

A blending of construction and demolition and agricultural wastes for efficient circularity: A sustainable approach for ceramic tile coarse aggregates and rice husk ash in M20 concrete

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Abstract The present study evaluates a sustainable approach of blending ceramic tile coarse aggregates (CTCA) and rice husk ash (RHA) to produce M20 concrete. In the first step, CTCA was used to replace gravel stones by weight with the percentage replacements of 0% (C00 and control), 10% (C10), 20% (C20), 25% (C25) and 30% (C30) in M20 concrete. The best CTCA replacement result was used as the control for the second step. In the second step, ordinary Portland cement (OPC) was replaced by RHA in the range of 0% (C00R=C20=control), 5% (C05R), 10% (C10R), 15% (C15R) and 20% (C20R). The workability of fresh concrete, compressive strength at 7, 14 and 28 days, bulk density and water absorption were tested for each step. When blending CTCA in concrete, 20% CTCA replacement showed the maximum compressive strength of 22.43 ± 0.01 MPa on the 28th day. An increased compressive strength of 23.30 ± 0.02 MPa and relatively low water absorption (3.13%) resulted when blending C20 and C05R. The bulk density of concrete increased gradually as curing age increased, while showing an inverse relationship with RHA. The study recommends the replacement of 20% natural gravel stones and 5% OPC with CTCA and RHA, respectively, in concrete.

Keywords: Ceramic tile coarse aggregates, circular economy, compressive strength, M20 concrete, rice husk ash, water absorption

Introduction

Construction and demolition (C&D) waste is the materials generated during the construction of new buildings, renovation of old structures, partial deconstruction of buildings, and entire building demolition (Cook et al., 2022). However, C&D waste receives considerably less attention in the literature than municipal solid waste despite being a substantial global contributor toward total solid waste generation (estimated 36% wt.), as stated by Wilson et al. (2015). The growing environmental challenges and pollution through construction and demolition waste thrive in search of sustainable approaches to minimize many negative environmental impacts.

Being one of the major construction materials, ceramic tiles play a key role in almost all buildings. However, it has been estimated that about 30% of the daily production in the ceramic industry goes to waste without recycling (Subedi et al., 2020). As described by Cook et al. (2022), this waste can be

transformed into useful coarse aggregate as the properties of ceramic waste coarse aggregate are well within the range of the values of concrete-making natural aggregates (i.e. natural gravel stones). Studies on the partial replacement of natural gravel stones by ceramic tile waste of appropriate size in concrete mixtures have also drawn attention to the material re-use. Not like in a linear economy, material recovery in a circular economy saves vast amounts of natural resources while reducing their carbon footprints. As described by Daniyal and Ahmad (2015) and Tavakoli et al. (2018), the compressive strength of concrete gradually increased with the increase in the quantity of coarse waste ceramic tile aggregate up to certain limits.

Ordinary Portland cement (OPC) is mainly added to the preparation of concrete to enhance the binding properties of the mixer. As stated by Arora (2022), the estimated amount of CO₂ produced during the burning and grinding of the Portland clinker is 8 % or even 10 % of the global annual



emission of CO₂. Being the leading greenhouse gas emitter and the most expensive raw material of concrete, searching for suitable substitutes for OPC is a timely need. Rice husk ash (RHA) is a common waste material produced by rice mill industries in countries with agriculture-based economies. Supplementing a portion of OPC with RHA has been shown to encourage the formation of a highly dense, minutely porous calcium-silica-hydrate (C-S-H) gel around cement particles and to improve the microstructure of the interfacial transition zone between the cement paste and the aggregate in cement-stabilized systems (Oleng, 2018). These characteristics of OPC-RHA concrete contribute to superior early and ultimate-compressive strengths, improved impermeability, exceptional resistance to chloride ion penetration and improved freeze-thaw durability (Saraswathy and Song, 2007).

Thus, the present study planned to blend both CTCA and RHA in M20 concrete to develop efficient circularity for C&D and agricultural waste.

Materials and methods

Raw materials and their properties

Crushed gravel stones and tile aggregates with a maximum size of 20 mm, manufactured sand (M Sand) free from clay, loam, debris and organic or chemical matter with a size less than 4.75 mm, OPC, and RHA were used as raw materials (Figure 1) for the preparation of M20 concrete. Gravel stones, M sand, and OPC used in the present study were purchased from a hardware shop. CTCA and RHA were obtained respectively, from a construction site in Colombo, Sri Lanka, and a nearby rice milling factory. The particle shapes and surface texture of the RHA were observed by a scanning electron microscope (SEM). The materials complied with standards prior to the preparation of the concrete (Table 1).



