INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

IJIE

Vol. 17 No. 5 (2025) 274-289
https://publisher.uthm.edu.my/ojs/index.php/ijie

A Sustainable Practices of Utilizing Ceramic Tile Waste to Replace Coarse Aggregate in Normal Concrete

X. Y. Lim[1]*, N. Y. Zainun[1], H. Ahmad[1], H. Mansor[2]

[1] *Faculty of Civil Engineering and Built Environment,*
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA

[2] *Faculty of Civil Engineering,*
Universiti Teknologi MARA, 40450 Shah Alam, Selangor, MALAYSIA

*Corresponding Author: alexuslim0c3@gmail.com

DOI: https://doi.org/10.30880/ijie.2025.17.05.021

Article Info

Received: 14 August 2024
Accepted: 20 March 2025
Available online: 30 August 2025

Keywords

Normal concrete, ceramic tile waste, recycling, coarse aggregate replacement

Abstract

Due to poor construction waste manegement and disposal problem, construction waste is an emerging issue in the Malaysian Construction Industry (MCI). Massive construction projects affect the environment and produce huge amount of construction waste, including ceramic tile waste. The research aim is to figure out the mechanical characteristics of normal concrete under compressive strength and four-point bending tests with different percentages of ceramic tile waste replacement. Ceramic tile waste is recycled to replace coarse aggregate in developing a designed strength of 30 N/mm^2 at 28 days. 10% of the cement is substituted with fly ash. Maximum particle for fine and coarse aggregates are 5 mm and 10 mm in sizes. A uniform ratio of 0.545 water-to-cement (w/c) and a concrete mix ratio of 1:2.61:2.71 (Cement: Fine aggregate: Coarse aggregate) are applied in the Department of Environment (DOE) technique. Thirty-six-cylinder specimens (150 mm X 300 mm) and eighteen prism specimens (400 mm x 100 mm x 100 mm) are casted, cured and tested to examine their properties. 20% crushed gravel is replaced with ceramic tile waste to obtain higher compressive and flexural strengths, measured 39.21 N/mm^2 and 3.51 N/mm^2 respectively. By turning waste into wealth, this research can reduce the dependency on natural raw materials, recycling recyclable resources, reduce the disposal of ceramic tile waste and minimize negative impacts on the environment.

1. Introduction

Concrete consumes more natural raw material and contributes a significant amount of waste [1]. A total of 120 million tons of construction waste are produced, but only half of them is recycled [2]. Besides, an illegal dumping of construction waste has become an alarming trend in MCI for reducing cost of managing construction waste [3]. Construction activities generate a large amount of ceramic tile waste, accounting for 54% of all construction waste [4], [5]. Alternatively, there is approximately 30% of ceramic tile turn into waste during ceramic processing due to manufacturing error, inappropriate raw material and improper handling material by worker [6], [7]. Correspondingly, the disposal of ceramic tile waste has become an alarming challenge in MCI.

Utilizing ceramic tile waste in this research is subjected to various factors. First consideration revolves around durability [5], [8], [9]. Ceramic tile is widely acclaimed for their robustness and resistance to wear and tear. When employed as aggregates, they possess the potential to enhance the overall durability and endurance of construction materials. Secondly, ceramic tile often exhibit resistance to chemical, a valuable attribute for construction materials that may encounter corrosive substances. This resistance can significantly bolster the materials' ability to withstand chemical degradation. Lastly, ceramic tile is a material generally boast excellent thermal properties. The thermal performance of construction materials may be enhanced by using ceramic tile waste as aggregates, rendering them suitable for application where insulation or temperature control is crucial.

The research gap is low acceptance of recycled aggregate in normal concrete due to preference for natural resources in Malaysia. Limited understanding and knowledge prevent the acceptance of using recycled aggregate in concrete. Thus, Malaysia faces a challenge in managing the consumption of natural resources. However, concrete can consume fewer natural resources if ceramic tile waste is adopted in place of coarse aggregate. Besides, this research can close the current gap in examining the performance and optimal replacement levels of ceramic tile waste concrete. Lack of confidence among construction practitioners in using ceramic tile waste in the concrete production is affected by its inconsistent ideal replacement levels. Although ceramic tile waste concrete has been reported to be feasible in numerous studies in other countries, yet it is still relatively new in Malaysia. Lack of knowledge, applicability, regulatory standards and guidelines are the primary reasons for Malaysia's low adoption in ceramic tile waste to be a recognized construction substance. Hence, it seeks to fulfill the gaps and contribute a more sustainable construction sector.

The research purpose is to evaluate normal concrete's mechanical characteristics with various proportion of ceramic tile waste replacement under compressive strength test and four-point bending test. By replacing coarse aggregate with ceramic tile waste, experimental works are performed to develop a desired strength of 30 N/mm^2 concrete at 28 days. Meanwhile, 10% fly ash is added to cement to partially replace it. River sand particle is smaller than 5 mm in sizes. However, the particle sizes of crushed gravel and ceramic tile waste are ranging between 5 mm to 10 mm. Ceramic tile waste is gathered from the construction and renovation site located in Yong Peng, Johor. DOE method is adopted with a concrete mix ratio of 1:2.61:2.71 (Cement: Fine aggregate: Coarse aggregate) and a consistent ratio of 0.545 for water-to-cement. A total of thirty-six-cylinder specimens (150 mm X 300 mm) and eighteen prism specimens (400 mm X 100 mm X 100 mm) are casted, cured and evaluated in order to examine their physical and mechanical characteristics.

1.1 Problem Statement

Construction waste generation is expected to increase dramatically but the construction waste management in present is still unsatisfactory [3]. An estimated 1.5 million tons of ceramic tile waste are expected to be produced annually by the manufacturing factory [7]. Correspondingly, the disposal of ceramic tile waste has become an alarming challenge in MCI. In MCI, landfills disposal and illegal dumping activities are the popular ways to dispose ceramic tile waste [3], [10]. Majority of contractors decide to dump ceramic tile waste into legal or illegal landfills because they believe it has little or no value [10].

In recent years, research has been conducted on replacing ceramic tile waste with cement or aggregates. Recycled aggregates have been used in concrete systems in industrialized nations such as South Korea, Japan and the United Kingdom [11]. However, it is still new for Malaysia and there is lack of research on recycling ceramic tile waste to replace coarse aggregate in Malaysia [11], [12]. In Malaysia, there is no guidelines, standards and policies regarding the adoption of ceramic tile waste in making of concrete. Therefore, Malaysia differs from other nations in using recycled aggregates to produce concrete.

Besides, there is inconsistent findings of using ceramic tile waste in place of coarse aggregate to produce concrete. Based on the findings, concrete strength can be increased by raising the proportion of ceramic tile waste. Nevertheless, an argument is proposed by the past findings that adding ceramic tile waste can weaken concrete [9]. Also, the discovery of different optimum levels of ceramic tile waste may affect the confidence of construction practitioners to utilize them as recycled coarse aggregate in producing concrete. Consequently, inconsistent and unreliable findings obtained from replacing ceramic tile waste for coarse aggregate has led to the limited practical applicability of ceramic tile waste concrete.

2. Materials and Methodology

Fig. 1 describes the methodology's flow chart. It starts with the preparation of raw concrete ingredients such as Tasek OPC, river sand, crushed gravel, ceramic tile waste and fly ash. The physical characteristics of aggregates are examined through dry sieve analysis, specific gravity and water absorption. Meanwhile, morphology and chemical element of ceramic tile are investigated prior to concrete mix design, mixing and curing process. Thereafter, it divided into three phases such as fresh concrete's workability, hardened concrete's physical and mechanical characteristics (Density, compressive strength and flexural strength) and hardened concrete's material properties (Elasticity modulus and Poisson's ratio). Finally, results and discussions are interpreted from the experimental findings.

