Ceramic Tile Waste as Fine Aggregate for Marine Concrete Modules In Sri Lanka

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***Abstract**: Construction waste has a major impact on the environment. Reusing and recycling this waste can reduce the extraction of raw materials and help waste management. Therefore, this study was focused on ceramic tile waste which is released in the squaring process of tile manufacturing, and to develop a design to protect the coastal area as an end product. A mixed design based on BS 5328 with M15 targeted strength was achieved with the use of cement, water, and aggregates, where fine aggregates were replaced with ceramic tile waste in 25%, 50%, 75%, and 100%. XRD test was conducted to test the constituents of ceramic tile waste. Results indicated that a higher compressive strength was achieved when the replacement was at 25%. No heavy metals were detected in the XRD test. This study concludes that the optimum percentage and the water/cement ratio would be 25% of fine aggregates replaced with ceramic tile waste with a 0.5 W/C ratio. Two designs were introduced and samples were deployed in Polhena beach, Sri Lanka. The growth of corals on the designed structure indicated the appropriateness of the material and the structure of conserving corals.*

***Keywords**: Ceramic tile waste, Corals, Marine conservation, Mix designs, Waste management*

1. Introduction

All around the world is consuming an abundance of raw materials for their day-to-day construction works (Anuradha & Halwatura, 2020). Simultaneously, massive construction waste is also generated by creating numerous issues in management. From environmental, industrial, and sanitation, waste minimization is a significant area that needs to be vigilantly focused on (Elmahgary, et al., 2018). Therefore, the reuse and recycling of construction and demolition waste receive a high priority. This decreases the mismanagement of virgin raw materials and resolves the waste disposal problem leading to the availability of more land by averting the waste disposal sites. Not only that but also, but air and water pollution, deforestation, illicit mining of river beds for materials, and fossil fuel consumption, are also minimized through proper waste management (Bansal & Mishra, 2016). Furthermore, the reuse of waste gives aid in terms of energy, mostly when the waste of kiln industries such as ceramic industry or roof tile industry where high endothermic decomposition reactions occurred, consequently recovering the energy assimilated during the manufacturing stage. The ceramic tile industry has prevailed all around the world and Figure -1 portrays the variation of tile production as per the area.

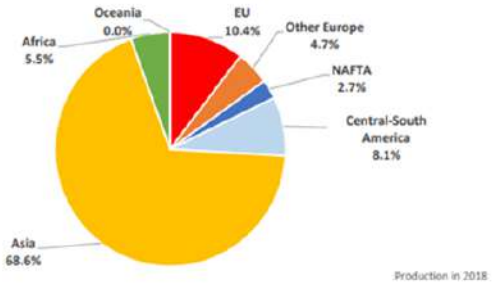


Figure 1. : World tile production by geographical area in 2018 (Ekop, 2016)

The Ball clay, Kaolin, Quartz, Feldspar, Silica, and Dolomite are used for the production of ceramic tiles and they can be easily found in Sri Lanka (Liyanage & Ranasinghe, 2019). The production of these tiles follows five main steps, raw material extraction, grinding and mixing the extracted materials, granulating by spray drying, pressing, firing, and finally polishing and glazing [4]. Due to the increment in infrastructure development in recent years, Sri Lanka has focused on using natural aggregates and waste reduction techniques (Deiyagala, et al., 2017). Currently, manufacturers are disposing the ceramic tile waste to fill the low lands and abandoned mines. Although ceramic tile waste is generated before the kiln process is reused, waste that is generated after the kiln process has become a real threat as it is disposed to the environment (refer to Figure 2).

Figure 2. Production and waste generation process of ceramic tiles.

Moreover, ceramic tile wastes are generated not only within the ceramic tile processing but also within the construction stage of the floor and the demolition stage.

Most importantly, ceramic tile wastes reason for the pollution of groundwater, air, and soil. Further, these ceramic tile wastes are stored as heaps at disposal sites. Assessed values show that approximately 30% of the daily production of the ceramic industry turns into waste and there is no form of recycling for the ceramic waste (Tabak, et al., 2016). Moreover, annually nearly 250,000 tons of tiles are dilapidated, whereas 100 million tiles are used for maintenance work (Topçu & Canbaz, 2007). Nevertheless, ceramic tile waste is, hard, durable, and highly resilient to physical, biological, chemical, and degradation processes (Bansal & Mishra, 2016). Waste ceramic tiles reason only the presence of pollution. Owing to these reasons ceramic industries are trying to find answers for the disposal of tons of ceramic tile wastes. In the meantime, conventional fine aggregate (sand) reserves are draining fast as they use for numerous construction works. Due to the post-war construction boom of Sri Lanka, these two issues are significantly posed. Even though ceramic tile waste generates prolonged negative effects on the environment, only a limited number of studies have been conducted in Sri Lanka to develop alternative construction materials from ceramic tile waste (Tabak, et al., 2016).