Figure 1: Raw materials. a: granite coarse aggregate b: CTCA c: OPC d: sand e: RHA

Table 1. Standard procedures applied for material properties

Property	Aggregates	OPC		Particle size distribution	Specific gravity	Bulk density	Aggregate Impact Value (AIV)
Method and Reference	ASTM C33 (ASTM C33-16, 2016)	BS 197-1:2011 (BS-EN 197-1, 2011)	EN	ASTM C136 (ASTM C136/C136M-14, 2007)	ASTM C127 (ASTM C127-88,1993)	ASTM C128 (ASTMC128, 1993)	BS 812-112:1990 (BS 812-112, 1990)

Experimental procedure

The experiment was carried out in two steps. In the first step, the natural gravel stone aggregates were replaced by CTCA according to the proportions shown in Table 2. In contrast, the second step was carried out after finding the optimum value of

substitution by analyzing the mechanical properties found in the first step.

In the second step, both the granite stone aggregate and OCP were replaced by CTCA and RHA (Table 3), while the CTCA was sustained as a constant percentage throughout the experiment.

Table 2. Mix proportion of concrete containing various amount of CTCA

Mix Code	CTCA (%)	Sand (kg/m ³)	Gravel (kg/m ³)	CTCA (kg/m ³)	Cement (kg/m ³)	Water (kg/m ³)
C00	0	742	1113	0	317	204
C10	10	742	1000	113	317	204
C20	20	742	890.33	222.66	317	204
C25	25	742	834.66	278.33	317	204
C30	30	742	779.16	333.83	317	204

Table 3. Mix proportion of concrete containing various amounts of RHA and constant amount of CTCA

Mix Code	CTCA (%)	RHA (%)	Sand (kg/m ³)	Gravel (kg/m ³)	CTCA (kg/m ³)	Cement (kg/m ³)	RHA (kg/m ³)	Water (kg/m ³)
C20	20	0	742	890.33	222.66	320	0	210.66
C05R	20	5	742	890.33	222.66	304	16	210.66
C10R	20	10	742	890.33	222.66	288	32	210.66
C15R	20	15	742	890.33	222.66	272	48	210.66
C20R	20	20	742	890.33	222.66	256	64	210.66

Casting and curing of test specimens

All concrete mixtures were prepared using a laboratory concrete mixture of 100 L capacity. Mixture time was about 8 minutes for each mixture, and the process of mixing included the mixing of gravel and sand in the mixer for 2 minutes, adding of binding materials (OPC in the first step and OCP and RHA in the second step) and mixing for 3 minutes, adding of water (as specified by Table 2 at

the first step and Table 3 as the second step) and mixing them for 3 minutes until get a homogenous mixture. The replacements in each step were done at a constant water/cement ratio of 0.64.

The fresh concrete was cast and compacted in 150 × 150 × 150 mm cubic moulds (Figure 2), applying mechanical vibration. After preparing the specimens, they were stored in an open room for 24 hours, covering them with wet paper bags. The specimens were de-moulded and moist cured,

keeping more than 95% relative humidity for 14 days. The specimens were then maintained at room temperature for another 14 days.



Figure 2: Hardened concrete cubes

Assessment of the properties of concrete

Workability

Slump is a measure of concrete's workability or fluidity. The workability of concrete was investigated as per ASTM C143 (ASTM

C143/C143M, 2015). Fresh concrete was filled in a slump mould placed on a flat surface and tamped with a steel rod 25 times at three different layers. After the top layer was tamped, the surface of the fresh concrete was struck off using screening and rolling motion with a tamping rod. The mould was immediately removed from the fresh concrete by raising it carefully in a vertical direction. The slump was immediately measured by determining the vertical difference between the top of the mould and the displaced original centre of the top surface of the specimen. The workability of the second step was maintained as per the mean workability (slump value) obtained in the first step for the optimum percentage of substitution.

Compressive strength

The compressive strength of the concrete (n=4 per each type) was measured at 7, 14 and 28 days using an automatic concrete compression testing machine (Figure 3) following the methodology given in BS EN 1015-11. This was tested by using the load at failure compression force. The maximum applied load for each test was recorded. The maximum bearing capacity was 3000 kN (3 MPa).



Figure 3: Equipment used for measuring compressive strength

Water Absorption

The water absorption was carried out for control and those different ratios of substitutions of concrete. This was done in two steps, viz. soaking the samples with water in the bath and drying the samples to a constant weight in a dryer with hot air circulation at 105°C for 24 hours. This was done according to the modified ASTM C642. When soaking, the bath was filled with water at a temperature of 22°C to half the height of the samples. After 24 h, water was added to the bath to a level 10 mm higher than the level of the samples.

The cubes were kept in the bath until the end of sample saturation. After another 24 h, the samples were removed from the water, the surface water was wiped off, and the weights of the cubes were recorded. The saturation of the samples ended for the following days, until two subsequent weighings showed no increase in mass. Then, samples were placed in a dryer with hot air circulation at 105°C. The samples were dried until they were at a constant weight, and the results were recorded.

The water absorption of the concrete cube was computed by Eq. 1. (Golewski, 2023)

$$\text{Water absorption} = \frac{W_s - W_d}{V} \times 100\% \quad (1)$$

Where,

W_d is the weight of the concrete cubes in a dry condition, W_s is the weight of concrete cube in wet condition and V is the volume of the concrete block.

