Reuse of Broken Tile as Coarse and Fine Aggregate in Concrete

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Recommendation of the Thesis Supervisor

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Declaration

This is to certify that the work presented in this thesis, titled, "**Reuse of Broken Tile as Coarse and Fine Aggregate in Concrete**", is the outcome of the investigation and research carried out by us under the supervision of Dr. Md. Tarek Uddin, PEng, Professor, Department of Civil and Environmental Engineering.

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Dedication

To our parents, whose unwavering faith in us has been our greatest strength. There countless sacrifices, endless encouragement, and unconditional love have been the foundation upon which we have built our dreams. They taught us the value of perseverance and hard work, and for that, I am eternally grateful.

To my thesis supervisor, **Dr. Md. Tarek Uddin, PEng** .Your expert guidance, immense patience, and invaluable insights were the compass that guided us through this challenging journey. Your mentorship has not only shaped this work but has also profoundly inspired our growth as researchers and individuals. Thank you for your immense support and .

This accomplishment is as much your as it is ours .

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CHAPTER 1. Introduction

1.1 General

Concrete production counts heavily on natural sand, and on gravel. The ongoing construction growth has increased pressure on these limited resources, and construction also added to landfill problems, due to industrial byproducts. Ceramic tile waste stands out as one very obvious type of these by-products, and it is quite durable. It is also non-biodegradable, so it is often stockpiled in significant quantities near manufacturing locations or near sites for construction. Initial studies indicate that tile, crushed or tile powdered, can replace conventional aggregates a bit. Also, concrete's performance isn't jeopardized and some qualities see improvement by way of greater interlock and/or the creation of pozzolanic effects. Yet, we can see the available details can be fragmented: many studies look at just a portion of the tiles. These also cap how much can be substituted, and often mechanical qualities go undocumented. This lacks matching strength data, so it limits insights used in practical concrete mixtures.

Ceramic tiles offer helpful qualities when we seek uses. They are treated with high heat so they don't break down as easily and fight rubbing well. They have typically lower specific weight than you get in natural stone and will even feature better water draw and sharpness, so they handle packing nicely and don't use much water and can yield high-quality ITZ. Reported industrial data says tile loss is notable. This suggests a good share of the tiles become trash, so cement structures could lower waste. Complete analysis of diverse replacement portions, regarding the size and structure, along with set water-to-cement balance will help convert findings into blending rules. Those must consider work factors and ensure balance with strength.

This research aims to tackle a key void by assessing both partial small aggregate, and large aggregate change for dust tile as well as big rough bits made out of ceramic pieces through five gradients, 0, 25, 50, 75, along with one hundred pct with duo water/cement aspects 0.45 and 0.50. The elements got their aspects marked down by measuring unique weight. We also calculated water intake. Then also the grading pattern was recorded in line with standardized approaches; Ten forms of premix concrete measured 400 kg/m³. We took down how easily it flows together, the compressive qualities around two benchmarks days from set plus overall break weight and motion power using sonar waves; And also assessed strength alongside how easily it fell to destruction when stress put to its exterior and through lab conditions utilizing pulse velocity via sound waves. Lastly, the length water molecules need get inside was determined together with how rapidly salts may travel through and past solid concrete via lab settings within specific instances. By this broad spread the individual influences of amount shift or w/c factors can potentially get disconnected plus looked over in relation to both mobility paired alongside bodily elements.

The important thing to recall through our program lies mostly to note constant excellent outcomes along a little shifting. At w/c equal to 0.45 we had found simply taking out 25% showed up with superior outcomes and enhanced firm footing that took longer through thirty days in time whereas with 0.50 even if shifted up to 50% it performed on parity levels; a suitable option for additional density created while looking for excellent suction through hard angled ceramic materials. Split stretching power often trailed beyond typical amounts the more content switched and is expected. Modularity also diminished that matches little weight as well increased fissures while important amounts shifted with 0.50 shifting off "minor" groups providing top quality which may improve overall arrangement through cement wherein the compound matches well and volume remains equivalent through particle form. Ultrasound motions looked within constantly in place so that needs additional testing for solidity next the facts from stress examination on its build or strength as entire package for how well mixes work so well engineered while lessening landfills and junk build ups!

Some contributions found stand around just about three marks - this shows what takes effect with little bits shifted next alongside heavy grade substitution. You're able to fully assess by zero means changing a few points close and across by both useful qualities related within fractions. Through combining robust aspects related as moving material qualities these have been paired together inside as part to give clarity regarding concrete at risk towards chlorides. Ultimately the investigation created working knowledge in the area alongside pulse actions while mixing in tensile motions these might gain practice at a higher level.

Through remaining parts for documentation methods involved as testing then through lab we may explore its mechanical aspects as it stops through guidance and use by great expanses which hold scrap waste at maximum value and use.

CHAPTER 2. Literature Review

Concrete is the most flexible development material since it is proposed to withstand the unsafe circumstances, with palatable quality and toughness. It is obtained by mixing cement, aggregates (fine & coarse), water, and admixture. It is also the most used product on the planet, and also it is comparatively cheap and can be used in various structures. In concrete mix design, typically, a mix is about 10-20 percent cement, 60-75 percent aggregate, and 15-20 percent water. As mentioned, aggregate plays an important role in the formula of concrete. So choosing aggregates is a big issue for the mix design.

But nowadays there is scarcity in materials. So, a few new materials that are locally available for low cost have to be introduced for replacing the fine aggregates and coarse aggregates. In search of fine and coarse aggregate alternatives and also keeping our mind in environmental friendliness, broken tiles have a huge potential as fine and coarse aggregates. As our environmental conditions are taking a nosedive, certain measures are to be taken; because of construction, our environment takes a huge toll [1-2]. The need to preserve nonrenewable resources requires the development and the utilization of renewable resources. [3-4] Our country's tile industry is flourishing in a rapid way. And from studies we can see that the ceramic industries produce 10-30% tiles as waste. [5-6] These broken tiles don't dissolve into the ground as easily and remain as they are. Because of that, they become hazardous or the people and also the environment. The sharp edges of tiles could harm roaming animals and also humans. So using broken tiles in concrete as coarse and fine aggregate is a viable solution. If we set aside the environmental impact, broken tiles used as fine and coarse aggregate show promising results in strength as well. Numerous researchers examined the flexural and compressive strengths of concrete by incorporating waste ceramic (WC) into concrete production [7-10]. Mashitah et al. [7] demonstrated the possibility of using ceramic tile wastes as coarse aggregates with varying volume ratios in the manufacture of concrete blocks with compressive strengths ranging from 41.4 to 48.8 MPa. On the other hand, Abdullah et al. [8] stated that ceramic tiles used as fine and coarse aggregate as a replacement of gravel show 85-100% greater compressive strength than ordinary gravel.We can also see that Gautam et al. [9] reported the use of waste ceramic powder (WCP) had a beneficial impact on the fresh characteristics of self-compacting concrete (SCC). Specifically, the combination of 10% WCP and 30% granite waste exhibited the highest strength. Gautam et al [9] also stated that using WCP (waste ceramic powder) reduces the carbon dioxide emission and also the impact on the environment. In these researches we can see that the substitution of ordinary gravel and sand with broken tiles and ceramic powder as percentage of 15%, 30%, and 45%. So we hope to achieve greater success trying to use other percentages.

Let’s see the properties of Broken tiles as coarse and fine aggregates

Impact value

12.5% for ceramic tiles—indicates good resistance to impact and suitability as coarse aggregate (Gautam et al.).

High durability:

Fired at 1000–1250°C, making them resistant to chemical/thermal damage

Irregular particle shape:

Improves interlocking but may reduce workability. Higher water absorption (up to 14.4%) compared to natural aggregates (0.5–1.24%).

Lower specific gravity:

(2.24–2.39 vs. 2.69–2.76 for natural aggregates), affecting concrete density.