Sri Lanka is an island surrounded by the Indian Ocean. Sri Lankan coastal area was rich with corals a few decades back and currently reducing rapidly due to various human activities. During the 26 years of civil war (1983-2009) tourism has been focused on the southern area rather than the Northern side. Therefore, the physical damage to the southern area is a bit higher. This has affected negatively the corals too. The coral cover on the southern beaches is being deteriorated at an increasing speed. The corals need ideal conditions and a very long time for their regrowth, but this has not been provided for the corals on the Southern coast. Thus, various precautions are adopted to protect corals as well as to plant them. Placing concrete sections is one of the methods to grow coral but they are not effective as the design of the concrete section is not very suit for the Sri Lankan coastal conditions. Therefore, it is necessary to come up with suitable designs for the concrete sections. Further, if it is possible to develop these suitably designed structures for coral plantation with concrete which is developed through ceramic tile waste, it would be ideal as it supports nature in two ways. But, no studies have been conducted related to this, and therefore, this research aimed to develop suitably designed structures for Sri Lankan coastal areas with concrete manufactured through ceramic tile waste. Therefore, two objectives were implemented to achieve the above aim (1) To develop a mixed design as a partial replacement for the fine aggregate of concrete and (2) To design and test the suitability of marine conservation modules constructed from the developed mixed design.

2. Materials and Methods

A. Material

Commercially accessible Ordinary Portland Cement following BS 12 [10] was used in testing. The coarse aggregate, size of between 20mm and 4.75mm was considered for the study. The fine aggregate used in the experiment was a mix of natural sand and ceramic tile waste. The ceramic tile waste was obtained from the wet squaring waste plant of Royal Ceramic Lanka (PLC), Horana, Sri Lanka.

The sieve analysis test confirmed that the major part of the fine aggregate is the powder passing through the 125 µm filter with a weight of 75g of the selected sample. Preliminary investigations were directed on the aggregates following BS 882 to determine their suitability. The water used for mixing and curing specimens was drinking quality water.

Table 1. Selected mixed design ratios

Mix designs	**Materials**			
	Cement	***Fine Aggregates***		***Coarse Aggregates***
		Ceramic Tile Waste	***Natural Sand***	
M1	1	0.5	1.5	4
M2	1	1	1	4
M3	1	1.5	0.5	4
M4	1	2	0	4
M5-Stand	1	0	2	4

B. Methodology

A mixed design based on BS 5328 with M15 (Anon., 1990) was achieved with the use of cement, water, and aggregates. There the fine aggregates were replaced with varying percentages of ceramic tile waste at 25%, 50%, 75%, and 100%. In each mix, nine (9) 150mm x 150 mm x 150 mm sized concrete cubes were produced as the total was 45 cubes. The water to cement ratio was varied from 0.5 – 1.1 to achieve the required workability yet no admixtures were used for the mixing. Then the materials were mixed within a mechanical mixer. The slump test was performed Mix designs Materials Cement Fine Aggregates Coarse Ceramic Aggregates Tile Waste Natural Sand M1 1 0.5 1.5 4 M2 1 1 1 4 M3 1 1.5 0.5 4 M4 1 2 0 4 M5-Stand 1 0 2 4 according to the BS EN 12350-2 (Anon., p. 2009) for the prepared concrete before the molds are filled with concrete for the cube test. The cast specimens (cubes) were covered with polythene only to be removed from the mold when it was up to 24 hours and cured in water until their testing age of 28 days (Refer to Figure 3). The compressive strength was tested using a universal compression testing machine.