Statistical Analysis

Data were subjected to One-way ANOVA followed by Tukey's pairwise comparisons in Minitab 19 version after following the Anderson Darling Normality test to determine the significant differences among different types of concrete manufactured. Percentage values were arc-sin transferred before subject to ANOVA.

Results and discussion

Raw materials and their properties

The compatibility of raw materials is the most critical factor in the concrete manufacturing process. The specific gravity, bulk density of all the raw materials, the percentage of water absorption and aggregates impact value (AIV) of coarse

aggregate are presented in Table 4. The specific gravity and the bulk density of CTCA were lower than that of the natural granite stones. This is due to the lower weight of the ceramic tile, as described by Ikponmwo and Ehikhenmen (2017). A higher water absorption percentage was observed for the ceramic. That may be due to its broken surface area, pore structure and aggregates. AIV of aggregate provides a relative measure of the resistance of an aggregate to sudden shock or impact. Aggregates specified 'strong' if the aggregate impact value is between 10% and 20% (BS 812-112, 1990). The value obtained from the study for CTCA was 19.65 %, which was within the above range. The actual property aggregate must minimize the effect benefit of the aggregations as they are softer and break-resistant. It was assumed that the aggregates used were medium-durable, and the effects were prone to crush.

Table 4. Physical properties of aggregates and binding material

Aggregates	Specific Gravity	Bulk Density (kgm ⁻³)	Water Absorption (%)	AIV (%)
Gravel stone aggregates	2.65	1464	1.8	15.62
CTCA	2.11	1307	3.0	19.65
RHA	2.34	135	Not measured	Not measured
Cement	3.15	1442	Not measured	Not measured

The particle size distribution of CTCA and natural coarse aggregate is more or less similar; all the particles were less than 37.5 mm. Nevertheless, around 93% of CTCA and 90% of natural coarse aggregate passed through a 20 mm sieve (Figure 4a). About 90% of particles of RHA passed through a 100 μm sieve, indicating that the collected RHA

samples consisted of more fine particles. The particle size ranged from 0.15 μm to 350 μm (Figure 4b). The particle size of OCP is much larger, and as described by Cordeiro et al. (2019), the particle size ranged between 0.4 μm and 80 μm , letting 90% of particles pass through a 50 μm sieve.