Workability

1. Gautam et al. (2022) found 10% ceramic powder (WCP) improved self-compacting concrete (SCC) properties.

2. Higher replacements (>20%) may require superplasticizers due to reduced slump.

3. Workability decreases as tile replacement increases due to angular shape and low water absorption of tiles (Islam et al. 2020).

4. Lower slump values at higher replacement—compensated with plasticizers if needed (Mujedu et al. 2014)

Sustainability

1. Gautam et al. (2022) noted reduced CO_2 emissions when using ceramic waste.

2. Use of crushed tiles reduces landfill waste and conserves natural stone resources (Ogunjiofor et al. 2025).

3. Incorporating recycled tiles aligns with green construction by cutting both waste and CO_2 emissions (Ogunjiofor et al. 2025).

Optimal Replacement Level

1. Ideal coarse aggregate replacement: 10–20% for strength and durability in structural concrete. (Hemanth et al., 2015)

2.For fine aggregate, partial replacement with tile powder up to 10% has shown positive results. (Gautam et al., 2022

Mechanical Properties

1. Splitting tensile and flexural strength remains comparable to the control mix up to 20% replacement. (Adeala et al., 2021)

2. Concrete density slightly decreases as tile content rises, but values stay within structural norms. (Adeala et al., 2021)

3. Modulus of elasticity and overall performance match conventional concrete for up to 20% tile use (Adeala et al., 2021).

CHAPTER 3. Methodology

3.1 Objective

The objective of our experiment is to use broken tiles as coarse and fine aggregate as the replacement of natural coarse and fine aggregates. To achieve the result, we created a concrete mix design, replacing the volume of natural coarse and fine aggregates with Broken tiles dust and broken tile aggregates. We replaced the volumes by 25%, 50%, 75%, and 100%. We also created a batch of controlled mix design with no broken tiles to compare the results. We created test cylinders to test the Compressive Strength, Split Tensile Strength,Ultrasonic Pulse Velocity (UPV) test,Rapid Chloride Permeability Test(RCPT),Rapid Chloride Migration Test(RCMT) and Scanning Electron Microscopy (SEM) analysis.These tests were done after curing of 14 and 28 days.

3.2 Material Properties

Broken tiles were collected from local construction sites. After collection, the broken tiles were chipped into coarse aggregate sizes and also crushed to get broken tile dust from the collected material. In Fig. 1 we can see that the broken tile aggregates are smooth on one side and rough on the other side. Tiles are generally hard, strong, durable, water-resistant, and resistant to wear. The aggregates applicable to this study were put to test on specific gravity, absorption capacity, abrasion resistance, gradation, and unit weight.

The specific guidelines are listed in Table 3.1.

Table 3.1. Specifications followed to test material properties

Name of the property evaluated	Specification/guideline followed
Specific gravity	ASTM C 127 (for coarse aggregate) ASTM C 128 (for fine aggregate)
Absorption capacity	ASTM C 127 (for coarse aggregate) ASTM C 128 (for fine aggregate)
Abrasion resistance	ASTM C 131
Unit weight	ASTM C 29
Gradation	ASTM C 33
Fineness Modulus	ASTM C 136

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3.2.1 Broken Tiles Aggregates

ASTM C128 Test Procedure (Specific Gravity of Coarse Aggregate)

1. *Sample Preparation:*
    - We cleaned the coarse aggregate sample to remove dust, dirt, and fine materials.
    - We dried the sample in an oven at 110 ± 5°C until it reaches a constant weight (oven-dry condition).
2. *Saturation:*
    - We soaked the aggregate sample in water at room temperature for 24 hours to fully saturate the pores.
3. *Surface Drying:*
    - We removed the saturated aggregate from water.
    - We dried the surface using a damp cloth or towel to reach Saturated Surface Dry (SSD) condition (pores filled with water, but no surface water present).
4. *Weighing:*
    - *Recorded the **oven-dry weight** (**W_{od}**) of the aggregate.*
    - *Recorded the **SSD weight** (**W_{ssd}**) of the aggregate.*
    - *Weighed the aggregate while completely submerged in water to record the **submerged weight** (**$W_{submerged}$**).*

5. Calculations:

Using the following formulas we calculated specific gravity and absorption.

- Bulk Specific Gravity (SSD specific gravity):

$$G_{bulk} = \frac{W_{od}}{W_{ssd} - W_{submerged}}$$

(3.1)

- Apparent Specific Gravity:

$$G_{apparent} = \frac{W_{od}}{W_{od} - W_{submerged}}$$

- Absorption Percentage:

$$Absorption\,\% = \frac{W_{ssd} - W_{od}}{W_{od}} \times 100$$

(3.2)

After calculation we obtained the value of the specific gravity of broken tiles' coarse aggregate, which was 2.19, and the absorption percentage would be 10%. This value may imply:

- Tile aggregate is moderately dense.

- Result from this aggregate should be significantly lighter concrete mix.

- The weight and strength properties of concrete or other composites containing this material will be affected accordingly.

ASTM C128 Test Procedure (Specific Gravity of Fine Aggregate)

1. Sample Preparation:

- We obtained a sample of broken tile dust as fine aggregates passing the 4.75 mm (No. 4) sieve.
- We dried the sample in an oven at 110 ± 5°C until it reaches a constant weight (oven-dry condition).

2. *Saturation:*
    - We soaked the entire aggregate sample in water for up to 24 hours at room temperature to saturate the pores.

3. *Surface Drying (SSD Condition):*
    - Removed the aggregate sample from water.
    - Manually stir and dried the surface by air circulation until the sample reaches a Saturated Surface Dry (SSD) condition (pores filled with water but no surface water).
    - Verified SSD condition with a cone test: fill a frustum of a cone mold with the sample, tamp it gently, and then remove the mold. If the sample slightly slumps, it is SSD.
4. *Weighing:*
    - *Weigh the* ***oven-dry mass (***W_{od} *)of the sample.*
    - *Weigh the saturated surface dry mass (*W_{ssd}*) of the sample.*
    - Place the SSD sample in a pycnometer or volumetric flask partially filled with water, remove trapped air by gentle agitation, and fill water to the calibration mark.
    - Weigh the pycnometer filled with water and SSD sample (W_{py_ssd}).
    - Remove the sample, dry it, and weigh the pycnometer filled with water only to get (W_{py_water}).
5. *Calculation :*

Using the given formulas we can calculate the Specific Gravity of the Broken Tiles fine aggregate.

Formulas:

- Bulk Specific Gravity (SSD condition):

$$G_{bulk} = \frac{W_{od}}{W_{ssd} - (W_{py\_ssd} - W_{py\_water})}$$

(3.3)

- Apparent Specific Gravity:

$$G_{apparent} = \frac{W_{od}}{W_{od} - (W_{py\_ssd} - W_{py\_water})}$$

- Absorption Percentage:

$$Absorption\,\% = \frac{W_{ssd} - W_{od}}{W_{od}} \times 100$$

(3.4)

After calculating we got the Specific Gravity value for Broken Tile fine aggregate which is **2.17** and the absorption capacity is **3%**.Which indicates that the Broken tiles fine aggregate is moderately dense, and this information is critical for determining quantities in concrete production and assessing aggregate quality.

Table 3.2 Specific Gravity

Type of aggregate	Specific Gravity
Broken Tiles Coarse Aggregate	2.19
Broken Tiles Fine Aggregate	2.17

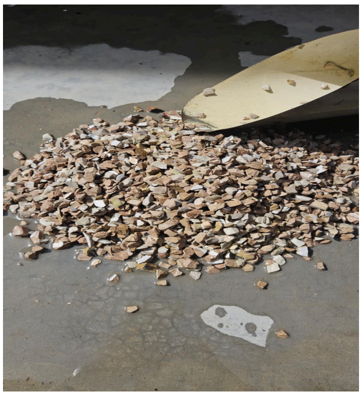


Fig.1-Broken Tiles Coarse Aggregate

Fig.2-Broken Tile fine Aggregates

3.2.2 Natural Coarse Aggregates

Coarse aggregates used in this study were crushed black stone sourced from Sylhet, Bangladesh. The aggregates were prepared for tests after passing it through an appropriate sieve, and the nominal size was 20 mm.