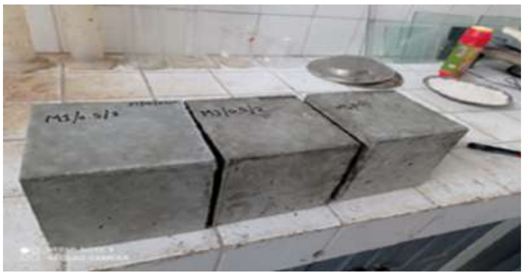


Figure 3. Prepared test samples before curing

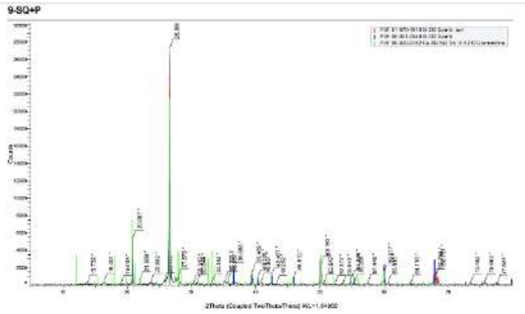


Figure 4. XRD results of ceramic tile waste.

An XRD test was conducted for the ceramic tile waste. This was mainly to understand the constituents of the ceramic tile waste (refer to Table 2) as well as to check the presence of heavy metals and other harmful chemical constituents which would have a negative effect on the coastal area.

Table 2. Composition of ceramic tile waste

Constituent	Clay	Na-Feldspar	Talc	K-Feldspar	Cyclone dust	Filter dust	Sludge
L.O.I	7.99	0.97	7.20	0.48	4.24	4.47	4.0
SiO_2	66.1	66.4	47.2	71.29	64.45	63.3	65.4
Al_2O_3	19.5	19.0	7.22	15.51	19.25	20.2	18.8
Fe_2O_3	1.66	0.75	7.13	0.54	3.07	2.76	2.10
TiO_2	1.95	0.41	0.15	0.07	1.16	1.04	0.74
CaO	0.06	0.60	0.35	0.47	0.81	0.74	2.80
MgO	0.05	0.12	30.2	0.00	1.87	2.19	2.99
K_2O	0.52	0.32	0.13	7.71	1.28	1.24	1.57
Na_2O	0.03	10.9	0.03	3.41	2.70	2.97	2.57
MnO_2	0.03	0.03	0.11	0.03	0.04	0.04	0.03
P_2O_5	0.00	0.03	0.00	0.00	0.57	0.47	0.46
Cl^-	0.16	0.06	0.05	0.08	0.00	0.00	0.00
SO_3^{--}	1.44	0.18	0.09	0.08	0.00	0.00	0.00
Total	99.7	99.8	99.9	99.67	99.44	99.5	99.58

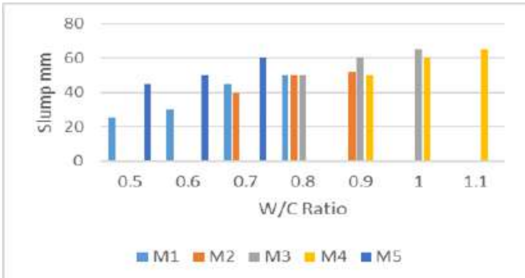
Source: (EI-Fadaly, et al., 2010)

An appropriate design was developed for a coral hub considering the environmental issues, easy handling, applicability, and adaptability to the marine environment.

3. Results and Discussion

Figure 4 displays the X-ray diffraction (XRD) analysis of the ceramic tile waste. The XRD indicates that the main peaks were noticed between 2-theta values of 20° and 30° which designates the existence of Silicon Dioxide (SiO_2). Results indicate that there are no heavy metals present in the ceramic tile waste.

Figure 5. Slump test analysis



The slump test was conducted using the selected sample concrete mixers. Most of the concrete mixes had zero workability for 0.5 – 0.7 water-cement ratios. According to Figure 5, M1 is the only mixed design with ceramic waste that shows a slump value of 0.5 water-cement ratios. M5 shows the conventional concrete without ceramic waste. So, the workability is higher in low water-cement ratios. Ceramic waste concrete shows workability for higher water-cement ratios which indicates this concrete needs more water to get a slump. In M1 the ceramic dust has only been used for 25%. In M2 where the dust is 50% increased there is no workability in a 0.5 W/C ratio. But in 0.7w/c workability was appropriate. The experiment has done without using any kind of admixture. In M1 the ceramic dust has only been used for 25%. In M2 where the dust is 50% increased there is no workability in a 0.5 W/C ratio. But in 0.7w/c workability was suitable. The experiment has done without using any kind of admixture. Figure 6 demonstrates conducting the slump test in the laboratory.

Figure 6. Conducting Slump test in the lab

Figure 7 demonstrates the variation of compressive strength against the w/c ratio with different compositions (25%, 50%, 75%, and 100%) of fine aggregate replacements in 28 days of curing age.