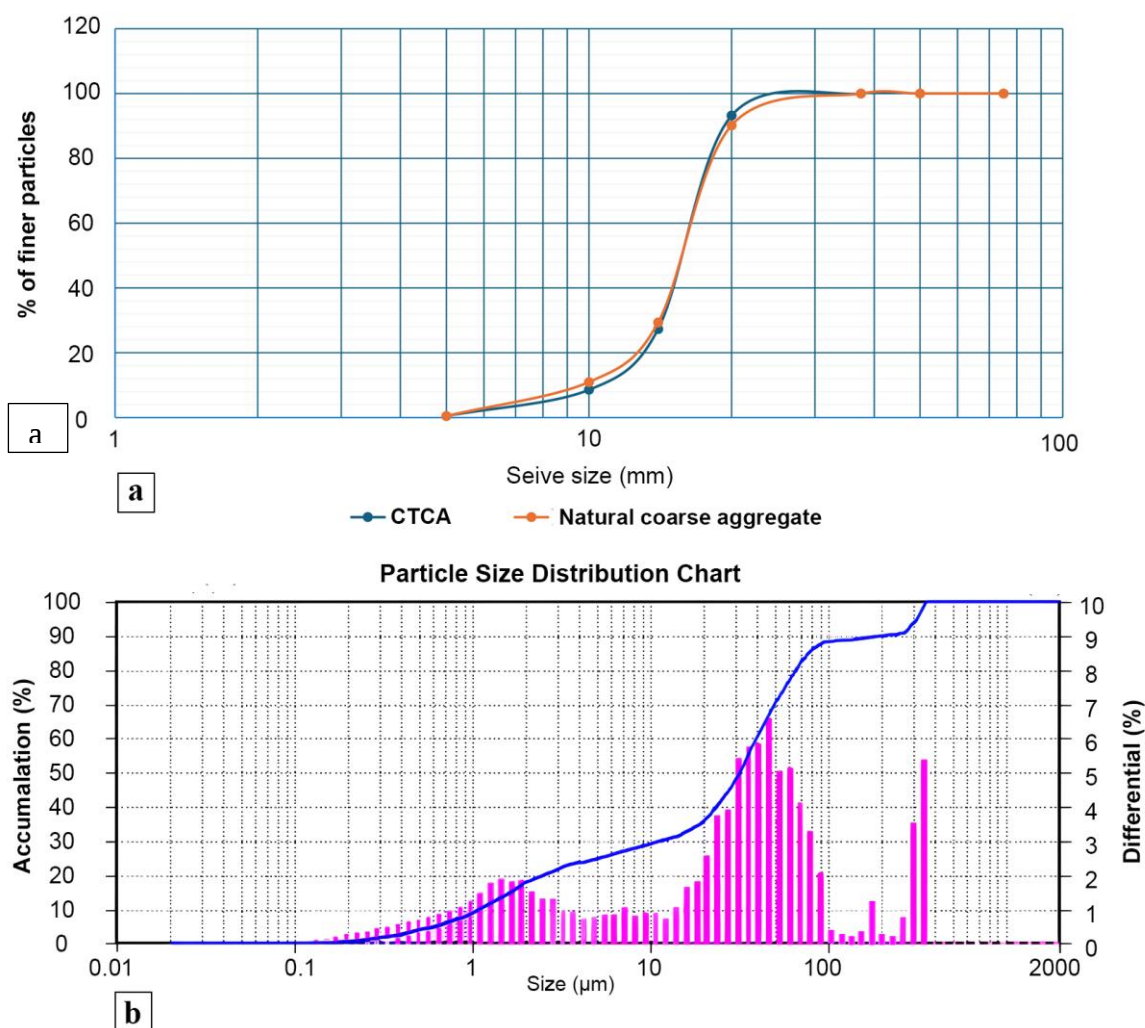


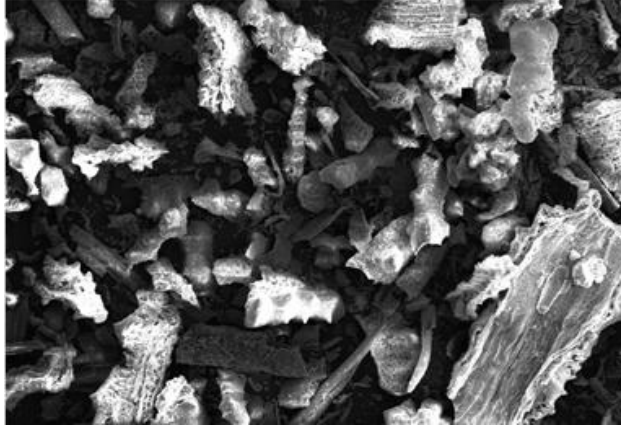
Figure 4: Particle size distribution : (a) CTCA and natural coarse aggregates, (b) RHA

The chemical composition of RHA indicated that RHA used in the present study contained 83.9 % of silicon dioxide (SiO_2) and 0.9 % of aluminium oxide (Al_2O_3) (Table 5). Pozzolana is a naturally occurring and siliceous and aluminum materials with little or no cementitious properties in themselves and the presence of moisture, it chemically reacts with calcium hydroxide released during Portland Cement hydration to form compounds with cementitious

properties (Neville and Brooks, 2010). The CaO percentage of OPC was 68.8%. In addition, the observed RHA by scanning electron microscope (SEM) (Figure 5) was slightly angular, with a smoother surface texture. The grains, therefore, connect with the surface of the cement matrix, and the pozzolanic reaction products are visible in its area as mentioned above.

Table 5. Chemical compositions of OCP and RHA

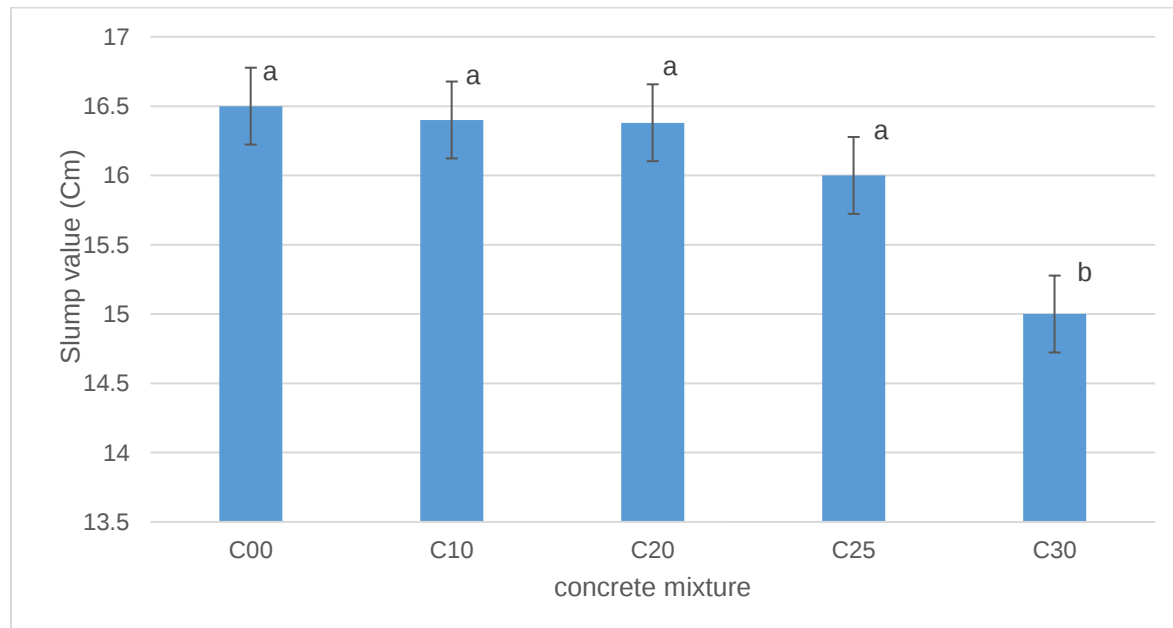
Chemical Composition %	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	MgO	Loss of Ignition
OCP	21.7	5.0	68.8	3.2	2.9	1.2
RHA	83.9	0.9	0.8	6.0	1.7	5.8