Required procedures for determining the specific gravity of the coarse aggregates were conducted as per ASTM C128 Relative Density (Specific Gravity) and Absorption of Fine Aggregate. The obtained specific gravity was 2.7; equation (1) was used for calculations. Sieve analysis was conducted as per ASTM C136—Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.

3.2.3 Natural Fine Aggregates

The fine aggregate that was utilized in the research was the High strength natural river sand that is found in Sylhet, Bangladesh. The fine aggregate was dried in the oven and then put on the testing program and subjected to a sieve of 4.75 mm diameter to remove any particle that is larger than the grading requirement on fine aggregates in concrete.

The procedure that needed to be followed in the determination of the specific gravity of the sand was conducted as per the Standard Test Method of Relative Density (Specific Gravity) and Absorption of Fine Aggregate ASTM C128 (ASTM International, 2015). We determined the specific gravity of the sand by using equation (3.3) and obtained 2.65.

The recommended absorption in the water by the sand is provided in ASTM C128 (ASTM International, 2015). A saturated surface dry sample of the sand was made, and the weight was taken. The sample was dried in the oven for 24 hours, and the weight was measured once again. Based on equation (3.4), the absorption capacity needed was 2%.

In order to find the particle size distribution, sieve analysis was performed in accordance with ASTM C136 (ASTM International, 2019)—Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. The sample was sieved (4.75 mm, 2.36 mm, 1.18 mm, 600 mm, 300 mm, and 150 mm), and the mass that remained was noted.

3.2.4 Water

The water we used for the experiment was potable tap water and the unit weight of the water as 1000kg/m3

3.2.5 Cement

In this study we used CEM Type II A-M cement, which meets the following standards: BDS EN 197-1:2000 and ASTM C595. Table 3.6 (as stated by the manufacturer) gives the composition of the mineral components. The common raw materials, clinker and gypsum, are inter-ground together with three major mineral components, namely Pulverized Fuel Ashes (PFA), Blast Furnace Slag, and Limestone, to produce it.

Table 3.3 Composition of Cement

Component	Percentage
Clinker	80–94%
Slag, Fly Ash, and Limestone	6–20%
Gypsum	0–5%

3.3 Concrete Mixture Proportions and Cases Studied

Ten mixes were prepared using w/c ratio of 0.45 and 0.50 crossed with BTA replacement levels of 0%, 25%, 50%, 75%, and 100%. Replacement was applied simultaneously to fine (BTD) and coarse (BTCA) fractions on a mass basis, maintaining a sand‑to‑aggregate volumetric ratio of approximately 0.44 and total cement content of 400 kg/m³. Cylindrical specimens (≈100×200 mm) were cast for mechanical and durability testing after standard moist curing.

Table 3.3 Cases

Case	w/c	BTD (fine) replacement	BTCA (coarse) replacement
1	0.45	0%	0%
2	0.45	25%	25%
3	0.45	50%	50%
4	0.45	75%	75%
5	0.45	100%	100%
6	0.5	0%	0%
7	0.5	25%	25%
8	0.5	50%	50%
9	0.5	75%	75%
10	0.5	100%	100%

The mix proportion used in this study was done on a weight basis, and the unit contents of the ingredients of concrete were assumed to sum up to 1 m³ of concrete and can be correlated by the following equation:

$$\frac{C}{G_c\gamma_w}+\frac{S}{G_s\gamma_w}+\frac{A}{G_A\gamma_w}+\frac{Air\ (\%)}{100}=1$$

(3.5)

Where,

C = Unit content of cement (kg/m³ of concrete)

S = Unit content of fine aggregate (kg/m³ of concrete)

A = Unit content of coarse aggregate (kg/m³ of concrete)

W = Unit content of water (kg/m³ of concrete)

γw = Unit weight of water (kg/m³)

Gc = Specific gravity of cement

Gs = Specific gravity of fine aggregate (SSD)

GA = Specific gravity of coarse aggregate (SSD)

Gw = Specific gravity of water

Air (%)= Percentage of air in concrete (assumed at 2% without air-entraining agent

Here is the mix design for each of the cases that are mentioned above.

				Unit Weight (kg/m^3)					
Group	Specimen	W/C	S/A	BTCA	BTD	Cement	Water	Coarse Agg	Fine, Agg.
1	S1.1-S1.3	0.45	0.44	0.0	0.0	400	180	1017.6	784.74
2	S2.1-S2.3	0.45	0.44	160.6	206.4	400	180	763.2	588.55
3	S3.1-S3.3	0.45	0.44	321.3	412.7	400	180	508.8	392.37
4	S4.1-S4.3	0.45	0.44	482.0	619.0	400	180	254.4	196.18
5	S5.1-S5.3	0.45	0.44	642.6	825.4	400	180	0	0
6	S6.1-S6.3	0.50	0.44	0.0	0.0	400	200	987.36	761.42
7	S7.1-S7.3	0.50	0.44	155.9	200.2	400	200	740.52	571.06
8	S8.1-S8.3	0.50	0.44	311.8	400.4	400	200	493.68	380.71
9	S9.1-S9.3	0.50	0.44	467.6	600.6	400	200	246.84	195.35
10	S10.1-S10.3	0.50	0.44	623.5	800.9	400	200	0	0

3.4 Sample Preparation

3.4.1 Mold Preparation

To investigate the effects of MAS of the brick coarse aggregate, the cylindric molds of height 200 mm, diameter 100 mm were utilized with 12.5 mm, 19.0 mm, 25.0 mm, and less.

37.5 mm MAS. 50.0 mm MAS was dried in cylindrical 150 mm diameter and 300 mm height molds. The screws were tightened before casting, and the grease applied to the inside surface was done following ASTM C 31 (2003).

3.4.2 Fresh Concrete Casting and Mixing.

Where fresh concrete was to be cast, a mixture machine was available in the Concrete Lab of the Islamic University of Technology (IUT). Each case was trial mixed and then finally mixed. The blending process used in this experiment was very different as compared to the standard technique of mixing used in construction sites in Bangladesh. A traditional method is to mix the mixture (containing all the ingredients, such as cement, sand, coarse aggregate, broken tile dust, broken tile coarse aggregates, and water) at the same time. However, in reality it is not the most effective method of achieving the required strength of concrete. Preparation of concrete was done by following the following steps to get the quality of the concrete:

Step 1: The mixing machine was wiped with a wet piece of cloth inside; otherwise, the mixing machine has the potential to absorb the mixing water.

Step 2: Half the sand was placed in the machine and covered to provide a significant bed-like surface on which the cement would be placed.

Step 3: Cement was applied on the sand bed.

Step 4: Remainder of the sand was subsequently added on top of the cement.

Step 5: Sand and cement were then mixed after 30 seconds.

Step 6: Water was added to the sand-cement mixture with caution to prevent spillage of the mixture from the machine. The machine was then allowed to turn and stir the cement-sand paste for an additional one and a half minutes.

Step 7: The coarse aggregate was then added in the mixing machine, and the mixture was left to mix for 3 more minutes.

The overall mixing time was 5 minutes. The concrete mix was then poured on a non-absorbent sheet after five minutes so as to proceed with the slump test and casting process at the same time.

3.4.3 Slump Test

The degree of conformity of a concrete sample is a term that is used to determine slump. The test also identifies the workability of concrete i.e. the capacity to work, compact, and shape concrete. Slump test in the concrete of the current study was conducted in accordance with ASTM C 143 (2003).

