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Study on the Usage of Ceramic Tile Waste as a Partial Replacement for Sand in Block Manufacturing

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Abstract: Due to heavy usage, natural materials have become scarce. As a solution, several studies have been conducted to investigate alternative materials including industrial and construction waste. For example, research studies have been conducted to use fly ash along with cement in concrete. Furthermore, research studies are being done to investigate alternative materials to replace river sand in concrete and masonry. In this context, ceramic tile waste (CTW) has emerged as a viable alternative for sand. The objective of the current study was to utilize CTW as a replacement for sand in the manufacturing of masonry blocks, with an investigation into the optimal utilization of sand properties in CTW-based blocks. The properties of CTW and the mechanical properties of masonry blocks manufactured with CTW were investigated. Sieve analysis was carried out for sand and CTW to investigate the particle size distribution of both materials. Solid masonry blocks having the size 215 mm x100 mm x 65 mm were cast with a mix proportion of 1:6 Cement: Sand. CTW as a replacement for fine aggregates was used in varying percentages: 0%, 10%, 20% 30%, and 100%. The compressive strength of the masonry blocks was determined by crushing them at the age of 7 and 28 days. Additionally, the water absorption properties and material cost of the blocks were investigated. The results of the sieve analysis test indicated a similar distribution of particle sizes of sand and CTW, suggesting that sand could be effectively replaced by using CTW in the manufacturing of masonry blocks. Moreover, compressive strength and water absorption test results showed that sand can be replaced up to 20% by CTW in masonry blocks.

Keywords: Ceramic tile waste, Cement sand block, Compressive strength, Sand replacement, Alternative materials

1. Introduction

Raw materials such as sand, coarse aggregates, and cement are needed for the numerous construction projects in Sri Lanka. Due to their increased usage, these natural materials are becoming scarce. There is an urgent requirement for the investigation of alternative materials to replace them, fully or partially. Fly ash, a byproduct of coal incineration, is already being utilized to produce cement. Furthermore, several studies have been conducted to search for alternative materials for sand, for example replacing sand with bottom ash. However, no research studies are available on investigating the suitability of unused ceramic tile waste (CTW) as a replacement for sand in manufacturing blocks.

The objective of this research study was to utilize CTW as a partial replacement for sand in the manufacturing of masonry blocks, with an investigation into the optimal utilization of sand properties in CTW-based blocks. In this context, it was expected to investigate an optimal mix proportion to use CTW to replace sand for blocks and to determine the economic feasibility of using CTW as a replacement for sand in block manufacturing.

The effort of reusing CTW for the creation of blocks is not only aimed at reducing the load of waste management but also supporting the general objective of sustainable building techniques. The problems caused by waste accumulation and environmental effects are addressed by this strategy, utilizing technology to help the building industry become environmentally friendly in Sri Lanka.

To understand the mechanical properties of blocks created with CTW, the study was conducted based on laboratory investigations.

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Here, CTW is incorporated as a viable alternative for sand. Using CTW, unburned blocks were made, and strengths were compared for different ratios.

2. Literature Review

Studies highlight that, in Sri Lankan building construction applications, ceramic floor tiles show a significant contribution when compared with other floor development materials [1].Tiles are the most widely used ceramic product in Sri Lanka. Presently, there is a growing global emphasis on environmental consciousness due to the persistent expansion of unsustainable manufacturing methods. Consequently, numerous manufacturers are striving to develop increasingly environmentally friendly procedures and goods by reducing the impact of their operations on the environment. However, as a developing nation, enhancing the environmental efficiency of the tile manufacturing sector and enhancing the quality and performance of the product are pivotal factors in advancing sustainability.

Considering that the volume of tailings in the world has increased rapidly in recent years, it poses a substantial ecological threat. To reduce negative impacts on the environment and reuse the abandoned slate tailings, the possibility of making eco-friendly unburned bricks by using slate tailings from the Shaanxi Province of China was investigated [2]. Raw materials including slate tailings, fly ash, cement, and bricks were produced through the process of mixing, moulding, and curing.

The ideal compressive strength of the product was discovered with the slate tailings: fly ash: cement ratio of 5:2:3 (by weight) with 7-day curing at room temperature and 1-day curing in the oven. Additionally, the forming water content is 15% by weight. Under these parameters, the compressive strength and water absorption rate measured were 26 MPa and 14.32%, respectively.

