

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/341766896>

Effect of Porcelain Waste as a Fine Aggregate on the Mechanical Properties of Concrete

Conference Paper · August 2019

CITATIONS

0

READS

221

2 authors:



Dhanushka Kobbekaduwa

Xi'an Jiaotong-Liverpool University

3 PUBLICATIONS 10 CITATIONS

SEE PROFILE



Janaka Perera

Sri Lanka Institute of Information Technology

5 PUBLICATIONS 0 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Innovative Reusable Concrete Blocks Using Sustainable Materials [View project](#)



Innovative Concrete Mix Designs for Ultra-High Strength Concrete [View project](#)

EFFECT OF PORCELAIN WASTE AS A FINE AGGREGATE ON THE MECHANICAL PROPERTIES OF CONCRETE

K.W.D. Kobbekaduwa¹ and S.V.T.J. Perera^{1*}

¹Sri Lanka Institute of Information Technology, Malabe, Sri Lanka.

* E-mail: janakaperera2005@yahoo.com, janaka.p@slit.lk

Abstract: The demand for concrete keeps significantly increasing worldwide throughout the past few years period. The exponential development rate and construction processes on developing infrastructure facilities all over the globe has resulted this situation. As an outcome of that, the excessive production of concrete has led to several environmental impacts all around the world. This study investigated the suitability of crushed porcelain waste as a replacement for fine aggregates by analysing the strength gains and other mechanical properties depending on the replaced proportions. Porcelain Waste Fine Aggregate (PWFA) which is a low water absorbing material was used in replacing conventional fine aggregates in the proportions of 25%, 50%, 75%, 85% and 100% for the concrete of Grade 30. It was found that the most suitable and economical replacement proportion of PWFA is the 75% mix as it comprised a 28-day compressive strength of 54.31 MPa which is 50% greater than the compressive strength of control mixture. Due to the higher strength, the 75% PWFA Grade 30 mix can be implemented as Grade 45 concrete which can save up to 10% of the cost. The partial replacement of sand using PWFA significantly improved the performance of concrete while addressing several environmental and economic issues related to concrete industry.

Keywords: Concrete; ordinary Portland cement; fine aggregate; porcelain waste fine aggregate

1. Introduction

As the development rate of Sri Lanka in construction field increases exponentially, the excessive use of concrete has turned out to be a major consideration. The technology development and high demand for concrete has enforced people to come up with innovative methods to produce economical and sustainable concrete. The main objective of sustainable concrete is to guarantee the required mechanical properties and the ability to be prepared with a relatively low material cost and energy consumption.

The cement industry is considered as one of the largest manufacturing processes in the world. This particular process has led to various complications to the entire globe as it is a process which consumes higher amount of energy and contributes exceedingly in depletion of natural resources. The destruction of natural resources has created major problematic situations as a result of cement industry. Therefore, improving the quality of concrete with the use of lesser quantity of cement while utilizing least

amount of energy is considered as of utmost important (Shen et al. 2017). Also, around 5% of the global Carbon Dioxide (CO₂) emissions are accounted from the production process of Portland cement. Hence, a sustainable solution to reduce the environmental impacts of cement production is essential (Kannan et al. 2017).

Major concerns regarding concrete industry are the cost of natural aggregates due to scarcity and the hazardous environmental impacts such as erosion of river banks, dropping of ground water table, and destruction of riparian vegetation due to the excessive abstraction of sand all around the world.

Therefore, a numerous number of researches are being conducted throughout the globe in order to produce concrete effectively and sustainably by introducing innovative materials such as glass, plastic, rice husk ash, ceramic wastes, and porcelain wastes (Jamal et al. 2018).

Although ceramic is a common terminology used for all clay products such as porcelain,

earthenware, terracotta, stoneware and pottery. Porcelain and ceramic consist of different properties due to reasons such as the firing temperature of the clay, content of clay which used as raw materials, appearance, and water absorption. Porcelain is a durable and a harder material used to produce tiles, mugs cookware, etc. The researchers have found out that the water absorption of porcelain is much lesser than the water absorption of ceramic (Bertolissi, 2014).