A free sample of freshly blended concrete was laid and smoothed out by tamping it with a tamping rod, in a mold taking the form of the frustum of a cone. The tamping rod was a round, straight, steel rod that was 16mm in diameter and about 600 mm in length; with the tamping end rounded to a hemispherical end, the diameter of which was 16 mm. The mold was made of nonabsorbent metal, which could not be easily attacked by the cement paste. The metal had not been less than 1.5 mm. The shape of the mold was that of a frustum of a cone, and its bottom was 200 mm in diameter, the top was 100 mm in diameter, and the height was 300 mm. The concrete was then raised and compacted using the mold, and the concrete was left to settle. Vertical distance between the initial and the displaced location of the center of the upper surface of the concrete was checked and recorded as the slump of the concrete.

The concrete was put into the mold in three layers, each of roughly equal volume, and tamped 25 times with the tamping rod.

3.4.4 Casting of Concrete Samples

The concrete sample was put into the cylinder mold by dragging the sampling tool or pouring concrete around the edge of the mold to help in the even distribution and reduction of segregation. The hemispherical end of the tamping rod was used to rod each layer of concrete 25 times. The base layer was rodded through its thickness. The rodding was laid evenly around the cross section of the mold. In the case of every upper layer, the tamping rod was left to penetrate through the layer being rodded and into the layer below by about 25 mm.

Once each layer had been rodded the outside of each mold was tapped a few times with a hammer, 10-15 times, to close any hole caused by rodding and to get the large air bubbles that might have been trapped out. When tapped, the concrete sides of each of the molds were scaled with a steel scale on each of the layers. Representative concrete was added to underfilled molds in the process of consolidating the top layer. Following the consolidation, the surface was stroked with a trowel to remove the excess concrete.

3.4.5 Curing of Specimen

ASTM C 192 (2003) was followed to cure the specimens. To avoid water loss through the evaporation process of the unhardened concrete, all the specimens were covered directly with a wet burlap and a non-absorptive polythene sheet on the top of the wet burlap. The specimens were kept under this preliminary curing until the demolding of the samples was done.

All the specimens were demolded 24 hours later and proceeded to be moist cured. The whole lot was moist cured at a temperature of 23.0 +- 20°C from the period of molding until the period of testing. The specimens were put in a curing bath to the extent that free water was on all surface areas of the specimen. Each specimen was then cured till the day of testing.

3.5 Testing

The properties of hardened concrete were evaluated by both destructive and nondestructive testing. In destructive tests (DT), a specimen is completely destroyed by applying pressure to evaluate the concrete strength, e.g., compressive strength, tensile strength, Young’s modulus, and stress-strain curve. In nondestructive tests (NDT), the specimen strength is determined without damaging the specimen. In this study, concrete properties were evaluated by means of NDTs like Ultrasonic Pulse Velocity (UPV) test

3.5.1 Destructive Test

3.5.1.1 Compressive Strength

The compressive strength of concrete in this study was determined according to ASTM C 39 (2003). In this method, compressive axial load was applied to molded cylinders at a rate that is within a prescribed range of 0.15 to 0.35 MPa/s until failure occurred. The compressive strength of the specimen was then calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen. The diameter and length of each cylinder specimen were measured using a Vernier caliper, and the cross-section was calculated. To determine the compressive strength of a particular batch of concrete on a particular age, the average compressive strength of three specimens was taken. Since the specimen length-to-diameter ratio for cylinder samples was not less than 1.75, the compressive strength measured was not multiplied by any correction factors as specified by ASTM C 39 (2003).

The compressive strength of concrete was measured at 14 days & 28 days using compressive strength testing machine according to ASTM C 39 (2003)

3.5.1.2 Splitting Tensile Strength

The splitting tensile strength of concrete was determined according to ASTM C 496 (2003) by applying a diametral compressive force along the length of cylindrical concrete specimens until failure. The rate of loading was 0.7 to 1.4 MPa/min. This loading induces tensile stresses on the plane containing the applied load and relatively high compressive stresses in the area immediately around the applied load. Tensile failure occurs rather than compressive failure because the areas of load application are in a state of triaxial compression, thereby allowing them to withstand much higher compressive stresses than would be indicated by a uniaxial compressive strength test result. The maximum load sustained by a specimen is divided by appropriate geometrical factors to obtain the splitting tensile strength as shown in equation (3.6).

$$T = \frac{2P}{\pi l d}$$

Where,

T = splitting tensile strength (MPa)

P = maximum applied load indicated by the testing machine (N)

l = length (mm)

d = diameter (mm)

Before placing the specimen in the testing machine (Universal Testing Machine, UTM), the diameter of each specimen was determined by averaging three diameters measured near the ends and the middle of the specimen. Diametral lines were drawn on each end of the specimen using a marker to ensure that they are in the same axial plane. The specimen was placed in between the UTM bearing plates and aligned so that the lines marked on the ends of the specimen are vertical and centered.

3.5.1.3 Young's Modulus

Under the compressive strength test of the specimen, the Young modulus of each specimen was measured in reference to the ASTM C 469 (2003) standard. The specimen was held in the strain-measuring equipment the bearing block of compressive strength testing machine. The specimen axis was then perfectly aligned on the center of thrust of the spherically seated upper bearing block. The constant rate of loading was between 35 +- 5 psi (241 +- 34 kPa/s). The measurement of the applied load and the corresponding longitudinal strain were continued till the specimen failed without interruption. Stress was directly or linearly interpolated at a strain level of 0.0005.. The Young's modulus was calculated using the following equation:

Young's Modulus = $f_{0.0005}/0.0005$
(3.)

Where, $f_{0.0005}$ is the stress at a strain level of 0.0005 in MPa

Chapter 4: Result and Discussions

4.1 General

The results from various tests and studies on concrete that uses broken tile aggregates are presented and discussed in this chapter. The feasibility of using recycled broken tiles as a substitute for natural coarse and fine aggregates in different proportions (0%, 25%, 50%, 75%, 100%) is evaluated. This chapter looks at how tile aggregates affect the workability, compressive strength, splitting tensile strength, and density of concrete. It also examines the connection between the mechanical properties and the specific characteristics of the tile aggregates. Ultrasonic pulse velocity test, chlorine ion penetrability of concrete, stress strain relationship of concrete and other things are discussed in this chapter

4.2 Results of different tests

4.2.1 Workability of Concrete

The effect of tiles aggregate on workability of concrete for w/c ratio of 0.45 and 0.5, s/a ratio of 0.44 , cement content 400 kg/m3 is shown in fig 4.1 and 4.2. the workability of concrete decreases with the increase of percentage replaced by broken tiles for w/c ratio of 0.45 . For w/c ratio of 0.5 the workability slightly increases for 25% percentage of tiles replaced by natural aggregate then it gradually decreases

Workability (Slump)

Case	Slump (mm)
1	153
2	130
3	126
4	110
5	110
6	130
7	131
8	129
9	126
10	110

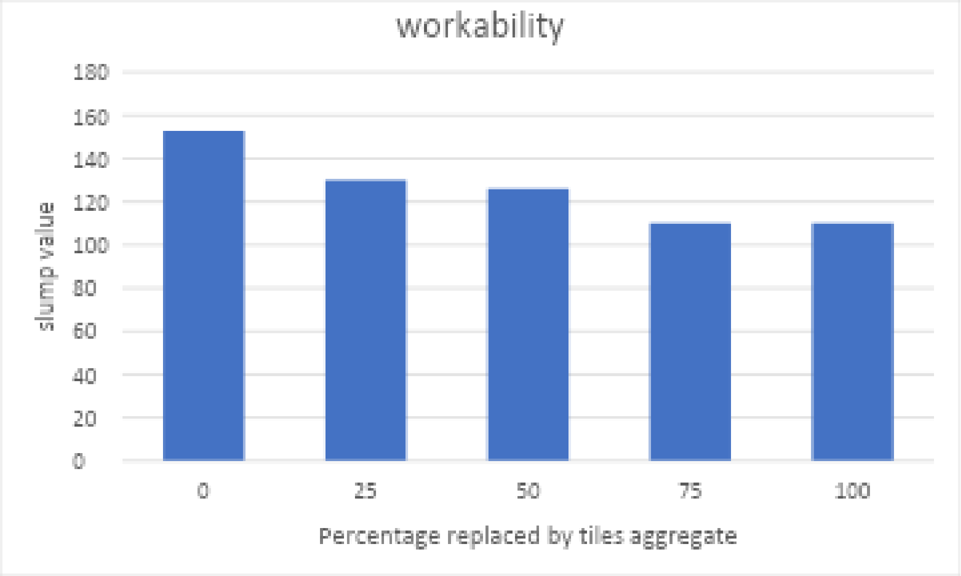


Fig 4.1 Effect of tiles aggregate on workability of concrete for w/c ratio of 0.45