**Figure 5:** SEM observation of RHA at ×250 magnification level

Properties of concrete incorporated with CTCA (step 1)

Workability

The comparison of slump test results for different CTCA concrete mixes, including the control mix is shown in Fig. 6. The slump values ranged between 150 mm and 165 mm. The slump value decreased as CTCA increased, while the control mix exhibited the highest workability. It should be noted that the slump was obtained at the constant water/cement ratio of 0.64 without a plasticizer. Al-Hashem et al. (2022) stated that incorporating a super plasticizer or water reducer could improve the workability of concrete.

**Figure 6:** Mean slump value for the different concrete mixture

Data shown in the graph are mean $\pm$ SEM. Mean value indicated in the graph share the same superscript were not significantly different. ($p \leq 0.05$; One-way ANOVA followed by Tukey's pairwise test)

Compressive strength

Compressive strength is the most accepted procedure for determining the quality of the concrete. The mean compressive strength of concretes containing various proportions of CTCA with different ages is illustrated in Figure 7. Accordingly, with the increasing duration of the curing period, the strength of concrete showed a significant increase continuously and started to decline the significant increase. The strength increased progressively when the curing age increased, an indication of the effect of curing age

on concrete strength development. C20 showed the maximum strength (22.43 ± 0.01 MPa) while C30 showed the lowest (16.30 ± 0.06 MPa). This increase could be attributed to the irregular shape and rough surface of ceramic tile aggregates, which enhances the adequate bonding effect between aggregates and hardened cement paste (Liu et al., 2015). Nevertheless, the decrease in strength may be due to the non-proportional amounts of CTCA in concrete together with the flaky nature of ceramic waste aggregate on one side.

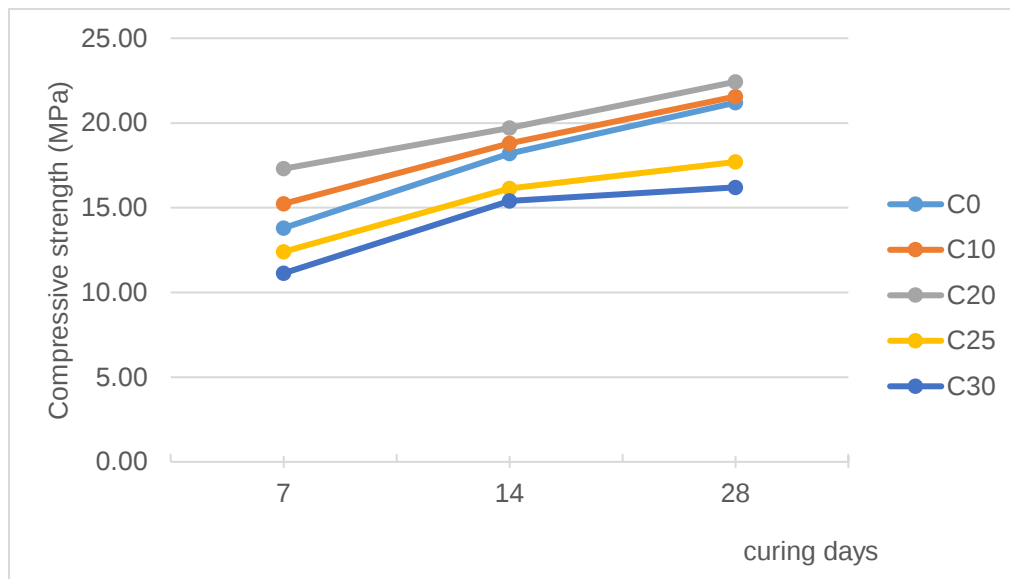


Figure 7: Variation of mean compressive strengths at different ages

Water absorption

Water absorption is defined as the amount of water that concrete can absorb at atmospheric pressure (Golewski, 2023). The mean percentage of water absorption varied from 0.84 ± 0.01 to 0.88 ± 0.01 (Figure 8). Water absorption comparison with the control concrete mix showed a measurable trend, despite the water absorption of coarse ceramic tile aggregate was higher than that of the natural coarse aggregate. The highest water absorption (0.88 %) was observed from C30. This might be due to that

the increased amount of ceramic tile aggregate has most probably reached its saturation when mixing water as described by Wadie et al. (2017). The water absorption of C10 and C20 was not significantly different from control. The percentage increments of water absorption of C10 and C20 with respect to the control were 1.19% and 1.78%. However, to ensure proper durability, water absorption should be within 4–6 % (Tracz and Sliwinski 2012). All the concrete types complied as stated by Tracz and Sliwinski (2012).