Pushpakumara and De Silva [3] experimented with rice husk ash (RHA) as a partial replacement for cement in masonry blocks. They discovered that when 0%,5%,10% and 20% of RHA was used as replacements, the optimum 28-day average compressive strength of the block was found to be 4.937 N/mm^2. Solid masonry blocks, having the size of 360 mm x 100 mm x 170 mm, were cast with the mix proportion of 1:6 cement-sand. Blocks were manufactured in two series. In the initial series, RHA was utilized as a supplement relative to the weight of cement. In this series, four varying RHA proportions (0%, 5%, 10%, and 15%) were incorporated while maintaining a constant lime content (10%). In the subsequent series, RHA was employed as a partial substitute for cement, featuring four distinct RHA proportions (5%, 10%, 15%, and 20%) alongside a consistent lime content (10%). The blocks underwent testing for compressive strength at 7 and 28 days. With the presence of lime (10%), the optimal 28-day compressive strength was observed at the 10% RHA level.

Abeykoon et al. [4] examined bottom ash (BA) as a replacement for sand for manufacturing masonry blocks. In that study, sieve analysis was carried out for sand and BA to investigate the particle size distribution of both materials. Solid masonry blocks measuring 360 mm x 100 mm x 170 mm were fabricated with a mix ratio of 1:6 Cement: Sand. BA, substituting for fine aggregates, was incorporated at different ratios: 0%, 10%, 20%, 30%, and 100%. Compressive strength was assessed by crushing the masonry blocks at 7, 14, and 28-day intervals (Figure 1). In addition, the water absorption properties and material cost of the blocks were investigated.

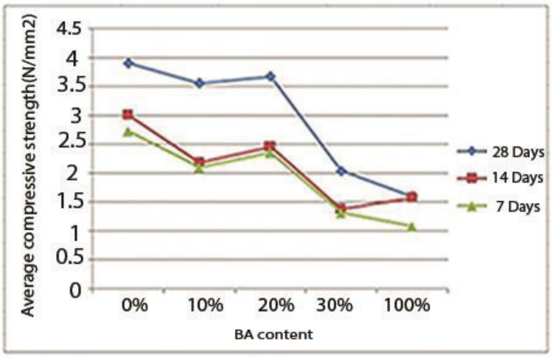

Figure 1 - Average Compressive Strength of Cement Sand Blocks for Different Bottom Ash Replacement Levels

The study showed that the findings of the sieve analysis test according to the distribution of particle sizes in the sand and BA are similar, suggesting that BA can be used in place of sand for making masonry blocks. It was discovered that substituting 20% of BA for sand results in a higher compressive strength. This study discusses the cost and water absorption qualities of BA based blocks. In the study by[4], 28-day compressive strength values are greater than the minimum required value (i.e., 2.8 N/mm^2)[5]. It is observed that the 20% BA replacement level has the highest compressive strength among the blocks manufactured with BA (Figure 1). The 10% replacement level of BA has shown a compressive strength of about 3.5 N/mm^2, which is also greater than the minimum required value. However, the research emphasized that the optimum replacement level of BA is 20% of sand with the highest compressive strength value [4].

There are four types of tiles used in Sri Lanka: ceramic tiles, porcelain tiles, terracotta tiles, and granite tiles. This study focused only on ceramic tile waste. According to a most recent update in "ceramic tile" [6], tiles can be categorized as: porcelain tiles, tantalum tiles, enamel tiles, and ceramic tiles. In Sri Lanka only porcelain and ceramic tiles are widely used. Both are made from a mixture of clay and other materials, then kiln-fired. Both porcelain and ceramic tile fall in the broader category of "ceramic tile" [7]due to their shared manufacturing process involving clay and firing. However, there are significant differences between porcelain tiles and traditional ceramic (non-porcelain) tiles. Porcelain tiles are made from a specific type of clay called porcelain or kaolin clay, which is finer and more refined than the clays used for ceramic tiles. This difference in clay composition affects the tile density and porosity, which makes it stronger than a ceramic tile. Both ceramic and porcelain tiles can be unglazed or glazed. Unglazed tiles tend to be denser, thicker, and scratch and slip-resistant. Glazed tiles are thinner, and more prone to cracking but more stain-resistant. They are also better on walls than floors, since the glazing is slippery.

On the other hand, ceramic tiles are typically made from a mixture of clays, minerals, and water. These raw materials are blended to achieve a desired consistency and then shaped into tiles through pressing or extrusion. Ceramic tiles are lighter and less dense. Ceramic tile is easier to cut because it is not as dense. Porcelain tile can be more difficult to cut because it is denser. One of the clearest differences between ceramic and porcelain is its water absorption rate. Water absorption rate of ceramic tiles can be up to 20%, while porcelain tiles are almost impervious to water with a low rate of 0.5%.