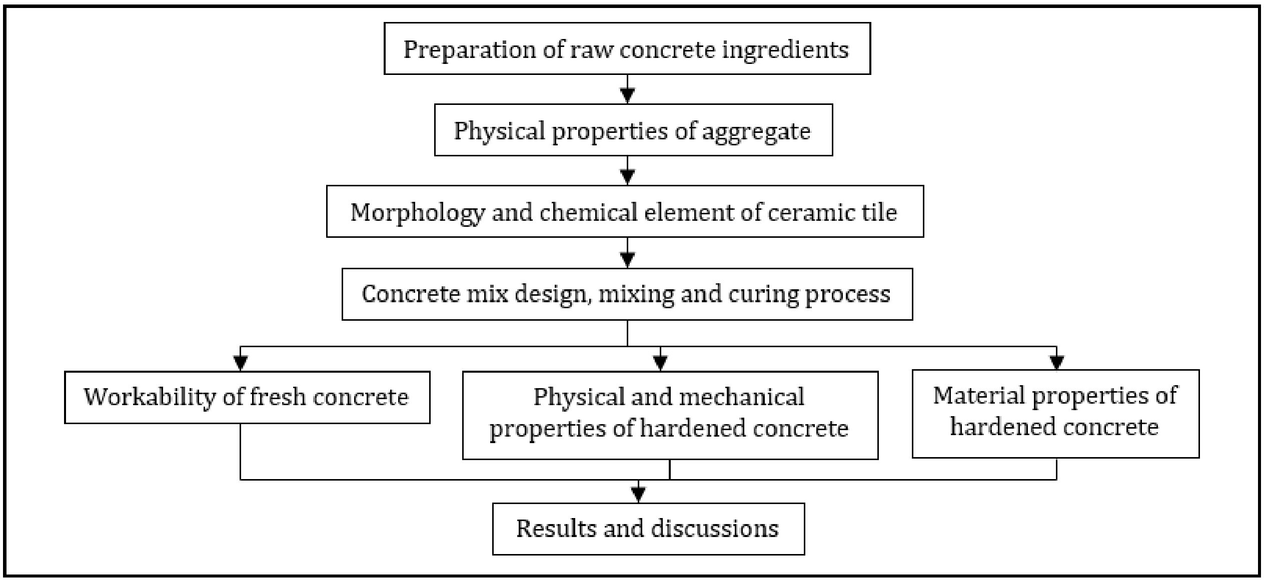


Fig. 1 *Flow chart of the methodology*

2.1 Testing Series

Concrete with a 28 days target strength of 30 N/mm^2 is developed to examine normal concrete's mechanical characteristics with various proportion of ceramic tile waste. Cylinder specimen (150 mm X 300 mm) is prepared to assess density, elasticity modulus, Poisson's ratio and compressive strength. Yet, prism specimen (400 mm X 100 mm X 100 mm) is used to measure concrete's flexural strength. A total of thirty-six-cylinder specimens and eighteen prism specimens are casted, as tabulated in Table 1.

Table 1 *Number of samples*

Testing designation	Cylinder specimens		Prism specimens
	7 days	28 days	28 days
	f_c	Density, E, v, f_c	f'_c
WT0	3	3	3
WT10	3	3	3
WT20	3	3	3
WT30	3	3	3
WT40	3	3	3
WT50	3	3	3
Total	18	18	18

2.2 Specimen Preparation

Tasek OPC, fly ash, water, crushed gravel, ceramic tile waste and river sand are used as concrete constituents. According to ASTM C150/C150M-22, Tasek OPC is selected with an approved specification as Type I and comply with MS EN 197-1:2014 CEM 1 42.5N standards. The cement strength class of Tasek OPC is 42.5. Besides, 10% fly ash is added to replace cement. Tanjung Bin Power Plant, Kukup, Johor provide the fly ash utilized in this research. Since fly ash is readily available in powder form, thus no preparation work is needed before using it in place of cement. Tap water is chosen for mixing and curing concrete. Particle sizes of river sand smaller than 5mm are chosen. Crushed gravel and ceramic tile waste with particle sizes of 5mm to 10mm are selected. Ceramic tile waste is collected from construction and renovation sites located in Yong Peng, Johor. Then, as-collected ceramic tile waste is cleaned, crushed by a hammer and sieved. The thickness of ceramic tile waste ranges from 6.5 mm to 9 mm. As can be seen visually in Fig. 2, ceramic tile waste has an angular shape with sharp edges.

Fig. 2 *Sizes of ceramic tile waste*

DOE technique is used to design 30 N/mm^2 concrete. As tabulated in Table 2, a consistent ratio of 0.545 water-to-cement and a 1:2.61:2.71 (Cement: Fine aggregate: Coarse aggregate) concrete mix ratio is developed. Besides, target slump level of fresh concrete is between 10mm to 30mm. Table 3 stated a concrete mix design with different proportion of ceramic tile waste. Every aggregate, fresh and hardened concrete tests complies with the British Standard or American Standard.

Table 2 *Concrete mix design using DOE technique for 30N/mm2 concrete*

Description	Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
Mix ratio	0.545	1.00	2.61	2.71
Quantity per m^3	190	345	900	935

Table 3 *Concrete mix design with different proportion of ceramic tile waste*

Testing designation	Cement (kg/m^3)	Fly ash (kg/m^3)	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Ceramic tile waste (kg/m^3)
WT0 (0%)	310.5	34.5	190	900	935	0
WT10 (10%)	310.5	34.5	190	900	841.5	93.5
WT20 (20%)	310.5	34.5	190	900	748	187
WT30 (30%)	310.5	34.5	190	900	654.5	280.5
WT40 (40%)	310.5	34.5	190	900	561	374
WT50 (50%)	310.5	34.5	190	900	467.5	467.5

2.3 Physical Characteristics of Aggregates

2.3.1 Dry Sieve Analysis

Dry sieve analysis is used to grade river sand, crushed gravel and ceramic tile waste. The weight retained or passed through several sieves is complying with BS EN 933-1:2012 [13]. The acceptable particle sizes of fine aggregate are smaller than 5 mm [14], [15]. However, the acceptable particle sizes of coarse aggregate are ranging from 5 mm to 10 mm. River sand is grouped utilizing sieve sizes in 5 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm and 150 µm. Besides, sieve sizes used to classify crushed gravel and ceramic tile waste are 14 mm, 10 mm, 5 mm and 2.36 mm. Thereafter, the findings of dry sieve analysis are used in DOE method.

2.3.2 Specific Gravity

Fine and coarse aggregates' specific gravity is assessed using ASTM C128 [16] and ASTM C127 [17]. Firstly, dry the aggregates in an oven at 110±5℃ and followed by cooling the aggregates in air at room temperature for one hour to three hours. Later, immerse the aggregates in water for 24±4 hours. Equation 1 provided the formula for measuring the aggregates' specific gravity. Meanwhile, the specific gravity is used to design concrete mix.

$$\text{Specific gravity of aggregates} = \frac{A}{(A-(B-C))} \tag{1}$$

where A represents the oven aggregates' mass in air (g), B represents the mass of aggregates in a water -filled container (g) and C represents the mass of the water-filled container (g).