In Sri Lanka the most common disposal method of porcelain waste is landfill as these wastes are non-recyclable. Since porcelain is hard and a durable material it is non-degradable, and landfilling is not an ideal way of disposal. Hence the disposal of porcelain waste can cause severe environmental impacts such as contamination of ground water and soil. (Porcelain waste is generated by ceramic industries) It has been found that a higher percentage of waste generation is caused by ceramic factories from abortive products which pass the manufacturing stages.

The research carried out by Awoyera et al. (2016) using waste ceramic wall and floor tiles aggregate concluded that, the natural aggregates can be partially replaced using crushed ceramic wastes and the experiment has revealed the fact that concrete produced using ceramic wastes has higher compressive strength when compared to concrete made out of natural aggregates. According to the results, 100% replacement of coarse aggregates and 100% replacement of fine aggregates separately attained highest compressive and tensile strengths (Awoyera et al. 2016). Most of the available research studies are based on ceramic aggregates while studies based on porcelain aggregates are rare. Hence, it is important to study and investigate the behaviour of porcelain based aggregates in order to fill the research gaps.

This study was undertaken by replacing natural fine aggregates using mechanically crushed porcelain waste in the process of concrete mixing. Investigation was based on to ensure that, this research would provide

solutions to the scarcity of natural fine aggregates, reduce the usage of cement and to minimize the disposal of porcelain waste facilitating with environmentally friendly solutions.

2. Methodology

2.1 Materials

Ordinary Portland Cement of strength class 42.5 N was adopted in all the experimental procedures. Coarse aggregates of 20 mm size were adopted, and they were ensured that the aggregates used in the experiments are of proper grading, clean and tough. River sand passing through 4.75 mm British Standard test sieve (BS812, 1990) was adopted in the investigations and the fine aggregates used was ensured to be clean and free from any other impurities. Clean and fresh water of drinking quality was used ensuring no foreign impurities. Crushed porcelain waste was used in the form of powder as a replacement to natural fine aggregates as Porcelain Waste Fine Aggregate (PWFA).

2.2 Test Variables

Replacement proportions of 0%, 25%, 50%, 75%, 85% and 100% of crushed porcelain waste was adopted to prepare concrete specimens of Grade 30 which were checked for compressive strength, tensile strength, and flexural strength after curing in water.

2.3 Test Program

The tests were carried out in two stages as, tests for aggregates and tests for concrete. Sieve analysis, particle density, water absorption and Aggregate Impact Value (AIV) test were carried out for natural aggregates and porcelain waste aggregates. Compressive strength, tensile strength, flexural strength, and slump test were carried out in similar conditions to obtain the properties of concrete in the fresh and hardened stages.

3. Results and Discussion

The Building Research Establishment method (BRE method) was adopted in the calculation of the Grade 30 mix design. In BRE method to obtain the mix proportions, the properties of natural fine aggregates

were used although it was replaced by PWFA (Teychenne et al. 1997).

3.1 Compressive Strength

The compressive strength was obtained by testing cubes (150 mm × 150 mm × 150 mm) on 7 and 28 days of curing after casting. Cylinders were tested after 28 days of curing. Initially the control mix (0% PWFA mix) was done to obtain the reference values for all the other castings. Subsequently, the other castings were done by replacing natural fine aggregates using PWFA. It was ensured that all the castings as well as the curing process were undertaken at similar conditions.

According to the results shown in Figure 1 for 7-day and 28-day average compressive strength, it clearly indicates that the highest strength is obtained by the mix where natural fine aggregate was replaced by 75% using PWFA. Considering the average (28-day) strength results, it was observed that the 75% PWFA mix has a significant strength increment of 50% when compared to the strength of control mix. Although the 75% PWFA mix indicated the highest compressive strength, it was also observed that the 25% PWFA mix has achieved a value of 53.24 MPa which is almost equal to the strength value observed in 75% PWFA mix. The 25% PWFA mix shows a 47% strength increment while the 50% PWFA mix shows a strength increment of 42% when compared to the control mix.

Hence, it can be observed that the introduction of PWFA into concrete has improved the compressive strength and this could be due to the less water absorbing property of PWFA.