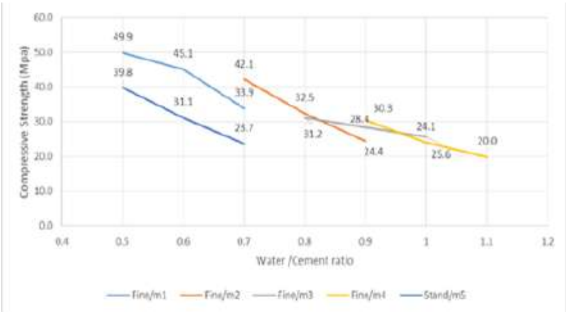


Figure 7. Variation of compressive strength against the w/c ratios

There the water to cement ratio (w/c) was increased with the increment of ceramic tile waste proportion. The test results show that using ceramic tile waste as fine aggregate replacements increases the compressive strength of concrete compared to the compressive strength of normal concrete. It can be identified that the highest compressive strength was obtained when the natural sand was replaced by 25% (M1) from the ceramic tile waste having a value of 49.9 MPa with a W/C ratio of 0.5.

So M1 mix design was chosen for the final product design.

As the next step, two designs were introduced from the newly developed concrete.

1. Design A - This structure was developed to conserve the corals. When the structure is deployed, the corals can be grown on the structure. (Refer to Figure 8)
2. Design B – This structure was introduced to build a walking path where people can walk without harming the corals. This also creates a breeding environment for fish. (Refer to Figure 9)

Structures are designed to be attached to existing infrastructure, while others sit independently on the substrate underneath or adjacent to infrastructure. Figure 8 shows the developed coral hub design.

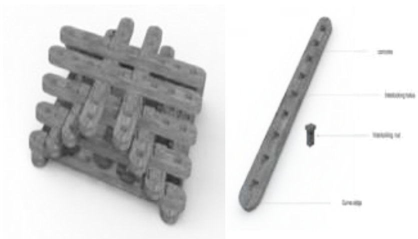


Figure 8. Structure of Design A

These single modules or structures with multiple modules can be used as new infrastructure or added to existing structures. Most importantly, single modules can be modified to hang on aquatic infrastructure. Figure 9 represents the design developed for the building of the walking path.

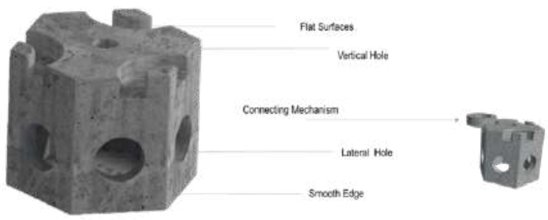


Figure 9. Structure of Design B

These modules can be attached to the infrastructure and anchored to the substrate to provide additional stability in high-energy environments such as tidal waters, storm, and flood conditions.

To assess the suitability of these designs, prepared samples were deployed in Polhena beach, Sri Lanka. Polhena is a well-known beach that includes coral reefs and reef lagoons. Many local and foreign visitors visit Polhena as the area is blessed with immaculate stretches of coral reefs, enriched with high biodiversity (refer to Figure 10).

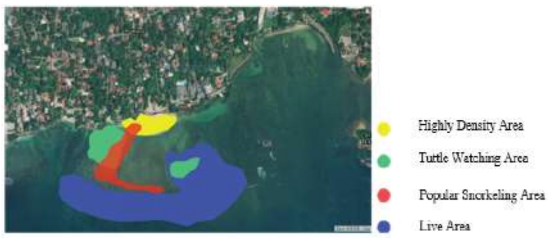


Figure 10. Selected study area, Polhena Beach, Sri Lanka

Most importantly, lots of coral reefs and reef lagoons in this beach have been damaged due to these visitors and the fishermen in the area. Therefore, the purpose of these developed designs was to replant the corals.

The deployed samples and designs A & B were checked after 2 months, 6 months, 1 year, and 2 years (refer to Figure 11-18) for the growth of corals. It was identified that even without planting the corals on the structure, they have grown confirming the appropriateness of the product.

Figure 11. After deploying the samples to the research area, coral development was observed after 2 months

Figure 12. After deploying the samples to the research area, coral development was observed after 2 months

Figure 13 Puff fish choosing Marine Condo as its habitat

Figure 14. Design B after 1 year of deploying

Figure 15. Coral development after 2 years of Design B

Figure 16. Design A after 3 days of deploying the sample

Figure 17. Design A after 1 year of deploing the sample

Figure 18. Development of corals on Design A after 2 years of deploying the sample.