2.3.3 Water Absorption

The standard of BS 812-2: 1995 [18] is used as a guideline to ascertain the aggregates' water absorption. Equation 2 gave the formula used to calculate the aggregates' capability to absorb water. Thereafter, the extra water needed for designing concrete mix is computed employing the findings obtained from dry aggregates' water absorption.

$$\text{Aggregates' water absorption} = \frac{(a-b)}{b} \text{ X } 100\% \tag{2}$$

where a and b are the masses of saturated surface dry aggregates in air (g) and oven dry aggregates in air (g) respectively.

2.4 Morphology and Chemical Element of Ceramic Tile

As given in Fig. 3, ceramic tile waste's morphology and chemical element are examined employing Scanning Electron Microscope and Energy Dispersive X-Ray Spectroscopy (SEM-EDS). First step is to prepare ceramic tile with sizes of no larger than 5mm and placed on a sample plate. Afterward, sample plate is placed into the chamber of SEM-EDS machine and the chamber is vacuumed. Lastly, morphology and chemical composition of ceramic tile is obtained by modifying the scanning area with brightness and contrast controller.

Fig. 3 *SEM-EDS machine*

2.5 Fresh Concrete's Workability

Every concrete mixture undergoes slump test to assess its workability following BS EN 12350-2: 2019 [19]. Slump cone is made with dimensions of 300±2mm for height, 200±2mm for base diameter and 100±2mm for top diameter. Meanwhile, the diameter of tamping rod is 16±1mm with a length of 600±5mm. In a slump cone, three equal layers of fresh concrete is poured. Before measuring the slump level, a tamping rod is utilized to compact each layer of fresh concrete with 25 strokes. Fresh concrete's slump level is measured in millimeter (mm). The result of slump test is used as a standardized criteria to examine same quality of the fresh concrete and to determine whether the concrete mix is accepted or rejected.

2.6 Physical and Mechanical Characteristics of Hardened Concrete

2.6.1 Density

By complying with BS EN 12390-7:2019 [20], the density of concrete is measured on 28 day of curing age. Equation 3 stated the formula employed to figure out concrete's density.

$$\text{Concrete's density} = \frac{\text{Unit weight (kg)}}{\text{Unit volume } (m^3)} \tag{3}$$

2.6.2 Compressive Strength

With regard to BS EN 12390-3: 2019, a 1200kN load-cell capacity Universal Testing Machine (UTM) is utilized to examine cylinder specimen's compressive strength [21], as presented in Fig.4. The loading rate is maintained at 0.6±0.2MPa/s to offer sufficient time for crack propagation. On 7 days and 28 days, three-cylinder specimens made from the same concrete mix are tested. Equation 4 can be applied to compute concrete's compressive strength, where is measured in N/mm^2.

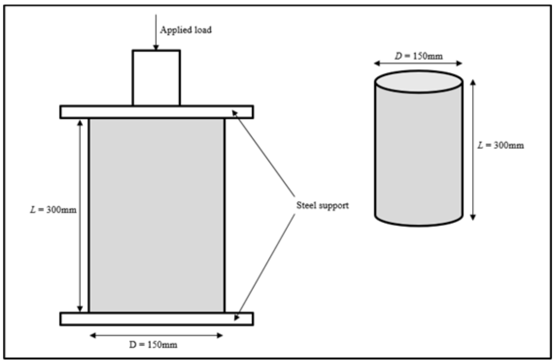


Fig. 4 *A schematic of compressive strength test setup for cylinder specimen*

$$\text{Compressive strength} = \frac{\text{Maximum load at failure } (N)}{\text{Cross sectional area of the sample } (mm^2)} \tag{4}$$

2.6.3 Flexural Strength

The 50 kN load-cell capacity UTM is used to evaluate the prism specimen's flexural strength. Four-point bending test for flexural strength of prism specimen is complying with BS EN 12390-5: 2019 [22]. UTM is set for four-point bending test at a consistent speed of 0.5mm/min to give adequate time to detect crack development and avoid catastrophic collapse of the prism specimen. The loading rate is maintained until the prism specimen failure. A schematic of prism specimen undertaking four-point bending test to evaluate flexural strength is illustrated in Fig. 5. Equation 5 indicated the formula employed to identify concrete's flexural strength.

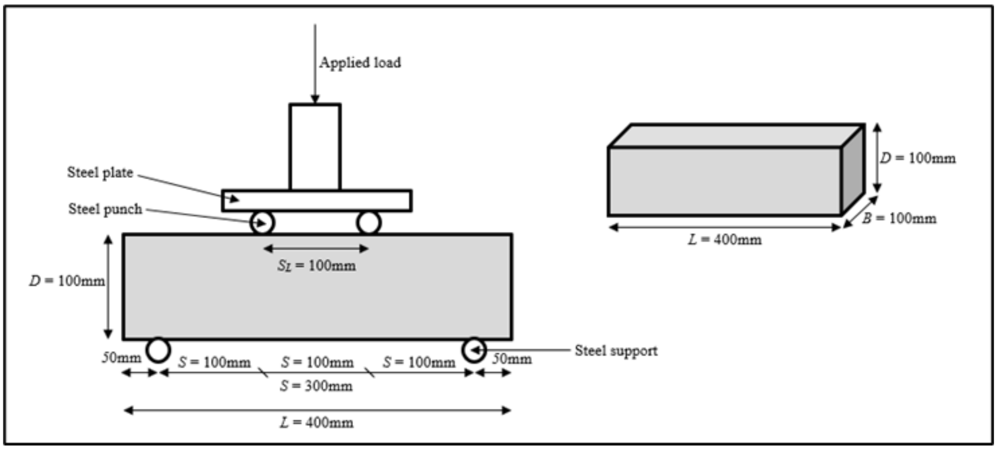


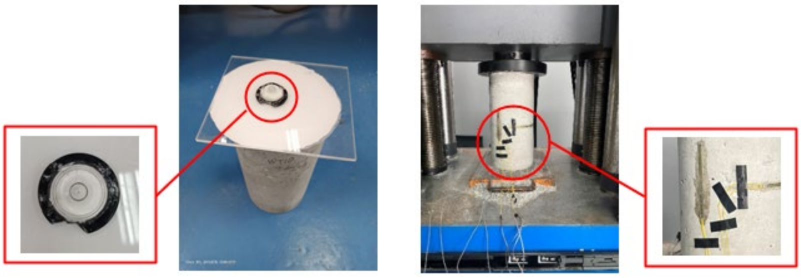
Fig. 5 *A schematic of four-point bending test setup for prism specimen*

$$\text{Flexural strength} = \frac{FL}{bd^2} \tag{5}$$

where F represents fracture point's load, L represents outer span's length, b represents prism specimen's width and d represents prism specimen's thickness.

2.7 Hardened Concrete's Material Properties

Under BS 1881-121: 1983 [23] and ASTM C469/C469M-22 [24], concrete's elasticity modulus and Poisson's ratio are assessed employing 150 mm X 300 mm (B X L) cylinder specimen. The cylinder specimen is tested to a 1200 kN load-cell capacity UTM at a consistent 0.6±0.2MPa/s loading rate. To capture data on the elasticity modulus and Poisson's ratio, UTM is connected to an external data logger. Gypsum S-630 is applied to cap the cylinder specimen's surface and its surface is leveled with a circular bubble level, as stated in Fig. 6(a). Besides, two strain gauges are glued in lateral and longitudinal directions at the middle length of cylinder specimen, as presented in Fig. 6(b). Equation 6 can be used to calculate modulus of elasticity while Equation 7 can be used to calculate Poisson's ratio.