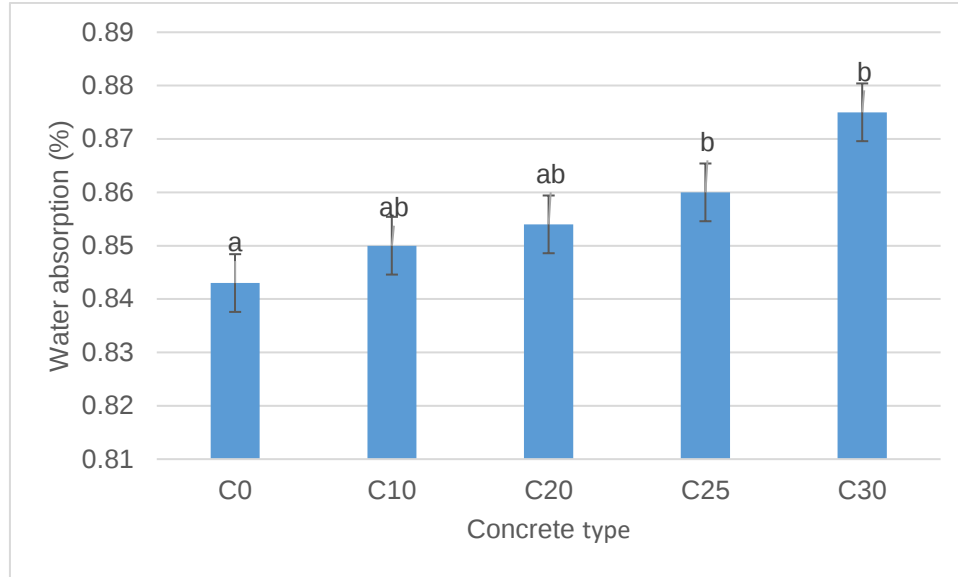


Figure 8: Variation of mean Water Absorption of concrete cubes incorporated with CTCA
[Data shown in the graph are mean $\pm$ SEM. Mean value indicated in the graph share the same superscript were not significantly different. ($p \leq 0.05$; One-way ANOVA followed by Tukey's pairwise test)]

Bulk density

Figure 9 illustrates the effect of ceramic waste content on the density of the hardened concrete for different curing ages. It was observed that the mean density of concrete gradually increased as curing age increased, while the mean density decreased with the increasing CTCA. In addition, when the content

of ceramic waste increased, the density of concrete decreased. Being lighter than the natural coarse aggregate (Table 1), CTCA could also have subsidized the lower density as a result of the loosely packed inner matrix. The numerical values of all the densities at all replacement levels were in the density range for natural concrete of between 2200–2550 kgm^{-3} .

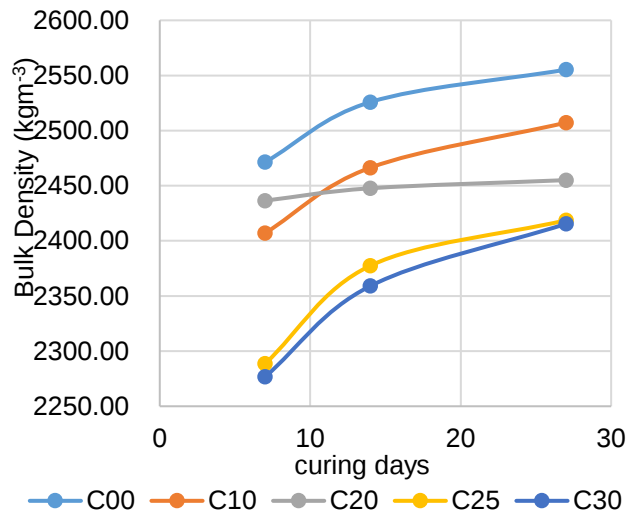


Figure 9: Comparison of mean density with the change in percentage of CTCA waste at different ages

Properties of concrete incorporated both CTCA and RHA (step 2)

This step mainly focused on replacing OPC with RHA in the concrete, consisting of partially substituted ceramic tile waste as coarse aggregates. The workability of fresh concrete was more or less similar to the values obtained for the C20 optimum substitution of CTCA (16.30 ± 0.09).

Compressive strength

The mean compressive strengths of the manufactured cubes increased with the curing period, but the increment was slightly reduced after the 14th day of the curing period (Figure 10) as observed in Figure 6. As stated by Hearn (2023), curing directly influences the quality of overall structure and strength gain rapidly at early ages but continues more slowly for an indefinite period.