In this study, only CTW was selected for block manufacturing. As mentioned before, porcelain tile is highly dense, has low water absorption, and is hard to break. Therefore, porcelain tiles may not be suitable for this type of block making.

In Sri Lanka, we can categorise ceramic tiles again as floor tiles and wall tiles. Floor tile is made thicker and harder to withstand foot traffic, appliances, and furniture. It can also have a texture to reduce the risk of slips. Wall tile tends to be thinner, smoother, and more delicate. It is also slippery when wet. In this study, floor tiles were used as CTW material.

Though there are different tiles available in Sri Lanka rather than ceramic and porcelain such as terracotta and granite, they may not be suitable for this type of study. Granite is a hard material and cannot break easily. This study incorporated manual crushing method. Terracotta tiles are durable but more porous than ceramic tiles and hence they may require sealing to prevent staining and water absorption.

Even though numerous studies have been performed to investigate the suitability of different tile waste in blocks such as the study in China [8], no studies have been carried out to incorporate waste generated by ceramic tiles used in Sri Lanka as a partial replacement for sand in manufacturing blocks. Therefore, this study aimed at examining the suitability of CTW in block manufacturing as a solution for sand scarcity as well as an effective method for reducing the waste disposed to the natural environment.

3. Research Methodology

3.1 Collection and Preparation of Unused Tiles

Collection of Unused Ceramic Tiles - Gathered unused ceramic floor tiles from construction sites and ensured they were free from contaminants or foreign materials.

Sorting and Cleaning - Sorted the collected ceramic tiles discarding any damaged or unusable pieces. Clean the tiles to remove dust, dirt, and any adhering substances.

3.2 Crushing the Ceramic Tiles

Crushing - The collected CTW was crushed using a hammer in this study, however, if there is a larger quantity, a tile crushing machine may be used.

3.3 Selection of Material

Identify and select materials such as cement, tile waste, sand, and water. Determine their proportions based on preliminary experimentation. Tile waste replaced selected percentages of sand.

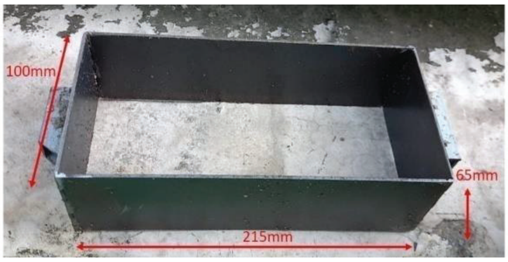

Figure 2 - Iron Mould

Material selection for the replacement of sand was done by considering the physical properties. Unused ceramic floor tiles were collected from construction sites and homes. Natural River Sand (NRS) free of clay, loam, dirt, and any organic or chemical matter as specified in Sri Lanka Standard 855: 1989 [8] was used in the current study. Ordinary Portland Cement (OPC) as specified in [8] was used. Fresh, clear, scentless, and flavourless potable water sourced from the piped water system of the National Water Supply and Drainage Board (NWS&DB) was utilized. The water had been verified to be devoid of organic matter according to the specifications outlined in [8].

3.4 Particle Size Analysis Test

A sieve analysis test was done for the natural river sand and tile waste according to BS 882:1992. According to BS code 10 mm, 5 mm, 2.36 mm,1.18 mm, 0.6 mm, 0.3 mm, and 0.15 mm sieve sizes were used.

3.5 Block Manufacturing and Testing

Conventional solid masonry blocks with dimensions of 215mm x 100mm x 65mm were cast using a mix proportion of 1:6cement:sand (volume basis). CTW-based blocks were manufactured incorporating CTW at four different levels of replacement (i.e., 10%, 20%, 30%, and 100%) for sand, while maintaining the same dimensions. To prepare mortar, the cement, sand, and CTW were thoroughly mixed, and the mixture was turned over several times. Water was added to the mixture while maintaining a 0.7 water-cement ratio. A higher water-cement ratio was required as CTW absorbed more water [3]. The mixture was further turned over by using shovels until achieving a mix of the required workability as described in previous research [3].

Aniron mould (as in Figure 2) was used to make blocks, and it was filled with the mortar (i.e., 65 mm height) in two layers. Using a timber plate with the same area as the top face of the iron mould, each layer was properly compressed. Additional mortar was filled into the mould and again compressed. After being removed from the mould, the blocks were left on the ground. Twenty-four hours after manufacturing, the blocks were continuously cured until the day of testing. The curing process was carried out as the strength gained by the blocks depended upon their curing. The blocks were cured by immersing them in a bucket of water until the test day.