(a) **(b)**

Fig. 6 *Elasticity modulus and Poisson's ratio setup (a) Gypsum S-630 caps the upper surface; (b) Biaxial direction strain gauges*

$$E = \frac{\text{Stress}}{\text{Strain}} \tag{6}$$

$$v = -\frac{\text{Lateral strain}}{\text{Longitudinal strain}} \tag{7}$$

3. Results and Discussions

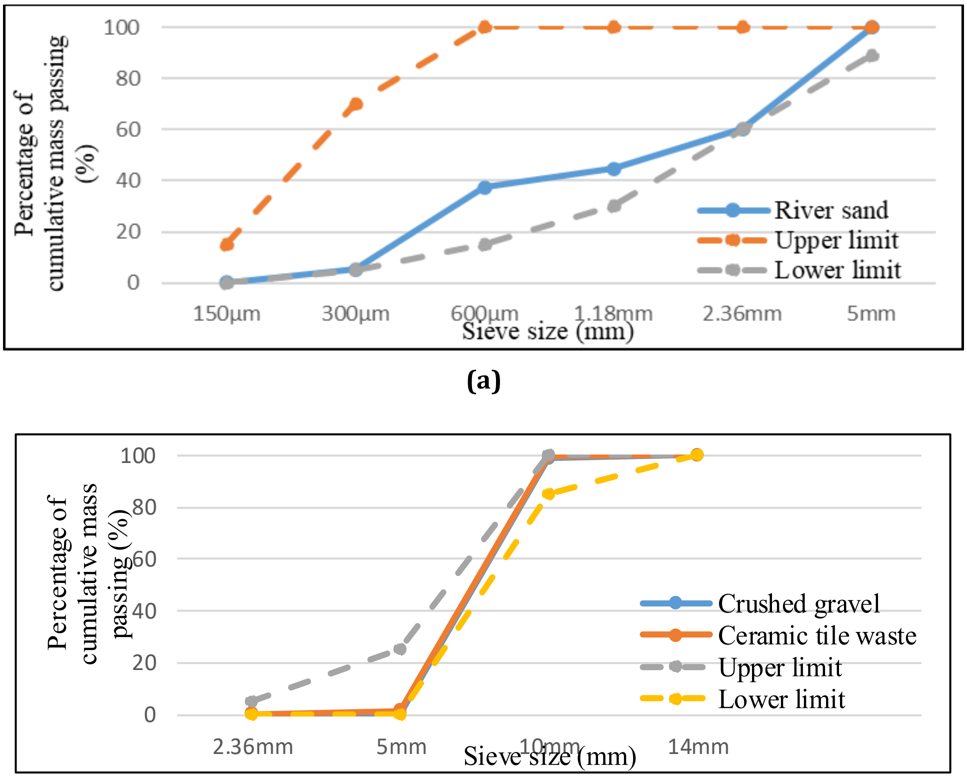
3.1 Physical Characteristics of Aggregates

3.1.1 Dry Sieve Analysis

The particle sizes of river sand, crushed gravel and ceramic tile waste are depicted in Fig. 7(a) and Fig. 7(b). Through dry sieve analysis, it is determined that river sand, crushed gravel and ceramic tile waste can be classified as well-graded, meeting the standard grading limits specified in BS 882:1992 [25]. Besides, it is found that 37.50% of river sand is passing 600 µm sieve size and it is adopted to design the concrete mix. The fresh concrete's workability and cohesiveness are enhanced by the fine river sand particles. It can fill the voids between larger aggregates and resulted in a denser concrete mix. If the river sand is well-graded, it takes less cement to provide the comparable workability. However, concrete strength is decreased if there is an imbalance amount between fine and coarse aggregate.

Based on Fig. 7(b), the particle sizes of ceramic tile waste are finer than crushed gravel adopted range from 5 mm to 10 mm. The finer particle sizes of ceramic tile waste can fill the voids between larger particle sizes of aggregates and potentially resulted in an improved packing and densification. Yet, excessive fine particles of ceramic tile waste may lead to a reduced workability. Thus, it requires additional water demand, plasticizer or superplasticizer to obtain adequate workability. Apart from this, the particle sizes of ceramic tile waste are coarser than crushed gravel at 2.36 mm. Although larger particle sizes of ceramic tile waste at 2.36mm improve aggregates interlocking and increase concrete strength, but it is potentially increasing the amount of cement or water needed to maintain the workability of concrete. If the concrete mix is not properly graded, the uneven distribution of aggregates caused by the coarser particle sizes of ceramic tile waste at 2.36 mm may resulted in a reduced workability.

The findings suggested that ceramic tile waste can be utilized to replace coarse aggregate, yet it is important to consider its grading compared to crushed gravel. Variations in particle sizes can influence the workability and strength of concrete's structural performance.



(a)

(b)

Fig. 7 *Particle sizes distribution (a) River sand; (b) Crushed gravel and ceramic tile waste*

3.1.2 Specific Gravity

In Table 4, specific gravity for river sand, crushed gravel and ceramic tile waste is listed. Based on Table 4, the specific gravity for river sand, crushed gravel and ceramic tile waste are 2.51 g/cm^3, 2.61 g/cm^3 and 2.33 g/cm^3, respectively. Generally, aggregates contribute to a significant volume of concrete. In the concrete mix, the occupied volume is affected by the aggregates' specific gravity. Lower ceramic tile waste's specific gravity may occupy larger volume when mixed with crushed gravel of the same mass but differing specific gravity. Hence, a low specific gravity of ceramic tile waste contributes to the lower density of concrete [26], [27].

The moderate specific gravity of river sand (2.51 g/cm^3) contributes to a workable concrete mix and reduce concrete's overall density. Meanwhile, a workable concrete mix can benefit from the rounded particle sizes of river sand. Besides, crushed gravel with a specific gravity of 2.61 g/cm^3 has the potential to develop concrete with greater strength and improved durability. However, it can also increase the overall density of concrete. In comparison to river sand and crushed gravel, the lowest specific gravity for ceramic tile waste is 2.33 g/cm^3. When used as an alternative for coarse aggregate, the lower ceramic tile waste's specific gravity can result in a lower overall density of concrete. Simultaneously, lower density may have an impact on concrete strength. Thus, higher cement content may be required to ensure ceramic tile waste concrete achieves adequate strength. Subsequently, the respective concrete mixture is designed employing the aggregates' measured specific gravity.

Table 4 *Aggregates' specific gravity*

Aggregates	Specific gravity (g/cm^3)
River sand	2.51
Crushed gravel	2.61
Ceramic tile waste	2.33

3.1.3 Water Absorption

Table 5 indicates how much water is absorbed by river sand, crushed gravel and ceramic tile waste. It is evident that river sand exhibits the highest percentages of water absorption compared to crushed gravel and ceramic tile waste, at 5.05%, 0.63% and 1.12% respectively. Additionally, ceramic tile waste absorbs more water than crushed gravel by 0.49%. The rounded particle sizes of river sand have high surface area to hold water, then resulted in a greater water absorption compared to crushed gravel and ceramic tile waste. In contrast to river sand and ceramic tile waste, crushed gravel has less voids to absorb water due to its compact structures and rough particle sizes. In concrete, low water absorption of crushed gravel has the potential to develop a more stable materials in terms of improved strength and highly durable.