Proper curing maintains a suitably warm and moist environment for the development of hydration products and thus reduces the porosity in hydrated cement paste and increases the density of microstructure in concrete (Uddin et al., 2012). At the end of the 28th day of the curing period, C05R showed the best compressive strength and was better than the controls (C20). When adding more RHA, the strength was reduced. This could be attributed to the high water absorption in the presence of more pores in RHA (Mayooran et al., 2017), and it is in line with the results of water absorption in the present study. However, results indicated that the blending of two aggregates (CTCA and RHA) resulted in the highest compressive strength (23.30 ± 0.01 MPa) than the

compressive strength (22.43 ± 0.01 MPa) of the blending of one aggregate (CTCA). Moreover, only CTCA blended resulted in high compressive strength compared to M20 concrete (21.20 ± 0.03 MPa). The higher compressive strength in the above mentioned mix combinations in the blending of CTCA and RHA concrete may be attributed to the formation of the high volume of C-S-H during the hydration reaction (Dave et al., 2018). Further, Malhotra (2006) indicated that the compressive strength of concrete improves not only with continuing curing for a longer duration but also with the replacement of cement with pozzolanic materials, and the strength values are significantly higher than the corresponding values obtained for controlled concrete at different curing periods.

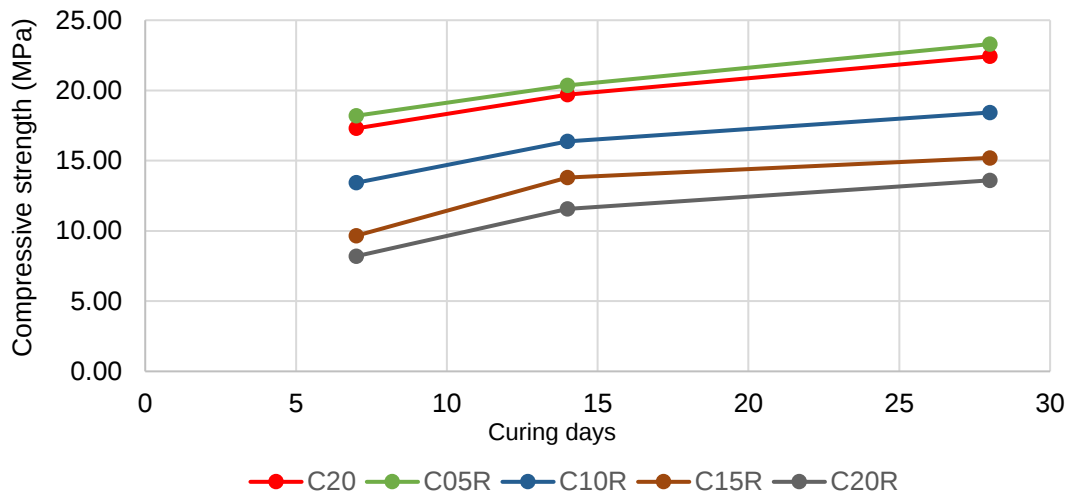


Figure 10: Variation of mean compressive strength of five different types of concrete cubes at different ages

Water absorption

The mean percentage of water absorption varied from 0.92 ± 0.01 to 10.30 ± 0.06 (Figure 11). A significant difference was observed in the water absorption of these cubes when increasing the percentage of RHA ($p \leq 0.05$; One-way ANOVA followed by Tukey's pairwise test). This significant change may be due to the highly porous nature of the concrete cubes with RHA compared to the control cubes (Mayooran et al., 2017). However, there was no significant difference between control and C05R. As stated by Czarnecki (2020), the

ability of a building structure to maintain its usable condition is an essential factor in the field of construction, and it is known as durability. Therefore, adequate durability of concrete is crucial to reduce maintenance costs and repairs for reinforced concrete structures involving concretes incorporating supplementary cementitious materials (Kewalramani and Khartabil, 2021). To be of good quality concrete, the water absorption should be below 5% (Willson and Tennis, 2021). Accordingly, the results revealed the 5% replacement of OPC by RHA for 20% CTCA-incorporated M20 concrete.