Bulk density test, specific gravity test and water absorption test were carried out for manufactured blocks according to BS 812: Part 2: 1995 [10]. Moreover, compressive strength tests were done at 7 days and at 28 days according to BS6073: Part 2: 1981 [5] for manufactured blocks.

3.6 Cost Analysis

Cost analysis was performed only considering the cost of material for manufacturing each type of block. The cost of block manufacturing usually includes the cost of material, labour, and machinery. As the cost of machinery and labour are the same for manufacturing both tiles waste-based and conventional blocks, only the cost of material was considered for this cost analysis. In the cost analysis, no expenditure for tile waste was considered as it is a waste material. The volumes of the cement and sand were calculated according to the particular proportions of the blocks. The cost of the blocks was determined by multiplying material quantity by the unit price of materials.

4. Results and Discussion

4.1 Particle Size Distribution

A sieve analysis test was done for the natural river sand and tile waste according to BS 882:1992 [9].

Figure 3 shows the particle size distribution of 1 kg of CTW collected from the construction sites and homes. Each CTW 1kg sample was tested to ensure that it falls within the limits of upper and lower.

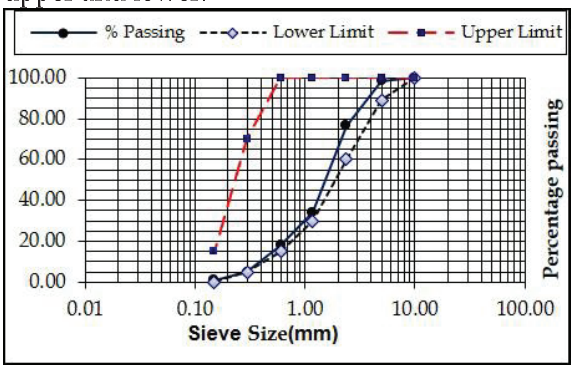

Figure 3 - Sieve Size vs Passing Percentage of the Tile Waste

It can be seen that the passing percentage through the 150 μm sieve is 0.8%. The particle size of CTW material, which was used for the block manufacturing work in this study, is between 5 mm and 150 μm and there is a considerable amount of CTW in this range of particle size (Figure 3).

4.2 Bulk Density

The bulk density for NRS and CTW was tested using the BS 812: Part 2: 1995 [10] clause 6. The approximate bulk density of sand that is commonly used in normal-weight concrete is between 1520- 1680 kg/m^3 [11].

The sample size was selected according to a mould volume of 0.003 m^{3}and bulk density was calculated.

In this study, the average bulk density of the NRS was obtained as 1565.1kg/m^3 which is an acceptable value. The difference between the bulk density of natural sand and the tile waste was 523.4 kg/m^3 (see Table 1). That means the average bulk density of the CTW was lower than the NRS. Due to the difference in the bulk density, the 100% ratio of CTW cannot replace the sand.

Table 1 - Average Results of Bulk Density

Samples	Bulk Density
Average Bulk Density of NRS	1565.1kg/m^3
Average Bulk Density of CTW	1041.7kg/m^3

4.3 Specific Gravity

The specific gravity tests for materials were also conducted according to [10], and the results were compared with standard values. Table 2 illustrates that the specific gravity of tile waste is lower than sand. This test was done for 500g of 2 samples each of CTW and NRS.

Table 2 -Average Specific Gravity Test Results

Sample	Specific Gravity
Average Specific Gravity For NRS	2.68
Average Specific Gravity for CTW	2.38

In this study, the average specific gravity of NRS was found to be 2.68, which closely aligns with the previous study [3]. The lower specific gravity of tile waste has contributed to the weight difference between the blocks. As a result, tile waste-based blocks are lighter than conventional cement-sand blocks.

4.4 Water Absorption

4.4.1 Water Absorption Tests of Fine Aggregates

For material quality checking, water absorption testing was conducted along side the specific gravity tests according to [10]. These tests were performed before making blocks (see Table 3).

Table 3 - Average Water Absorption Test Results

Sample	Water Absorption comparison
Average Water Absorption for NRS	0.29%
Average Water Absorption for CTW	9.7%

The average water absorption of NRS was determined to be 0.29%, as mentioned in [12]. According to BS 812:1995 [10] the water absorption of sand should not be greater than 3%.