Clay, sand and other materials are processed at high temperature to produce ceramic tile waste. Although it becomes relatively dense after the firing process, yet it remains its porosity properties. Higher level of porosity in ceramic tile waste can led to increased water absorption [9], [26]–[28]. This is because rough and angular shape of ceramic tile waste create voids to absorb water [29]. Besides, the incorporation of ceramic tile waste may alter the particle arrangement at the interface, particularly for cement paste-aggregates binding. Change in the aggregates' porosity may be necessary to adjust concrete mix proportion to ensure the concrete's workability and strength development [29]. Subsequently, the aggregates' water absorption is factored into the mixing water during concrete mix design.

Table 5 *Water absorption of aggregates*

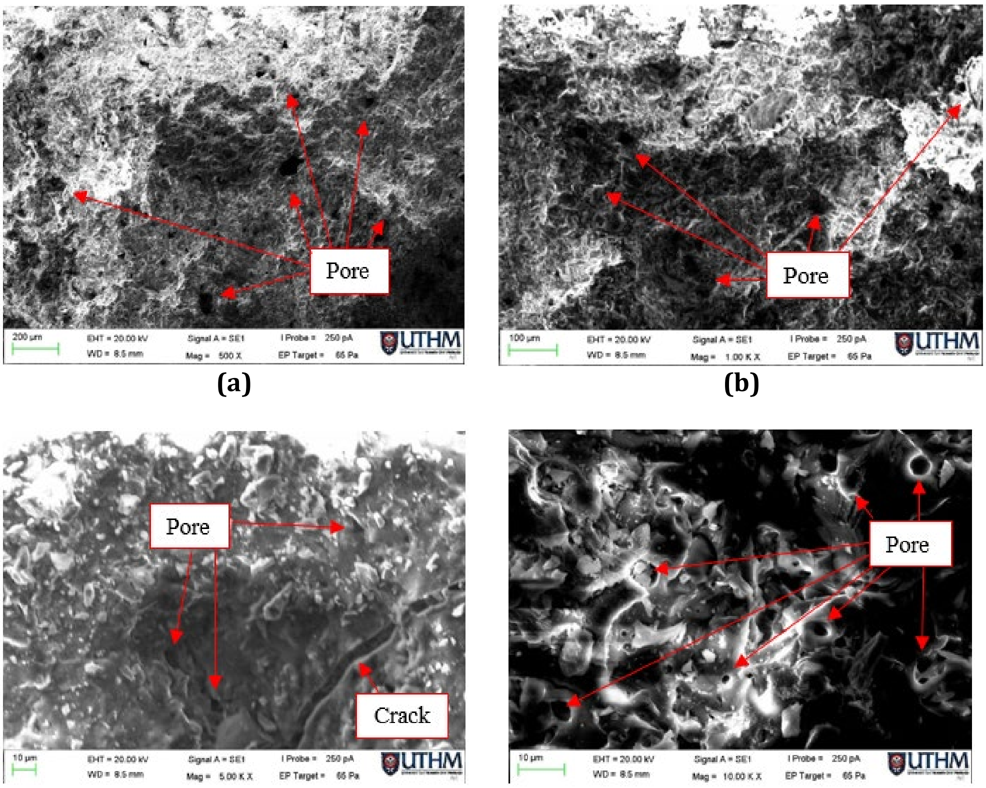
Aggregates	Specific gravity (g/cm^3)
River sand	5.05
Crushed gravel	0.63
Ceramic tile waste	1.12

3.2 Morphology and Chemical Element of Ceramic Tile

To assess ceramic tile's suitability as an alternative to coarse aggregate for making concrete, SEM-EDS analysis is conducted to examine its morphology and chemical element. Ceramic tile is chosen for its morphology evaluation at four different magnifications, as depicted in Fig. 8. It is evident from Fig. 8 that the surface textures of ceramic tile exhibit roughness and angular shapes. The rough and angular shapes of ceramic tile can increase the friction and interlocking between particles, then resulted in better bonding with cement and other materials in the concrete mix. Besides, it may potentially enhance concrete's mechanical characteristics. Additionally, irregular particle sizes of ceramic tile may affect the uniformity of concrete mixing. It may have an impact on the compaction, packing density and performance.

Moreover, ceramic tile exhibits higher porosity at different magnifications. Higher porosity of ceramic tile has more voids within the structures, so it can significantly affect its water absorption. Higher water absorption can also influence concrete's workability, strength and durability. The presence of surface cracks is possibly resulted from the crushing process. Cracks may reduce the interlocking bonding between particles and causing them more likely to break under loading. While, cracks can also increase the porosity of ceramic tile and resulted in higher water absorption. The findings obtained by Tanash *et al.* [27] are in agreement with these findings. Different insights on the surface properties are provided by the morphology of ceramic tile, particularly in examining the possible benefits and challenges of using them as coarse aggregate replacement.

As given in Table 6, ceramic tile is adopted to evaluate its relative chemical element. Oxygen (O), Silicon (Si) and Aluminum (Al) are the primary chemical elements of ceramic tile. On the other hand, Potassium (K), Sodium (Na), Iron (Fe), Calcium (Ca) and Magnesium (Mg) are other minor chemical elements. Primary chemical elements of ceramic tile are essential for ensuring hardness, strength and durability. Yet, other minor chemical elements contribute to color, firing process and others. Higher Si and Al concentrations support the pozzolanic reaction, which subsequently increase concrete's durability and strength. Since Calcium Hydroxide ($Ca(OH)_2$) in cement react with Silicon Dioxide (SiO_2) and Aluminium Oxide (Al_2O_3) in ceramic tile, then Calcium-Aluminate-Hydrate (C-A-H) gel and Calcium-Silicate-Hydrate (C-S-H) gel is created [29], [30]. Afterward, it can strength the interaction involving cement paste and aggregates in the Interface Transition Zone (ITZ) [29]–[31].



(a) **(b)**

(c) **(d)**

Fig. 8 *Ceramic tile's morphology at numerous magnification (a) 500X; (b) 1000X; (c) 5000X; (d) 10000X*

Table 6 *Chemical element of ceramic tile*

Aggregates	Ceramic tile
O	50.14%
Si	30.73%
Al	11.69%
K	2.56%
Na	2.09%
Fe	0.93%
Ca	1.42%
Mg	0.44%

3.3 Fresh Concrete's Workability

The fresh concrete's workability is presented in Table 7. All mixes (WT0 - WT50) maintained the designed slump level of 10 mm to 30 mm. Yet, control concrete (WT0) is more workable than ceramic tile waste concrete (WT10 – WT50). This is explained by the angular and rough shape of ceramic tile waste, which can weaken the bonding strength and resulted in reduced workability [26], [32], [33]. Besides, the findings reported that the workability of WT0 and WT10 are similar, yet the slump level declines when the percentages of ceramic tile waste rises. Because of its higher water absorption, rough surface and irregular particle sizes, concrete is less workable when the percentages of ceramic tile waste increases [26], [34], [35]. This is because large quantity of ceramic tile waste can increase specific surface area and weaken the bonding with cement paste [28]. Therefore, large specific surface area of ceramic tile waste requires additional cement paste to increase concrete's workability [36]. Even though the workability of all mixes is within the designed slump level (10 mm – 30 mm), yet a noticeable decrease in workability may be considered for concrete design, mixing, transporting and placing.