4. Conclusion

Ceramic tile factories in Sri Lanka produce waste products such as ceramic powder, ceramic glaze, and sludge and there is no mechanism to deal with that waste locally. Every factory had been made an effort to provide a better solution, but there arises a requirement of a common solution to dispose of these wastes. This is not only important for countries like Europe, India, China who are the giant in the manufacturing field of ceramic but also for Sri Lanka which is an island where there aren't many factories are situated and this is being a very severe problem in the long run because this ceramic waste will decay for many years and will not be added to the environment. Tile fragments were not considered in this study. The main focus has been on squaring and polishing waste. To simulate the interest, to re-use the ceramic waste, it should be cheaper to re-use than dispose of. Tile pieces are often used after a process of remaking. But due to the powdery nature of tile-squaring, it can be used to manufacture other products profitably. Although there are advanced techniques for waste management in the world, those are not properly utilized in Sri Lanka Reusing the maximum amount of waste without damaging the quality of the tile can prevent the wastage and by utilizing other waste in more suitable industries,

we can maximize the use of natural resources as well as protect the environment XRD testing can make it clear that it does not contain any harmful substance for the environment and organisms. Durability, strength, and heat resistant properties of this ceramic powder make it ideal for producing economically important products. According to many other study references, these are being used in concrete mixing. 50 Also, the amount of waste removed from dry squaring is subtle.

The compressive strength of concrete increased with tile waste content in the concrete and decreased with the increased water/ cement ratio of the concrete. The workability of concrete decreases with an increase in tile waste content in the concrete.

The highest compressive strength was obtained when the fine aggregate mixture was 1:3, ceramic tile waste: natural sand and the water/cement ratio is 0.5. This ceramic waste has the potential to cover a large area of production in addition to this, for further experiments, some field investigations are being carried out to use this waste for the growth of marine organisms. Within a short period of two months, we could observe a variety of algae appeared on it.These optimum values were used in producing the designed blocks. After observing the results, it can be seen that the structure wasn't moved yet corals have grown on covered the deployed structure. The product has blended with the environment preserving marine life.

References

Anon., n.d. *BS 5328 Part 2:1990, Methods for specifying concrete mixes.,* s.l.: s.n.

Anon., n.d. *BS EN 12350 Part 2:2009 Testing fresh concrete: slump test.,* London: s.n.

Anuradha, I. & Halwatura, R., 2020. *Life Cycle Embodied Carbon Assessment of Roofing Materials.* s.l., s.n.

Bansal, A. & Mishra, G. B. S., 2016. Recycling and reuse of construction and demolition waste: sustainable approach. *ICSBE,* Issue 129, p. 6.

Deiyagala, D. et al., 2017. Engineering and Economic Viability of Using Crushed Construction Waste in the Production of Concrete and Mortar. *ENGINEER; The Institution of Engineers, Sri Lanka,* L(03), pp. 41-53.

EI-Fadaly, E., Bakr, I. M. & Breka, M. A., 2010. Recycling of Ceramic Industry Wastes in Floor Tiles Recipes. *Journalof American Science ,* pp. 241-247.

Ekop, O. A. H. a. I. E., 2016. Compressive Strength Characteristics of Tile Waste Concrete. *International Journal of Engineering Sciences & Research Technology,* pp. 268-273.

Elmahgary, M. G., Amin, S. K., Sadek, M. A. & Abadir, M. F., 2018. Waste Minimisation of Ceramic Wall Tiles. *Chemical Engineering Transactions,* Volume 70, p. 6.

Liyanage, S. & Ranasinghe, D. W., n.d. *Identification of the posibility to reuse the ceramics glazed tile waste as an Eco friendly raw material for the manufacturing industry in Sri Lanka.* 2019, University of Moratuwa, Sri Lanka.

Tabak, Y. et al., 2016. *Ceramic tile waste as a waste management solution for concrete.* s.l., s.n., p. 9.

Topçu, B. & Canbaz, M., 2007. Utilization of Crushed Tile As Aggregate in Concrete. *Iranian Journal of Science & Technology, Transaction B, Engineering,* 31(The Islamic Republic of Iran), pp. 561-565.

Abbreviations and specific symbols

XRD - X-ray diffraction analysis

W/C ratio - Water /Cement Ratio

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