According to Chinese standards [6], ceramic tiles have a water absorption rate exceeding 10%.In this study, the CTW exhibited an average water absorption of 9.7%. This indicates that CTW absorbed more water than sand. While the water absorption rate of NRS was within the limited range of 3% [6], the CTW water absorption rate was high. This can be attributed to a higher water-cement ratio and lower specific gravity and bulk density of CTW.

4.4.2 Water Absorption Test of Blocks

The water absorption property of each block was investigated, and average water absorption was determined by averaging three corresponding values. According to [13], the acceptable water absorption value for masonry blocks is 12%.The conventional cement sand block exhibited a water absorption percentage of 8.66%,

0 10 20 30 40 50 60 70 80 90 100

comfortably within the acceptable range. Moreover, 10% and 20% CTW replaced blocks have a water absorption value of 10.00% and 10.72%, respectively, which are within the allowable limits. (Figure 4). However, the 100% CTW replacement block shows the highest water absorption percentage at 17.07%, suggesting that CTW is indeed a water-absorbent material. This increase may be attributed to the higher porosity resulting from the replacement of sand. The 30% CTW replacement has a higher water absorption value of 14.17% which exceeds the allowable limit.

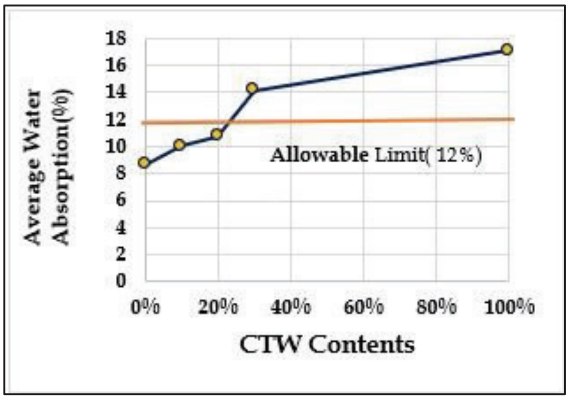

Figure 4 – Water Absorption vs CTW Content

It can be seen from Figure 4 that water absorption increases with increasing level of replacement of sand by CTW. However, replacement levels of 10% and 20% of CTW have approximately equal water absorption values (i.e., about 10-11%) within the acceptable limits.

4.5 Compressive Strength

The compressive strength of three blocks of each mix proportion was measured and averaged. The average compressive strength values of CTW-based blocks are shown in Figure 5.

The compressive strength test results show clearly that the partially sand-replaced CTW-based blocks satisfied the minimum standard value of 2.8 N/mm² according to BS6073: Part 2: 1981 [5] as shown in Figure 5. Though the average compressive strength values were greater than the minimum requirement for tested partially sand-replaced blocks, the compressive strength values gradually decreased with increasing CTW level.

Moreover, it can be observed from Figure 5 that the average compressive strength of the blocks increases with the age of the blocks. The trend of decreasing compressive strength with the increment of CTW level remains consistent regardless of the age of the blocks.

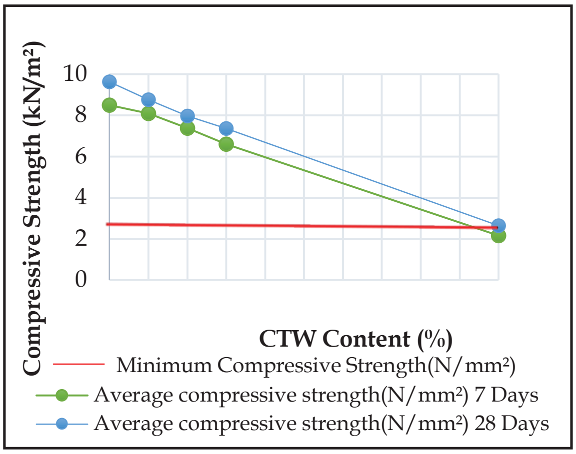

Figure 5 – Variation of Average Compressive Strength with % of CTW-Based Blocks

For this study, 20%CTW-based block compressive strength was 7.96 N/mm², which is also greater than the minimum required value. Therefore, 20% CTW-based blocks can be recommended because it has good strength and were within the water absorption limits when the CTW content was high. This emphasizes that the optimum replacement level of CTW is 20% of sand.

In the current study, the blocks were manufactured with an iron mould, using manual compaction. When making blocks manual compaction was used to compact blocks. However, advanced machinery, where compaction is applied using hydraulic pressure, can be used to produce CTW-based blocks with higher compressive strength than that found in this study.

