertas, F., Garcia, D. I., Barba, A., Gazulla, M., Gomez, M., Martinez, R. S.: Ceramic wastes as alternative raw materials for Portland cement clinker production. Cement and Concrete Composites, **30**(9), 798-805 (2008)
15. Lavat, A. E., Trezza, M. A., Poggi, M.: Characterization of ceramic roof tile wastes as pozzolanic admixture. Waste Management, 29(5), 1666-1674 (2009)
16. ASTM C150-07: Standard Specification for Portland Cement. ASTM International, West Conshohocken, PA, USA (2007)
17. ASTM C31-03: Standard Practice for Making and Curing Concrete Test Specimens in the Field. ASTM International, West Conshohocken, PA, USA (2003)
18. ASTM C39-03: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. ASTM International, West Conshohocken, PA, USA (2003).

19. ASTM C496-04: Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. ASTM International, West Conshohocken, PA, USA (2004)
20. ASTM C293-02: Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading). ASTM International, West Conshohocken, PA, USA (2002)
21. Sudarsana, R. H., Valikala, G., Ghorpade, V. G.: Influence of water absorption of the ceramic aggregate on strength properties of ceramic aggregate concrete. International Journal of Innovative Research in Science, Engineering and Technology, **2**(11), 6329-6335 (2013)
22. Lalji, P., Patel, I. N., Agarwal, V. V.: Analysis of the strength and durability of the concrete with partially replaced by the ceramic slurry waste powder. International Emerging Technology and Advanced Engineering, **4**(3), 725-729 (2014)
23. Manogna, P., Lakshmi, M. S.: Tile powder as partial replacement of cement in concrete. International Research Journal of Engineering and Technology, **2**(4), 75-77 (2015)