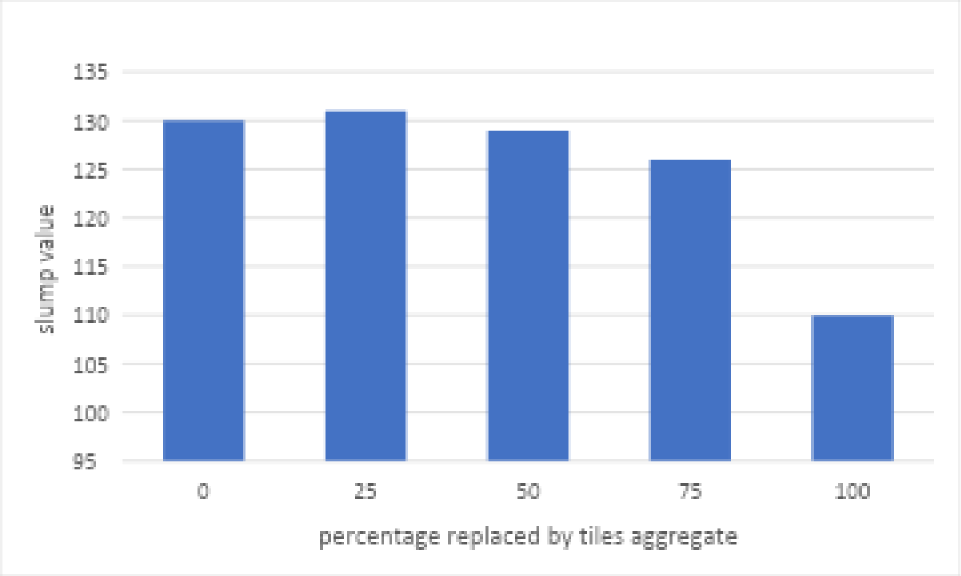


Fig 4.2 effect of tiles aggregate on workability of concrete for w/c ratio of 0.5

4.2.2 Compressive Strength of Concrete

The compressive strength tests were conducted on the 14 th day and 28 th day at the end of the casting. Table 4.1 tabulates the average compressive strength of the proportions of mixes of various proportions. In contrast to the linear decrease with other materials which have been used in replacement constructions, such as construction dust, the compressive strength of the concrete containing broken tile aggregates proves to be more complex, as the water cement ratio, and optimal replacement percentage affect the relationship.

case no	w/c	broken tiles	14th day compressive strength (mpa)	28th day compressive strength (mpa)
1	0.45	0%	31.42	42.25
2	0.45	25%	35.48	43.88
3	0.45	50%	31.48	35.48
4	0.45	75%	28.92	34.68
5	0.45	100%	36.16	41.92
6	0.5	0%	28.04	31.57
7	0.5	25%	30.01	39.7
8	0.5	50%	31.91	40.74
9	0.5	75%	32.24	36.28
10	0.5	100%	26.14	35.61

Table 4.1 Compressive strength of concrete for 14th and 28th days for different cases

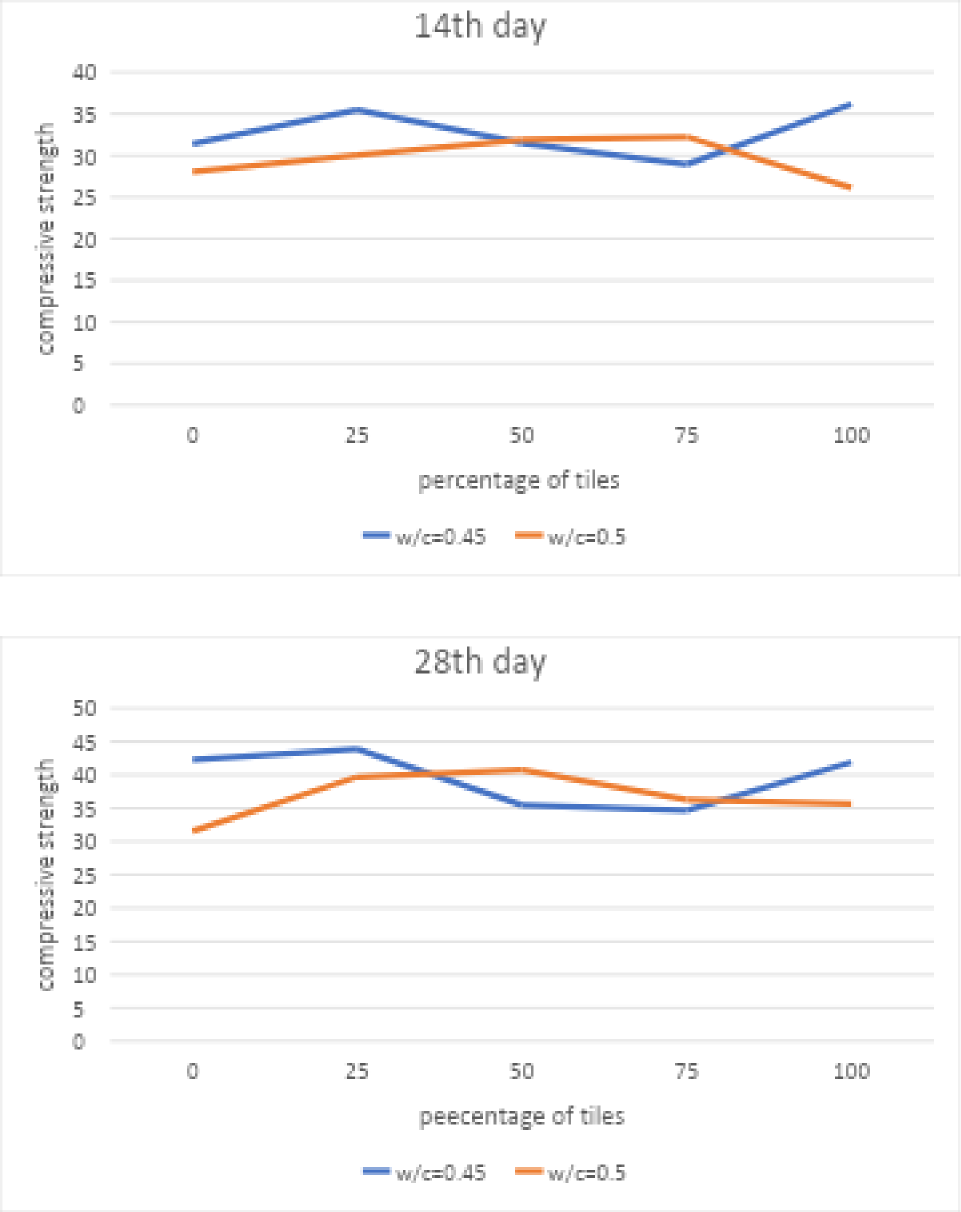


Fig 4.3 Effect of tiles as coarse and fine aggregate on compressive strength of concrete