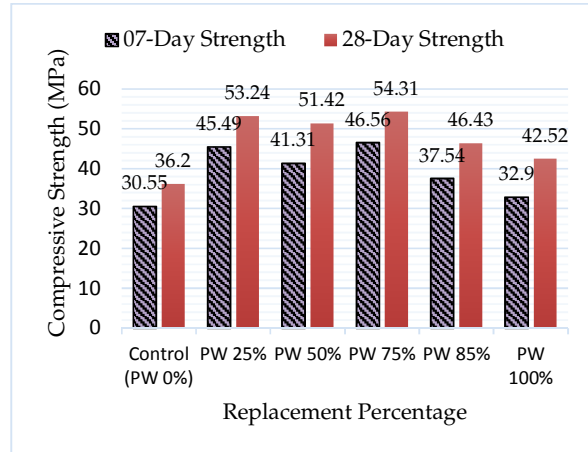


Figure 1: Cube compressive strength

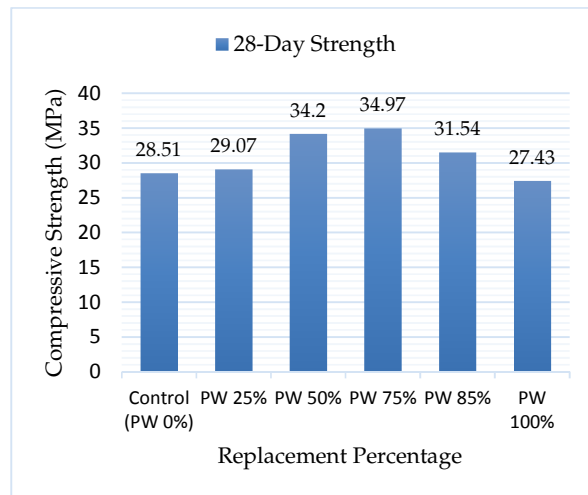


Figure 2: Cylinder compressive strength

As it was observed, the cube compressive strength of 75% PWFA mix was the highest, it can be further supported by the results obtained for the cylindrical compressive strength which is shown in Figure 2. It indicates the highest value of 34.97 MPa for the 75% PWFA mix which is 23% greater than the strength of control mix. Hence the results obtained from cube tests can be confirmed via analysing the results obtained by testing cylinders.

3.2 Splitting Tensile Strength

The cylinders cast and cured for 28 days under similar conditions were tested to obtain the following results which is indicated in Figure 3.

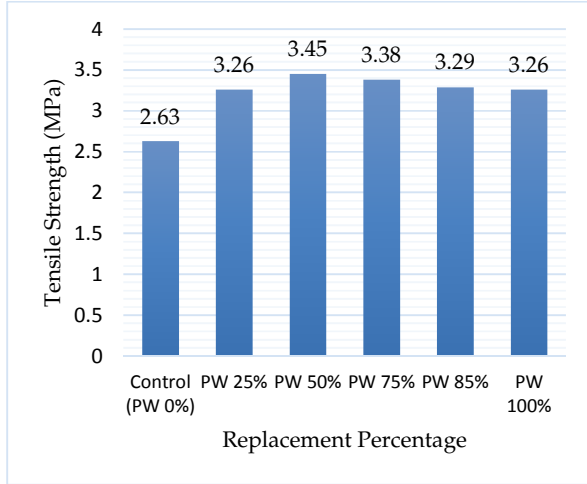


Figure 3: Splitting tensile strength

The obtained results for the tensile strength indicated similar values for the mixes of 25%, 50%, 75%, 85% and 100% of PWFA. As the rule of thumb for tensile strength of concrete is 5% to 10% of its compressive strength, the obtained tensile strength values for all the mixes with PWFA can be accepted. The increment of tensile strength with the introduction of PWFA could be due to its low water absorbing property.

3.3 Flexural Strength

Unreinforced concrete beams of Grade 30 were tested to determine the flexural strength of different mixes prepared including the control mix. The beams cast and cured for 28 days under similar conditions were tested to obtain the results which are indicated in Figure 4.

The mixes of 25%, 50%, 85% and 100% of PWFA indicate similar values while the 75% PWFA mix indicates a slightly higher value compared to the rest. A significant increment of flexural strength can be observed as a result of introducing PWFA. The 75% PWFA mix indicated an average flexural strength of 8.26 MPa which is 54% higher than the control mix.