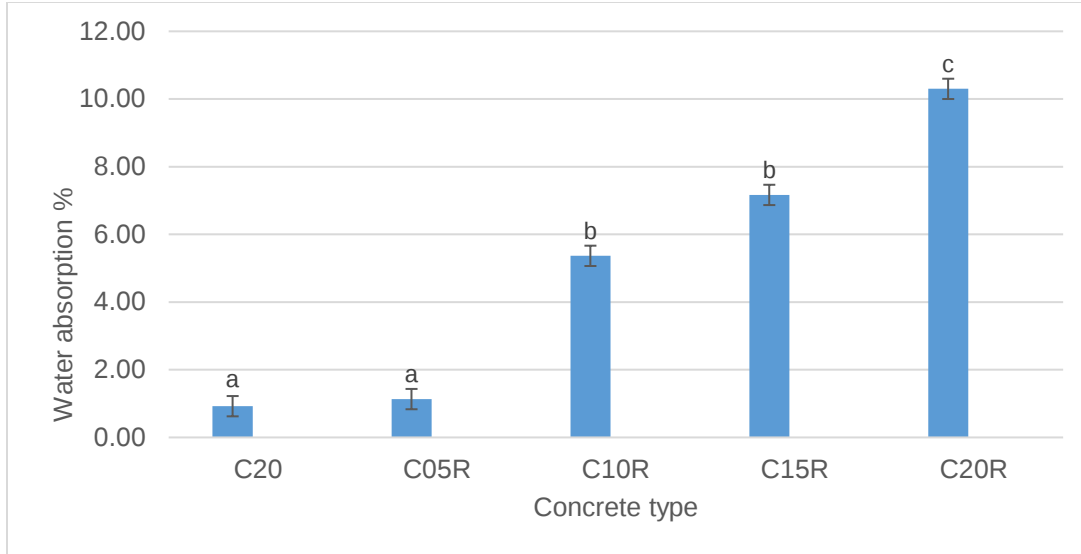


Figure 11: Variation of mean water absorption of five different types of concrete cubes [Data shown in the graph are mean $\pm$ SEM. Mean value indicated in the graph having different superscript were significantly different. ($p \leq 0.05$; One- way ANOVA followed by Tukey's pairwise test)]

Bulk density

Figure 12 illustrates the effect of ceramic waste content and RHA on the density of the hardened concrete for different curing ages. The mean density of concrete increased gradually as the curing age increased and decreased with the increasing RHA. Nevertheless, the primary speciality of light-weight concrete was its low density. The advantages of this contribute to reducing the dead load, faster building rates in construction and lower haulage and handling costs (Kalpana and Tayu, 2020). The main

characteristic of this type of light-weight concrete is its ability to maintain its large voids due to the use of RHA due to its porous nature. Water absorption is an essential factor due to the porous structure of light-weight concrete. Water absorption increased significantly when the percentage of RHA is increased. This type of concrete is feasible for light-weight concrete structures such as general insulation of walls, decks of long-span bridges, fire and corrosion protection, heat insulation on roofs, and filling for floor and roof slabs (Singh, 2016).

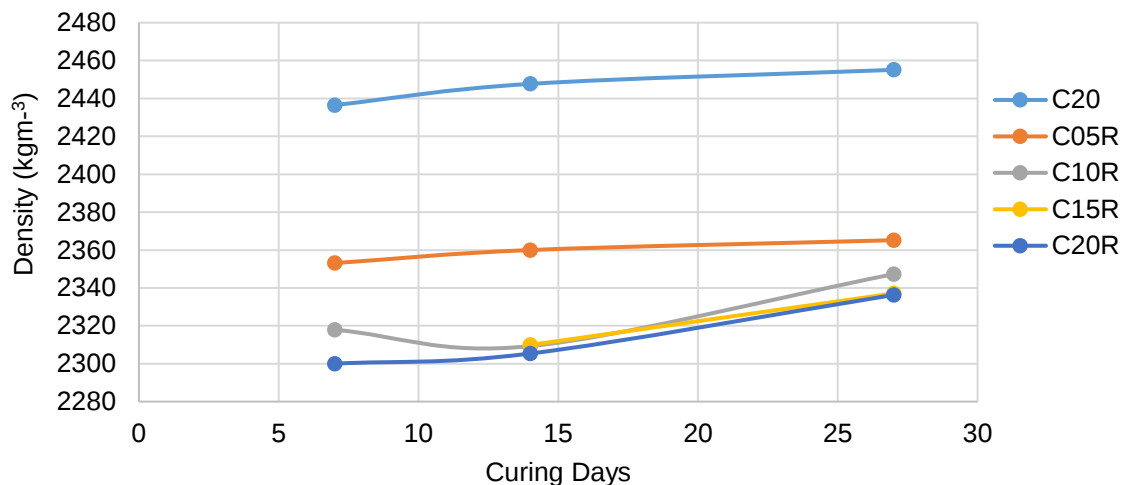


Figure 12: Variation of the density with the change in percentage of the RHA at different ages

Conclusions

The study focused on a blending of CTCA, which resulted in C&D with RHA, which resulted in rice milling industries. Based on the results, the following conclusions could be drawn.

- I. When adding CTCA in M20 concrete, 20% replacement of natural gravel aggregate with CTCA showed the maximum compressive strength.
- II. When adding both CTCA and RHA in M20 concrete, 20% replacement of natural gravel aggregate with CTCA and 5% replacement of OPC with RHA showed the maximum compressive strength.
- III. The blending of CTCA with RHA resulted in a higher compressive strength than the CTCA blended concrete.
- IV. The high porosity of the test samples decreased the concrete bulk density, affecting the poor compressive strength.
- V. The high level of porosity could be seen from the high water absorption that surpassed the expected limit of water infiltration.
- VI. The use of ceramic waste and RHA in concrete is a sustainable approach to manage waste efficiently resulting in C&D and rice milling industries.

The study recommends the replacement of 20% natural gravel stones and 5% OPC with CTCA and RHA, respectively, in concrete. In addition, use of superplasticizers or water reducers or superabsorbent polymers are suggested to improve the workability.

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Author Contribution

All authors contributed to the study conception and design. Sajitha Gawrinathan performed material preparation, data collection, and data analysis. Mangala Yatawara supervised the study and, reviewed and edited the first draft of the manuscript, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Availability of data and materials

All data and materials as well as software application support their published claims and comply with field standards. Data can be made available on request by interested parties.

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