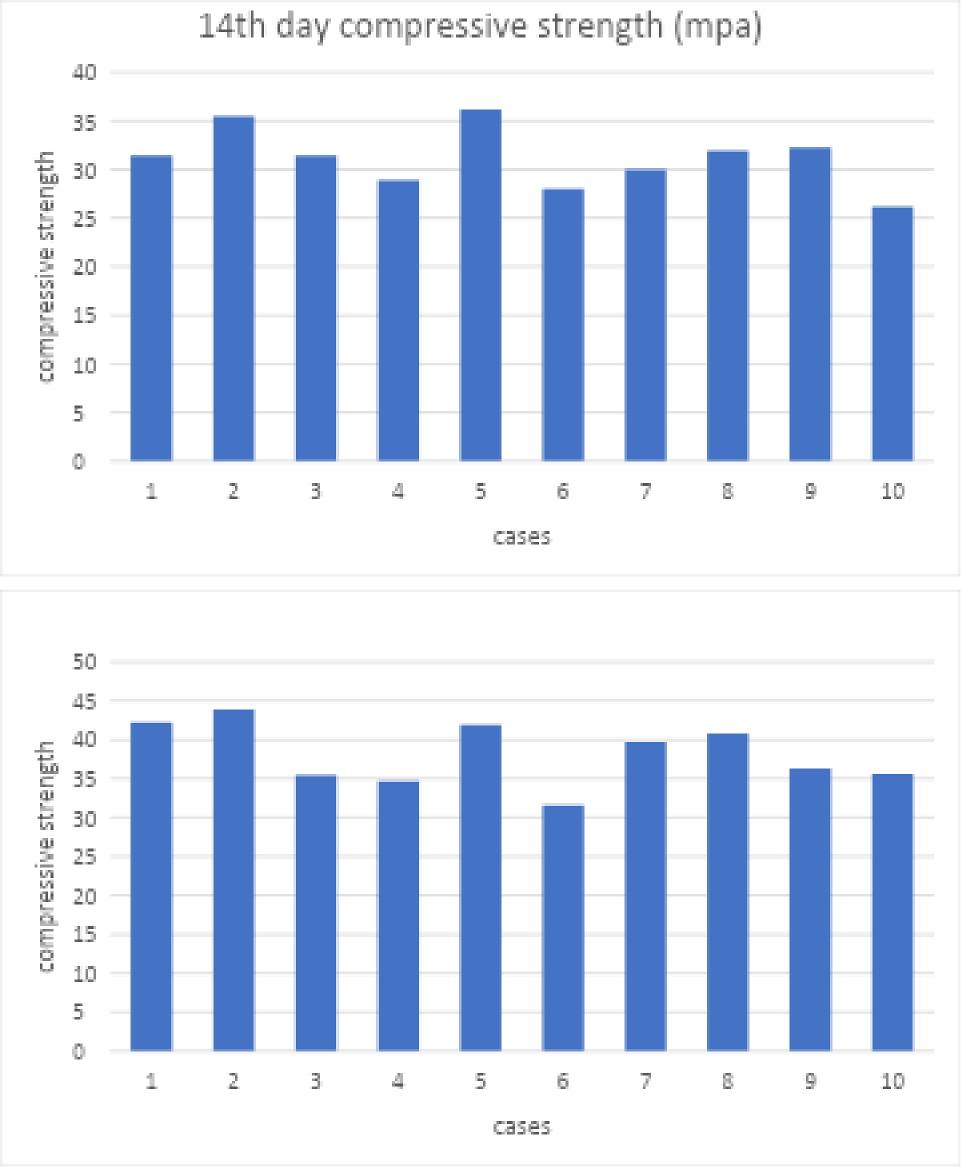


Fig 4.4 Compressive strength of concrete for different cases

Fig. 4.3 illustrates the influence of aggregates of broken tiles on compressive strength of concrete at varying w/c ratios (0.45 and 0.50). One of the major findings is that, with both w/c ratios, 25 percent substitution of natural aggregates with broken tiles led to the highest 28-day compressive strength (43.88 MPa with w/c= 0.45 and 39.70 MPa with w/c= 0.50), which was higher than in the control concrete. This implies that it has a best level at which the tough, stiff quality of the ceramic tiles enhances the concrete matrix.

As the replacement percentage gets higher than 50 percent, however, compressive strength begins to decrease significantly to the lower w/c ratio (0.45) to 34.68 MPa at 75 percent replacement. This is an indication that as the w/c ratios decreases, the concrete gets stronger but the concrete is not as accommodative of large volumes of tile aggregates, probably since the higher water requirement and resultant workability concerns it forms a less dense matrix. In the case of the higher w/c ratio (0.50), the 50% replacement mixture reached a competitive strength of 40.74 Mpa indicating that the additional water was able to allow the absorption of the tile to be accommodated and hence stronger cohesion in the middle replacement levels.

4.2.3 Splitting Tensile Strength of Concrete

Splitting Tensile Strength Test were carried out on the 28th day after casting. The average splitting tensile strength for different mix proportions are given in table 4.2

The influence of broken tile aggregates on splitting tensile strength of concrete with varying w/c ratios (0.45 and 0.50) is illustrated in Fig. 4.5. Against the compressive strength figure, we find that the splitting tensile strength tends to exhibit a negative directional change with the growth in tile content. Nonetheless, there is a significant exception of the mix with 0.45 w/c ratio at 75% replacement that exhibits tensile strength recovery.

It is worth noting that, at the majority of the replacement levels (0, 25, 50 percent), the tensile strength of concrete with the w/c ratio of 0.45 is greater than that of the concrete with the w/c ratio of 0.50. This is in line with the traditional behavior with lower w/c ratio giving a denser and stronger cement matrix. This result is opposite to what has been observed to be the case with some other recycled materials, in which an increased w/c ratio may occasionally enhance tensile performance, through increased flexibility.

To further emphasize the association given to the mechanical important properties, the compressive strength and splitting tensile strength of the 28 th day is presented in a shared figure of Fig. 4.6 to compare the two cases under consideration.

Cases	w/c	Broken tiles	Splitting Tensile Strength(Mpa)
1	0.45	0%	3.715
2	0.45	25%	3.635
3	0.45	50%	2.85
4	0.45	75%	3.47

5	0.45	100%	2.805
6	0.5	0%	3.505
7	0.5	25%	3.365
8	0.5	50%	3.365
9	0.5	75%	2.91
10	0.5	100%	2.54

Table 4.2 Splitting Tensile Strength of Concrete on 28th day for different cases

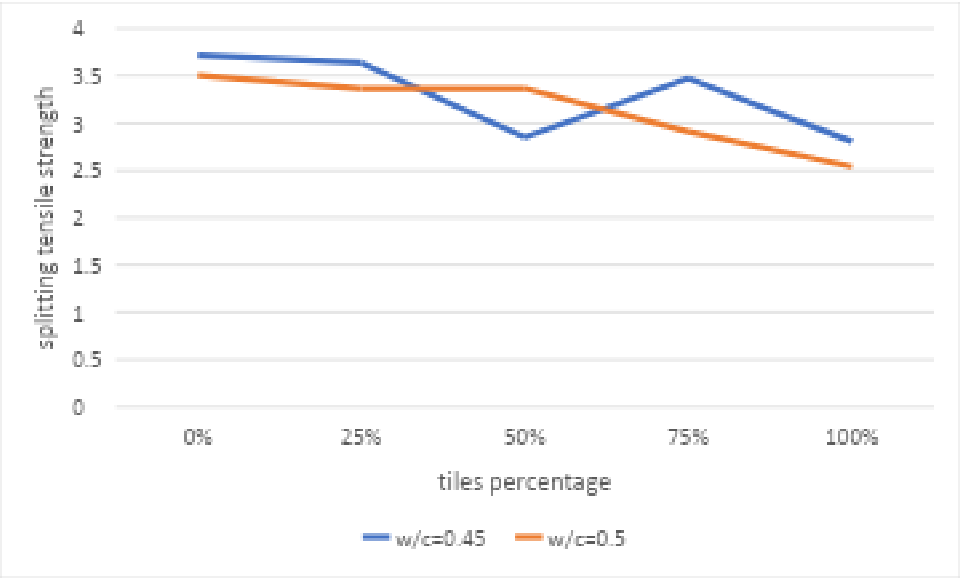


Fig 4.5 Effect of broken tiles aggregate on splitting tensile strength of concrete