Table 7 *Workability of fresh concrete*

Testing designation	Slump (mm)
Target	10-30
WT0	25
WT10	25
WT20	19
WT30	14
WT40	13
WT50	10

3.4 Physical and Mechanical Characteristics of Hardened Concrete

3.4.1 Density

Table 8 revealed that the densities of WT10, WT20, WT30, WT40 and WT50 are relatively lighter than WT0. Moreover, an increase in ceramic tile waste is gradually decreases the density of hardened concrete. This phenomenon occurs because ceramic tile waste possesses lower specific gravity compared to crushed gravel, as mentioned in Table 4 and supported by [26], [35]. Simultaneously, the particles in ceramic tile waste may absorb more water, which will reduce the density of concrete. The decrease in density may affect the concrete strength and durability. In contrast to control concrete (WT0), lighter ceramic tile waste concrete (WT10 - WT50) may be less resistant to loading and more likely to cracking or deterioration in adverse environmental conditions. Even though all replacement levels of ceramic tile waste concrete (WT10 - WT50) resulted in lower densities compared to control concrete (WT0), they still fall within the 2200 kg/m^3 to 2600 kg/m^3 range of normal weight concrete [32], [37]. Although employing ceramic tile waste has reduced concrete's density and potentially to lower the dead load of concrete structures, but the dosage of ceramic tile waste should be carefully considered to prevent negative effects on structural performance.

Table 8 *Density of hardened concrete*

Testing designation	Density (kg/m^3)
WT0	2266.68 ± 4.747
WT10	2264.17 ± 3.927
WT20	2247.67 ± 2.643
WT30	2235.87 ± 2.178
WT40	2235.02 ± 2.078
WT50	2232.10 ± 4.747

3.4.2 Compressive Strength

Hardened concrete's compressive strength with various proportion of ceramic tile waste is presented in Table 9. According to the Table 9, it becomes evident that recycling ceramic tile waste to replace crushed gravel can guarantee compressive strength meeting or surpassing the designated grade, at 30 N/mm^2. At 28 days of curing age, WT0, WT10 and WT20 achieved a minimum of 30 N/mm^2. Additionally, WT20 exhibited the highest compressive strength among the mixes, at 39.21 N/mm^2. Conversely, the compressive strength of WT30 to WT50 range between 28.02 N/mm^2 to 28.12 N/mm^2, which is almost identical to 30 N/mm^2.

The findings also indicated that 20% is the ideal replacement level for ceramic tile waste, where the compressive strength is gradually increasing up to this level before declining. The research observed an improvement of 7.06 N/mm^2 or 21.96% between WT0 and WT20, indicating a positive reaction between ceramic tile waste and cement paste at the interface. The angular surface textures and sharp edges of ceramic tile waste contribute to a strong bonding strength [5], [27] and an effective pozzolanic reaction [38] between ceramic tile waste and cement paste at the interface. Additionally, ceramic tile waste contains reactive chemical elements (Si and Al) that can react with cement, generating additional cementitious compounds to enhance compressive strength [36].

Nevertheless, the compressive strength is decreasing once the percentages of ceramic tile waste exceed 20%. Numerous underlying mechanisms may be responsible for the observed decrease in strength beyond a threshold of 20% ceramic tile waste. Firstly, the homogeneity of the mixture diminishes if the ceramic tile waste's percentages in a mixture increase. This leads to uneven distribution of ceramic tile waste particles within the matrix, creating weak points and reducing overall structural integrity. Secondly, overuse of ceramic tile waste may weaken the bonding between the other constituent materials such as cement or aggregates, compromising the interfacial strength and cohesion within the composite material. Additionally, the physical characteristics of ceramic tile waste itself, such as irregular shape and varying composition can introduce discontinuities and stress concentration points to further weakening the material.

Furthermore, the increased porosity resulted from higher ceramic tile waste content can reduce the material's density and increase susceptibility to moisture absorption, leading to deterioration over time [9]. As mentioned in Section 3.2 and supported by [9], ceramic tile waste is likely to easily braking under compression due to its flaky and brittle nature. The flaky nature of ceramic tile waste has resulted in higher voids and porosity, it allows them to absorb more water than crushed gravel and thus weaken the bonding strength at the interface [9], [38]. Therefore, it is essential to understand and mitigate these underlying mechanisms to optimize ceramic tile waste's adoption for maintaining the desired strength characteristics.

Table 9 *Hardened concrete's compressive strength at 28 days*

Testing designation	Cylinder		Compressive strength (N/mm²)	
	Diameter (mm)	Height (mm)	Cylinder	Cube
Target	-	-	-	30.00
WT0	149.93	299.87	22.50 ± 2.325	32.15 ± 3.322
WT10	149.87	299.93	26.91 ± 2.313	38.45 ± 3.304
WT20	149.93	299.90	27.45 ± 1.591	39.21 ± 2.273
WT30	149.90	299.93	19.68 ± 1.652	28.12 ± 2.360
WT40	149.87	299.97	19.66 ± 0.739	28.08 ± 1.056
WT50	149.97	299.90	19.61 ± 1.727	28.02 ± 2.467

3.4.3 Flexural Strength

Table 10 illustrates that hardened concrete's flexural strength varies from 3.25 N/mm² to 3.51 N/mm², showing an increase from WT0 to WT20, followed by a gradual decline from WT30 to WT50. As compared to WT0, both WT10 and WT20 exhibit higher flexural strength. Conversely, WT30, WT40 and WT50 exhibit lower flexural strength than WT0. Notably, WT20 achieved the highest flexural strength among all mixes, measuring 3.51 N/mm².

According to the findings, the ideal replacement level for ceramic tile waste to achieve the highest flexural strength is 20%. Concrete strength and bonding strength have a mutually beneficial relationship. Higher concrete strength often correlates with better bonding strength due to denser and more uniform concrete matrices, facilitating stronger interfacial adhesion. Conversely, concrete structures' performance is impacted by weak bonding strength, possibly resulted in delamination, cracking or even failure under load. Therefore, optimizing both concrete strength and bonding strength is essential for ensuring the long-term structural resilience of concrete element in diverse engineering applications.

The rising trend in flexural strength is a result of ceramic tile waste being used as a micro filler in the concrete mixture [39]. Fine particles of ceramic tile waste can fill the voids between aggregates in the concrete matrix. Concrete strength may increase as a result of better particles interlocking caused by this improved packing density. Ceramic tile waste exhibits pozzolanic reaction, which resulted in additional cementitious compounds and contribute to the strength development. As demonstrated by WT10 and WT20, ceramic tile waste offers higher bonding strength at the interface and thereafter increase the flexural strength. Additionally, ceramic tile waste's hardness may enhance the resistance to breaking and withstand extra tensile force [36].

Nevertheless, the flexural strength is prone to a reduction if the percentages of ceramic tile waste exceed 20%. When the amount of ceramic tile waste beyond 20% without adding extra cement paste, then the surface area increases and may resulted in a weaker binding between ceramic tile waste and cement paste at the interface. Besides, excessive ceramic tile waste has led to increased porosity due to its higher water absorption capacity [9]. When a prism specimen is subjected to a tensile force, poor adhesion between ceramic tile waste and cement paste caused by the dispersion of absorbed water in ceramic tile waste can lead to easy cracking and braking at the interface [40].