The compressive strength of blocks is also influenced by the curing time. The cementing process, in particular, is a slower reaction compared to the hydration of cement. It requires a significantly longer time for completion. This process thrives in a hydrous environment, meaning that with ongoing curing, there is a gradual increase in compressive strength.

Furthermore, Pushpa kumara and De Silva [3] said that the curing temperature plays a crucial role in accelerating chemical reactions, thereby enhancing the rate of strength gain. Moreover, higher pH may accelerate the formation of secondary cementitious products.

4.6 Cost Analysis

The cost comparison was done considering no expense for CTW material and assuming equal labour and transport costs for manufacturing each type of block. Material cost for manufacturing each block type is compared in Table 4.

Table 4 - Cost of Materials for Blocks

Sample Identification	CTW content	Material cost per block (Rs.)	% cost reduction
Sample 1	0%	56.38	-
Sample 2	10%	53.56	5%
Sample 3	20%	50.74	10%
Sample 4	30%	47.92	15%
Sample 5	100%	28.2	50%

The total material cost required to manufacture conventional cement sand blocks was about Rs. 56.38 per block. The total material costs required to manufacture blocks based on 10%, 20%, 30%, and 100% CTW were Rs. 53.56, Rs. 50.74, Rs. 47.92, and Rs. 28.2, respectively. From Table 4, it was observed that the amount of money saved increased with the increasing replacement level of tile waste for sand. This was attributed to the utilization of tile waste to replace sand. Specifically, there were savings of 5%, 10%, 15%, and 50% per block due to the replacement of NRS by CTW as shown in Table 4.

CTW, used in the current study, was a waste material from sites or homes. This waste was typically dumped in remote places, leading to the eventual transformation of the dumped land into unusable terrain over time. Therefore, the utilization of waste would provide numerous benefits. In the current study, it was observed that there was no expense for CTW, which would provide considerable benefits.

During the block manufacturing process in this study, the CTW was crushed manually to the required size since the material requirement for the casting of blocks was considerably low. However, at the industrial level, CTW-based block manufacturing cost analysis needs to include the cost of using a material crusher, transport cost, etc.

Life Cycle Assessment (LCA) is a way to get a better picture of the suitability of the proposed blocks. In Sri Lanka, there are no case studies related to CTW blocks. However, due to time constraints and limiting to Sri Lankan-based CTW blocks, only the cost of CTW blocks was analysed. But in the future, researchers should focus on considering different tile-types and conducting their LCAs.

5. Conclusions

Ceramic tiles are divided into two groups: non-porcelain tiles (or ceramic) and porcelain tiles. However, there are significant differences between porcelain tiles and traditional ceramic tiles. Both porcelain and ceramic tiles fall under the broader category of ceramic tiles due to their shared manufacturing process involving clay and firing. This study has focused only on ceramic tiles because porcelain tiles are dense, hard to break, and have a low water absorption rate. Due to these reasons, porcelain tiles are not suitable for making these blocks. Moreover, other types of tiles such as terracotta tiles and granite were not considered in this study as their properties are different. Therefore, for making blocks, this study focused only on ceramic floor tiles (non-porcelain tiles) in Sri Lanka.

Regarding compressive strength, the blocks showed promising results, with the compressive strength generally increasing with the age of the blocks. The 10% - 30% CTW-based block demonstrated favourable compressive strength, surpassing the minimum required value specified by [5]. When the water absorption is considered, the replacement levels of 10% and 20% of CTW have water absorption values within the acceptable limits. A cost analysis revealed significant savings in material costs associated with the use of CTW, with higher replacement levels resulting in greater cost savings. This underscores the economic viability of incorporating CTW into block manufacturing processes.

This research study highlights the potential for utilizing CTW in masonry block manufacturing, not only to reduce environmental pollution but also to enhance the mechanical properties of the blocks.

The blocks that were made of CTW as a replacement for sand showed higher compressive strength than the required standard value, implying that the blocks can be used to construct load-bearing walls. Based on the results, the study recommends a 20% replacement level of CTW-based blocks for optimal compressive strength and costeffectiveness while ensuring that water absorption remains within acceptable limits.

CTW-based blocks are cost-effective as well as help to utilize the waste material and prevent the environmental pollution caused by open dumping of CTW which creates more problems. This approach not only contributes to sustainable waste management by reducing environmental pollution but also offers economic benefits to the construction industry. This block also has an additional advantage as a lightweight block compared to conventional cement-sand blocks.

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