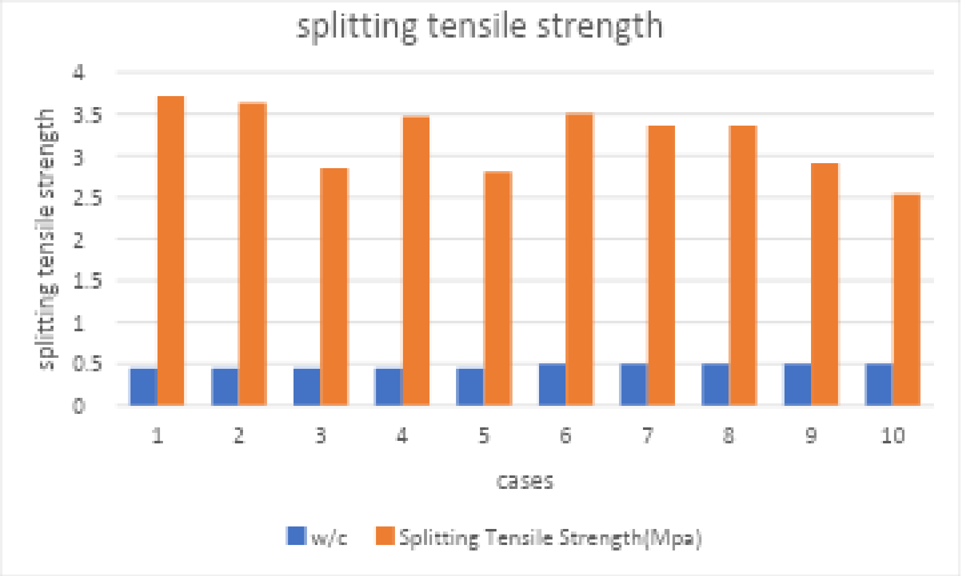


Fig 4.6 Splitting Tensile Strength of Concrete for different cases

4.2.4 Ultrasonic Pulse Velocity Test

CASE NO	BT	w/c	After 14days		After 28days	
			Time (µs)	Vel (km/s)	Time (µs)	Vel (km/s)
1	0%	0.45	42.9	4.709	41.4	4.87
2	25%	0.45	43.8	4.60	42.2	4.83
3	50%	0.45	46.1	4.407	45	4.56
4	75%	0.45	45.8	4.378	45.2	4.46
5	100%	0.45	46.0	4.38	45.5	4.46
6	0%	0.5	44.9	4.49	42.9	4.73
7	25%	0.5	45.4	4.49	44	4.60
8	50%	0.5	43.7	4.69	45.8	4.53
9	75%	0.5	48	4.21	46.6	4.35
10	100%	0.5	49.6	4.06	48.9	4.15

Table 4.3 UPV Time and Velocity After 14th and 28th days

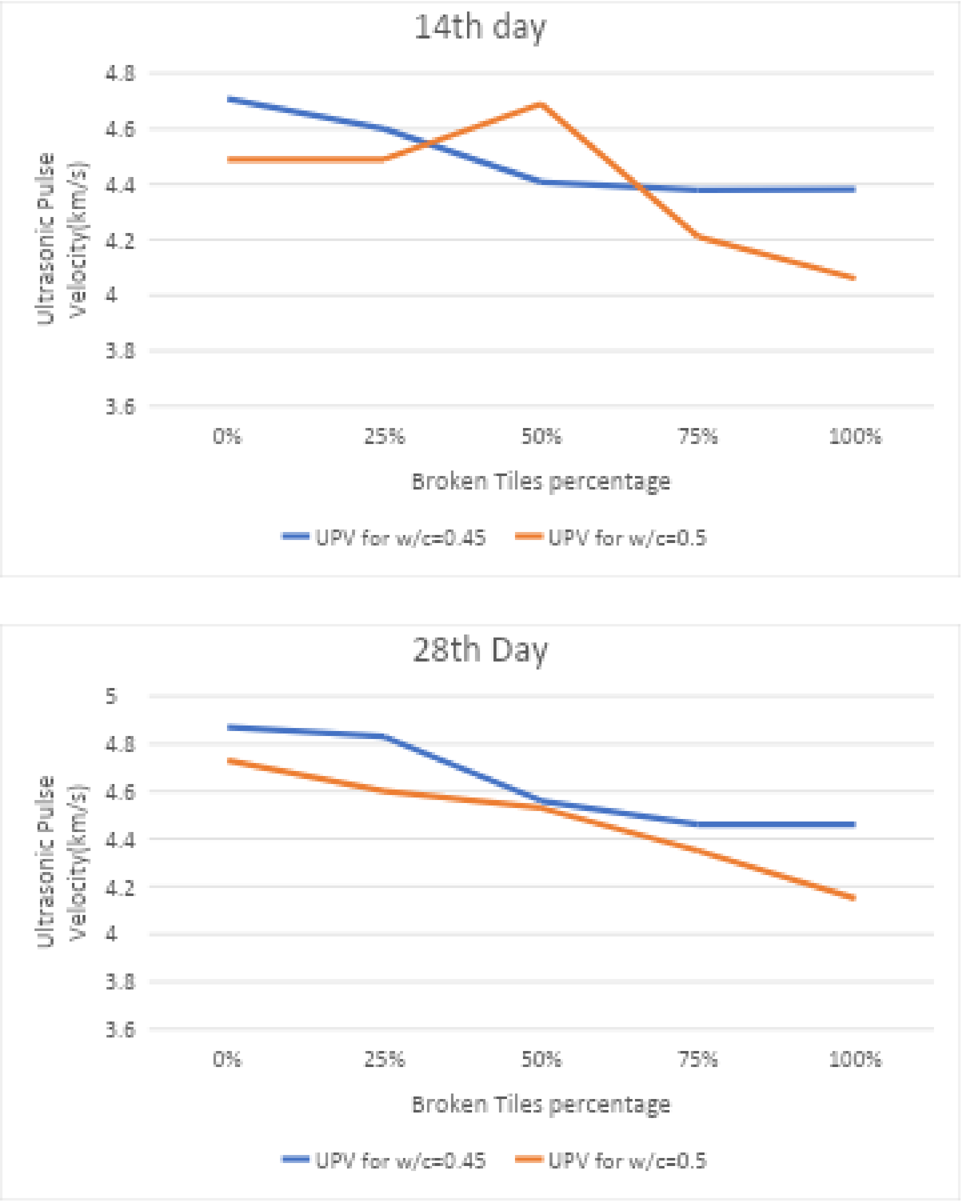
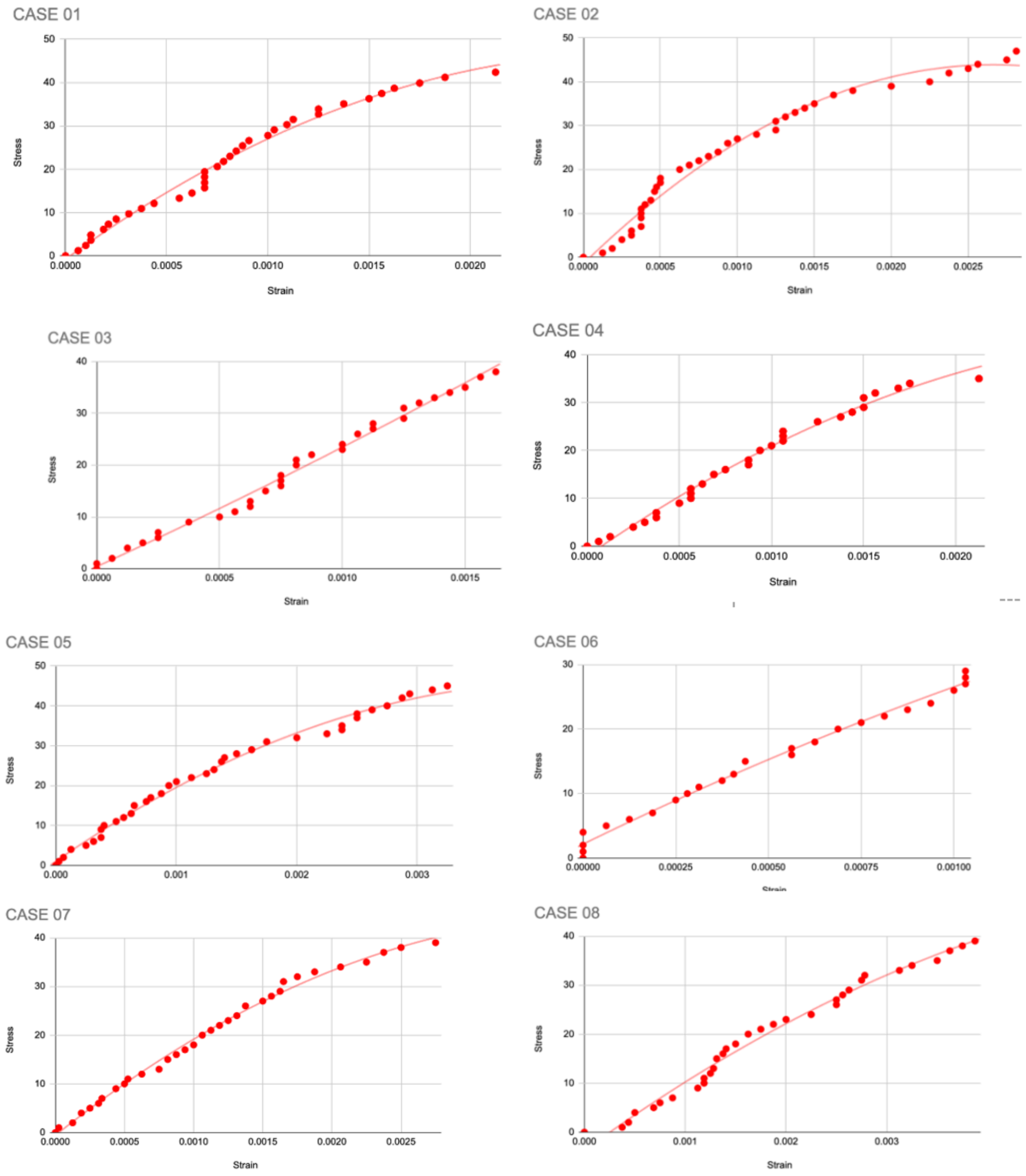