Table 10 *Hardened concrete's flexural strength at 28 days*

Testing designation	Width (mm)	Depth (mm)	Flexural strength (N/mm^2)
WT0	99.87	99.90	3.44 ± 0.039
WT10	99.90	99.93	3.48 ± 0.111
WT20	99.97	99.93	3.51 ± 0.026
WT30	99.93	99.87	3.41 ± 0.145
WT40	99.90	99.87	3.31 ± 0.095
WT50	99.87	99.97	3.25 ± 0.143

3.5 Hardened Concrete's Material Properties

Based on Table 11, WT10 and WT20 exhibit higher modulus of elasticity values compared to WT0, measured at 29.12GPa, 29.42GPa and 26.63GPa respectively. The values of modulus of elasticity should surpass 15.00GPa for all replacement levels of ceramic time waste [9]. The angular surface textures of ceramic tile waste contribute to the improvement in the modulus of elasticity [27]. A uniform distributed microstructure can improve the packing density and then strengthen its modulus of elasticity. Besides, the stiffness and hardness of ceramic tile waste is positively affecting concrete's modulus of elasticity [36]. The harder the ceramic tile waste, the greater the modulus of elasticity.

When ceramic tile waste's amount rise, the modulus of elasticity value declines. Interfacial bonding within the concrete matrix is affected by a major quantity of weak ceramic tile waste [40]. Additionally, the primary causes led to these findings are ceramic tile waste's material properties [12]. Increased porosity is a result of ceramic tile waste's high water absorption capacity, which can absorb more water and reduce the bonding strength between cement paste and aggregates. Concurrently, crushed gravel is typically harder than ceramic tile waste. A significant volume of ceramic tile waste may change the packing density of concrete and resulted in lower modulus of elasticity if it exceeds the ideal dosage level.

Table 11 *Modulus of elasticity*

Testing designation	E (GPa)
WT0	26.627 ± 1.372
WT10	29.123 ± 1.270
WT20	29.423 ± 0.849
WT30	24.910 ± 1.044
WT40	24.907 ± 0.468
WT50	24.863 ± 1.083

Table 12 listed the values of the Poisson's ratio. It revealed that the Poisson's ratio values for all mixes ranged from 0.195 to 0.224. WT10 and WT20 exhibit higher Poisson's ratio values compared to WT0, yet the trend indicated that Poisson's ratio decreased as the percentages of ceramic tile waste rose. For WT10 and WT20, it remains relatively homogeneous in the concrete mix and offered a slightly higher Poisson's ratio. Concrete becomes less homogeneous since the percentages of ceramic tile waste increase from WT30 to WT50. This is because the presence of excess ceramic tile waste may cause the cement paste-aggregates bond weaker. Poorly bonded ceramic tile waste may be more likely to cracking and less capable to deform plastically. When compared to crushed gravel, ceramic tile waste is typically harder and brittle. If a significant quantity of ceramic tile waste is mixed with concrete, concrete may become more rigid and less capable to undergo plastic deformation. Hence, the ability to react with deformation may be diminished if the percentages of ceramic tile waste exceed the threshold of 20%, which resulted in a decrease in Poisson's ratio.

Table 12 *Poisson's ratio*

Testing designation	v
WT0	0.195 ± 0.006
WT10	0.222 ± 0.004
WT20	0.224 ± 0.002
WT30	0.215 ± 0.005
WT40	0.207 ± 0.006
WT50	0.201 ± 0.005

4. Conclusion

Throughout the experimental works, ceramic tile waste can be utilized instead of coarse aggregate in normal concrete. The aggregates' particle sizes distribution is within the standard grading limit. Besides, all mixes have adequate workability because the slump level is between 10 mm and 30 mm. By replacing 20% ceramic tile waste with crushed gravel, higher compressive strength and flexural strength are achieved, measuring 39.21 N/mm^2 and 3.51 N/mm^2 respectively. Meanwhile, up to 20% ceramic tile waste can be replaced to produce lightweight concrete without compromise its strength. Furthermore, the viability of recycling ceramic tile waste for coarse aggregate in normal concrete is further supported by an examination of elasticity modulus and Poisson's ratio.

Recycling ceramic tile waste for coarse aggregate in normal concrete has implications for numerous key stakeholders such as construction practitioners, environmental and governmental agencies and academician. For construction practitioners, it offers them a sustainable construction by reducing dependency on natural resources. Meanwhile, it provides a cost-effective solution to the contractors in terms of lowering waste disposal cost. By fostering circular economy, minimizing the quantity of ceramic tile waste disposal and leading to reduced environmental impacts, it is corresponded to the Sustainable Development Goals (SDGs) for environmental and governmental agencies. For academician, it fosters innovation in recycled construction waste materials, particularly in construction practices of construction waste management techniques.

Future research is recommended in the following areas such as ceramic tile waste concrete's long-term performance in a range of environmental conditions, ceramic tile waste concrete combine with other recycled waste materials, performance of ceramic tile waste concrete under seismic condition, cost analysis by comparing ceramic tile waste concrete and conventional concrete, life cycle assessment on ceramic tile waste concrete and development of an innovative approach to processing and quality of ceramic tile waste.

Acknowledgement

With deep appreciation, the author acknowledges the Jamilus Research Centre (JRC) and the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia.

Conflict of Interest

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

Author Contribution

The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.

References

[1] Nasirhusen, C. M., & Pitroda, J. R. (2018) A critical literature review on construction waste management, *International Journal of Advance Engineering and Research Development*, *5(3)*, 434–439,

[2] Kareem, W. A., Asa, O. A. & Lawal, M. O. (2015) Resources conservation and waste management practices in construction industry, *Arabian Journal of Business and Management Review*, *4(7)*, 20–31, https://doi.org/10.4324/9781315800462-16

[3] Rahim, M. H. I. A., Kasim, N., Moham, I., Zainal, R., Sarpin, N. & Saikah, M. (2017) Construction waste generation in Malaysia construction industry: Illegal dumping activities, *IOP Conference Series: Materials Science and Engineering*, *271*, 1–8, https://doi.org/10.1088/1757-899X/271/1/012040

[4] Pawar, A., Vilas, M. R., Vilas, A. A., Kisan, M. S., Mansing, T. R. & Balaso, S. U. (2022) Reuse of ceramic tiles as coarse aggregates in concrete, *International Research Journal of Modernization in Engineering Technology and Science*, *4(6)*, 4284–4287.

[5] Ramirez, J., Remolisan, C., Coscos, M. J. & Canseco-Tunacao, H. A. (2023) Integrating fine ceramic tile aggregates in concrete hollow blocks, *IOP Conference Series: Earth and Environmental Science*, *1184*, 1–16, https://doi.org/10.1088/1755-1315/1184/1/012023

[6] Atkuri, V. K. & Rao, G. V. R. (2021) Strength properties of ceramic waste concrete, *IOP Conference Series: Materials Science and Engineering*, *1025*, 1–10, https://doi.org/10.1088/1757-899X/1025/1/012017

[7] Lim, S. K., Lee, Y. L., Yew, M. K., Ng, W. W., Lee, F. W., Kwong, K. Z. & Lim, J. H. (2022) Mechanical properties of lightweight foamed concrete with ceramic tile wastes as partial cement replacement material, *Frontiers in Built Environment*, *8(1)*, 1–12, https://doi.org/10.3389/fbuil.2022.836362

[8] Khan, S., Goliya, S. S. & Mehar, R. (2019) Use of ceramic tile waste in concrete mix by partial replacement of coarse aggregate: An experimental study, *Journal of Emerging Technologies and Innovative Research*, *6(3)*, 165–176, https://doi.org/10.22214/ijraset.2017.3086