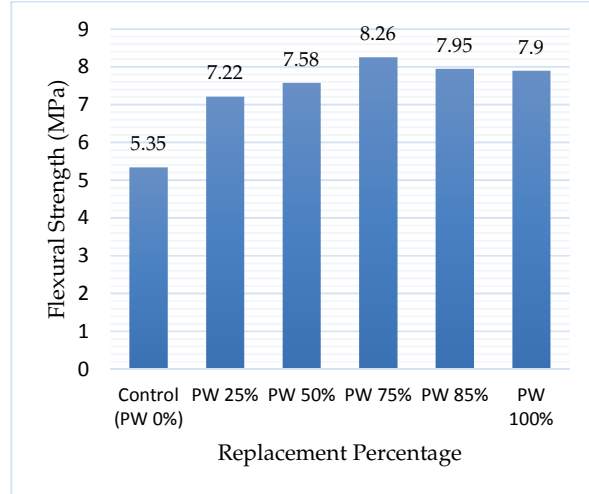


Figure 4: Flexural strength

3.4 Density

Cubes were used to obtain the density throughout the research study where the weight was divided by its volume in the fresh as well as in the hard stage to obtain wet and dry densities respectively. Figure 5 shows the variation of the average wet and dry densities with partial and full replacement of PWFA.

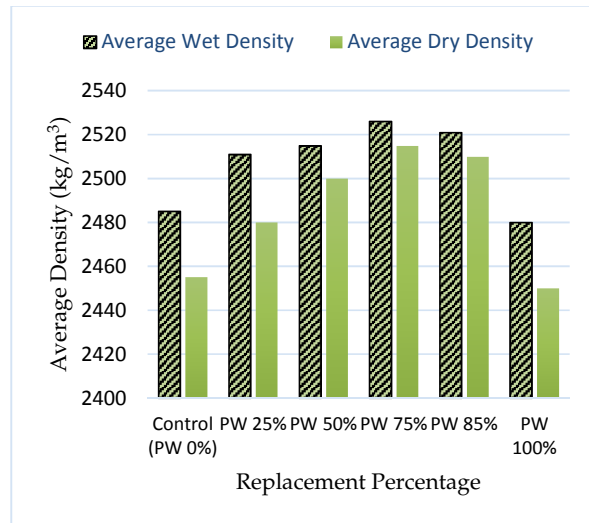


Figure 5: Variation of wet and dry densities

It was clearly observed that the introduction of PWFA to the concrete mix has minimized the water desertion from concrete since the gap between wet and dry densities are small for mixes of 50%, 75% and 85%.

3.5 Cost Analysis

Cost calculations were performed for 1 m³ of concrete for all the mix designs (unit rate method). Costs such as labour, tools or machinery and other overhead costs were not considered in the analysis. Cost of water was also ignored. The resource rates were obtained by Building Schedule of Rates (BSR, 2018) and by inquiring the market prices. The unknown resource rate of PWFA was calculated based on the actual cost which was spent on manufacturing and transporting.

Considering the cost per 1 m³ of concrete, the increment of the PWFA percentage has reduced the cost of concrete. The main reason for the reduced cost is that the PWFA used was obtained from landfills which was freely and readily available in excess. Hence it is clear that using PWFA in concrete mixing is an economical solution compared to the concrete made using conventional fine aggregates.

3.6 Economical Proportion

After analysing the properties of various mixes with different PWFA replacement percentages, it is clear that an optimum mix proportion cannot be identified as the results obtained for strengths are comparable for the replacement proportions of 25%, 50 % and 75%. Hence an optimum range can be presented from 25% to 75%.

The subsequent analysing tool which was used is cost analysis, and it indicated that the PWFA content is inversely proportional to the cost of concrete. That is, increment of PWFA reduced the cost. Therefore, in order to determine the most efficient and economical proportion the mechanical properties such as compressive/tensile strengths were observed with their respective costs as shown in Figure 6 and 7.