[9] Paul, S. C., Faruky, S. A. U., Babafemi, A. J. & Miah, M. J. (2023) Eco-friendly concrete with waste ceramic tile as coarse aggregate: Mechanical strength, durability, and microstructural properties, *Asian Journal of Civil Engineering*, *24(8)*, 3363–3373, https://doi.org/10.1007/s42107-023-00718-x

[10] Hasmori, M. F., Zin, A. F. M., Nagapan, S., Deraman, R., Abas, N., Yunus, R. & Klufallah, M. (2020) The on-site waste minimization practices for construction waste, *IOP Conference Series: Materials Science and Engineering*, *713*, 1–11, https://doi.org/10.1088/1757-899X/713/1/012038

[11] Nurulhaiza, R. R. N., Hazmizah, N. M. N. & Syazwani, W. N. W. M. (2022) Properties of concrete with the inclusion of ceramic waste as coarse aggregate, *International Journal of Academic Research in Business and Social Sciences*, *12(11)*, 1684–1693, https://doi.org/10.6007/ijarbss/v12-i11/15309

[12] Peter, D. M., Awang, A. Z., Sam, A. R. M., Ma, C. K. & Loo, P. (2020) Eco-efficient concrete containing recycled ceramic wastes aggregate, *IOP Conference Series: Materials Science and Engineering*, *849*, 1–8, https://doi.org/10.1088/1757-899X/849/1/012035

[13] BS EN 933-1: 2012. (2012). Tests for geometrical properties of aggregates - Part 1: Determination of particle size distribution - Sieving method.

[14] Laskar, A. I. (2015). Concrete technology practices (1st Edition). Alpha Science International Ltd.

[15] Gambhir, M. L. (2015). Concrete technology: Theory and practice (5th Edition). McGraw-Hill Education (India) Private Limited.

[16] ASTM C128. (2001). Standard test method for relative density (Specific gravity) and absorption of fine aggregate.

https://doi.org/10.1520/C0128-15.10.1520/C0128-22.2

[17] ASTM C127 (2001). Standard test method for specific gravity and absorption of coarse aggregate.

[18] BS 812-2 :1995. (1995). Testing aggregates - Part 2: Methods of determination of density.

[19] BS EN 12350-2: 2019. (2019). Testing fresh concrete - Part 2: Slump test.

[20] BS EN 12390-7: 2019. (2019). Testing hardened concrete - Part 7: Density of hardened concrete.

[21] BS EN 12390-3: 2019. (2019). Testing hardened concrete - Part 3: Compressive strength of test specimens.

[22] BS EN 12390-5: 2019. (2019). Testing hardened concrete - Part 5: Flexural strength of test specimens.

[23] BS 1881-121: 1983. (1983). Testing concrete - Part 121: Method for determination of static modulus of elasticity in compression.

[24] ASTM C469/C469M-22, A. (2014). Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression.

[25] BS 882: 1992. (1992). Specification for aggregates from natural sources for concrete.

[26] Goyal, R. K., Agarwal, V., Gupta, R., Rathore, K. & Somani, P. (2022) Optimum utilization of ceramic tile waste for enhancing concrete properties, *Materials Today: Proceedings*, *49(1)*, 1769–1775, https://doi.org/10.1016/j.matpr.2021.08.011

[27] Tanash, A. O., Muthusamy, K., Budiea, A. M. A., Fauzi, M. A., Jokhio, G. & Jose, R. (2023) A review on the utilization of ceramic tile waste as cement and aggregates replacement in cement based composite and a bibliometric assessment, *Cleaner Engineering and Technology*, *17(1)*, 1–27, https://doi.org/10.1016/j.clet.2023.100699

[28] Alshahwany, R. B., Abdulkareem, O. M. & Shlla, R. D. (2024) Influence of ceramic wastes as a recycled coarse aggregate with different maximum sizes on the concrete, *The Open Civil Engineering Journal*, *18(1)*, 1–19, https://doi.org/10.2174/0118741495298085240326062433

[29] Ahmad, J., Sabri, M. M., Majdi, A., Alattyih, W., Khan, I. & Alam, M. (2025) Durability and microstructure aspects of sustainable concrete made with ceramic waste: A review, *Frontiers in Materials*, *11(1)*, 1–22, https://doi.org/10.3389/fmats.2024.1508989

[30] Heidari, A., Tavakoli, S. & Tavakoli, D. (2019) Reusing waste ceramic and waste sanitary ware in concrete as pozzolans with nano-silica and metakaolin, *International Journal of Sustainable Construction Engineering and Technology*, *10(1)*, 55–67, https://doi.org/10.30880/ijscet.2019.10.01.006

[31] Xu, F, M., Lin, X. S., Zhou, A. & Liu, Q. F. (2022) Effects of recycled ceramic aggregates on internal curing of high-performance concrete, *Construction and Building Materials*, *322(1)*, 126484, https://doi.org/10.1016/j.conbuildmat.2022.126484

[32] Victor, O., & Racheal, A. A. (2022). The suitability and performance of ceramic waste as a substitute for coarse aggregate in the production of concrete using different mix ratio, *International Journal of Advances in Engineering and Management*, *4(10)*, 22–31, https://doi.org/10.35629/5252-04102231

[33] Joshi, P. H. & Parekh, D. N. (2022) Assessment of utilization of ceramic waste as a substitute to concrete constituents – A review, *Revista Ingenieria de Construccion*, *37(1)*, 69–78, https://doi.org/10.7764/RIC.00019.21

[34] Ali, A., Mangi, S. A., Soomro, F. A., & Kerio, M. A. (2021) Fresh and hardened properties of concrete containing ceramic tile waste as coarse aggregate and glass waste as fine aggregate. Journal of Structural Monitoring and Built Environment, 1(1), 40–44, https://doi.org/10.1016/j.jksues.2020.01.002

[35] Meena, R. V., Jain, J. K., Chouhan, H. S. & Beniwal, A. S. (2022) Use of waste ceramics to produce sustainable concrete: A review, *Cleaner Materials*, *4(1)*, 1–18, https://doi.org/10.1016/j.clema.2022.100085

[36] Ahmad, J., Alattyih, W., Jebur, Y. M., Alqurashi, M. & Garcia-Troncoso, N. (2023) A review on ceramic waste-based concrete: A step toward sustainable concrete, *Reviews on Advanced Materials Science*, *62(1)*, 1–24, https://doi.org/10.1515/rams-2023-0346

[37] Gautam, H., & Rajpoot, A. (2022). The effect of ceramic waste broken tiles as coarse aggregate on strength properties of concrete, *International Journal of Research Publication and Reviews*, *3(12)*, 1489–1497

[38] Najm, H. M. & Ahmad, S. (2022) The use of waste ceramic optimal concrete for a cleaner and sustainable environment - A case study of mechanical properties, *Civil and Environmental Engineering Reports*, *32(3)*, 85–115, https://doi.org/10.2478/ceer-2022-0030

[39] Bommisetty, J., Keertan, T. S., Ravitheja, A. & Mahendra, K. (2019) Effect of waste ceramic tiles as a partial replacement of aggregates in concrete, *Materials Today: Proceedings*, *19(1)*, 875–877, https://doi.org/10.1016/j.matpr.2019.08.230

[40] Mohan, A., Thomas, J. & Joseph, N. (2018) Use of clay tile chips as coarse aggregate in concrete, *IOP Conference Series: Materials Science and Engineering*, *396(1)*, 1–8, https://doi.org/10.1088/1757-899X/396/1/012002