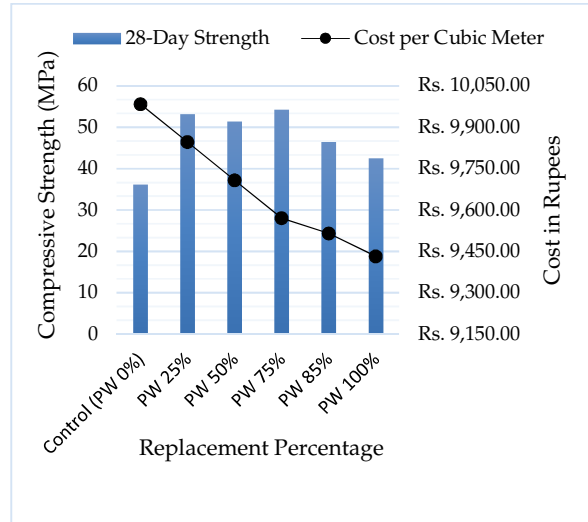


Figure 6: Variation of compressive strength with cost

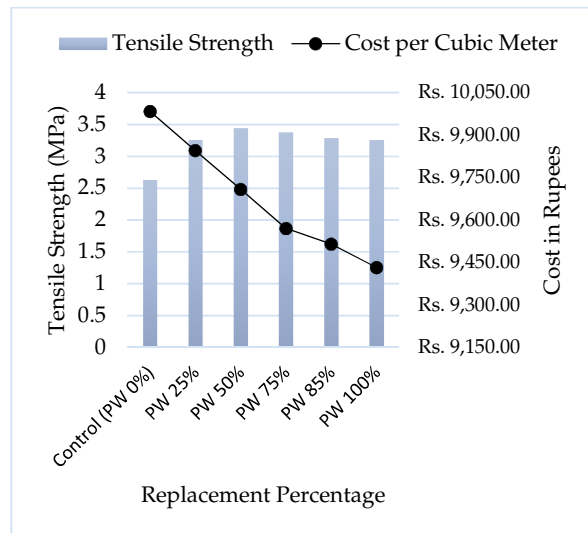


Figure 7: Variation of tensile strength with cost

According to the data analysis, the mix with 75% PWFA shows higher strength values and a minimal cost (4%) compared to the control mixture. Although the 100% PWFA mix showed a 6% cost lower than the control mixture its strength values are comparatively low. Hence the mix with 75% replacement of PWFA can be presented as the most economical proportion.

4. Conclusion

The study evaluated the properties of concrete upon fully and partial replacement

of fine aggregate using crushed porcelain waste for the concrete of Grade 30. The most economical proportion out of 25%, 50%, 75%, 85% and 100% of porcelain waste which yielded the highest compressive, tensile and flexural strengths for Grade 30 was found incorporating with the cost incurred.

The analysis of results presented similar strength values for the PWFA proportions of 25%, 50% and 75% for Grade 30 concrete. Hence, a typical optimum ratio was not recognized but an efficient range of 25% to 75% was identified. Out of the identified range, the 75% PWFA mix was selected as an economical mix which comprised a 28-day compressive strength of 54.31 MPa which is 50% greater than the compressive strength of control mix. Similarly, the 75% PWFA mix showed a tensile strength of 29% greater than the control mix. The other reason to select the 75% PWFA mix was, it can save 10% of the cost as it can be implemented as Grade 45 concrete due to its higher strength gain. Therefore, it can be concluded that, crushed porcelain waste in the form of powder can be utilized in the production of concrete successfully.

References

- Awoyera, P., Ndambuki, J., Akinmusuru, J. and Omole, D. (2016). Characterization of Ceramic Waste Aggregate Concrete. *Housing and Building National Research Center HBRC Journal*, 43(3), pp. 233-238.
- Bertolissi, N. (2014). Difference between porcelain and ceramic, or between fine china and bone china. [Online] Available at: <http://www.nicolettabertolissi.com/difference-between-porcelain-and-ceramic/> (Accessed: 21 July 2018).
- BSI, 1990. Testing aggregate. Testing concrete, 1 ed. London: BSI Publisher.
- Jamal, M., Noh, M., Juboor, S., Wan, M. and Takai, Z. (2018). Mechanical Properties of the Concrete Containing Porcelain Waste as Sand. *International Journal of Engineering and Technology*, 7(4.30), pp.180-184.
- Kannan, D., Aboubakr, S., EL-Dieb, A. and Reda Taha, M. (2017). High performance concrete incorporating ceramic waste powder as large partial replacement of Portland cement. *Construction and Building Materials*, 144, pp.35-41.
- Shen, W., Liu, Y., Cao, L., Huo, X., Yang, Z., Zhou, C., He, P. and Lu, Z. (2017). Mixing design and microstructure of ultra high strength concrete with manufactured sand. *Construction and Building Materials*, 143, pp.312-321.
- Teychenne, D., Franklin, R. and Erntroy, H. (1997). Design of Normal Concrete Mixes. Watford: Building Research Establishment.