Fig 4.7: Effect of Tiles on Ultrasonic Pulse Velocity

UPV measurements at 28 days indicated generally faster pulse velocities (lower travel times) for mixtures with improved internal continuity. Within the w/c = 0.50 series, the 100% replacement mix (Case 10) exhibited the highest UPV among its set, suggesting a denser or more continuous matrix–aggregate system in that series. UPV trends track, but do not perfectly mirror, compressive strength because microcrack distribution and pore connectivity influence wave propagation

4.2.5 Stress-strain Curve

A compressometer was employed to produce the stress-strain curve of the concrete as per ASTM C469 (ASTM international, 2014) standard on the 28th day post-casting. Based on the data obtained by the apparatus, strains were plotted against the various stresses and stress-strain curves were drawn against all the 10 cases as presented in Fig 4.8.



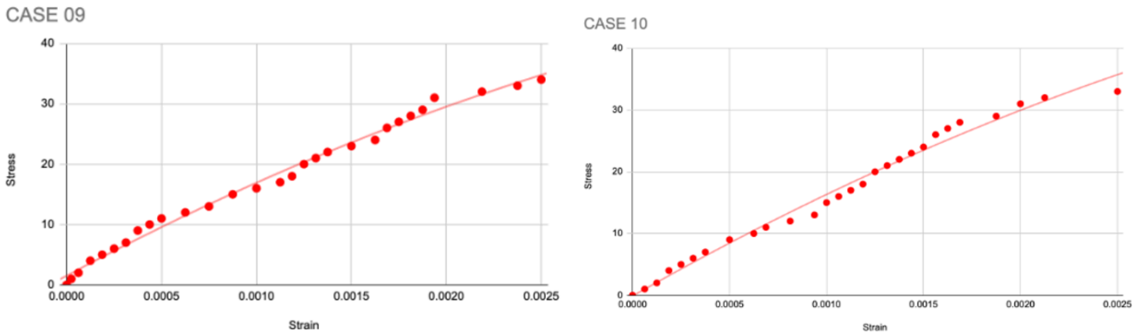


Fig 4.8 Stress-strain curve of different cases

4.2.6 Static Modulus of Elasticity of Concrete

Based on the stress-strain curve that was obtained, the modulus of elasticity (E) of concrete at static was calculated based on ASTM C469 (ASTM International, 2014). Table 4.4 shows the tabulated values of the static modulus of elasticity of concrete of all the cases.

Case	w/c	BTA replacement	E (MPa)
1	0.45	0%	26603.92
2	0.45	25%	35471.7
3	0.45	50%	23750.3
4	0.45	75%	22950.81
5	0.45	100%	21818.18
6	0.5	0%	21090.9
7	0.5	25%	19500.0
8	0.5	50%	28814.05
9	0.5	75%	28102.2
10	0.5	100%	27372.43

Table4.4: Static modulus of elasticity at 28 days.

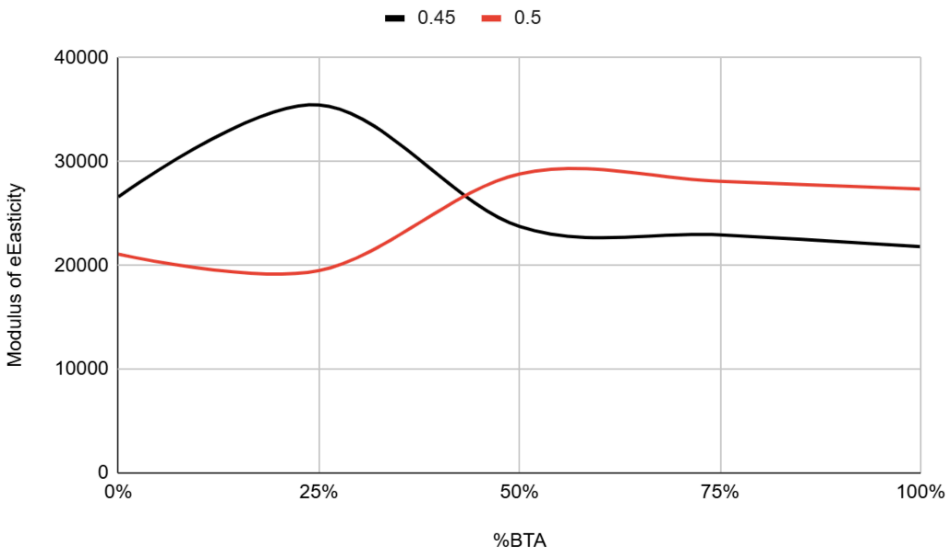


Fig 4.9 Effect of BTA on Modulus of Elasticity of Concrete

The degree of broken tiles replacement increases as the level of static modulus of elasticity of concrete declines. This is due to the fact that the increased water absorption capacity and the nature of micro-cracking of the ceramic particles leads to increase in porosity of the concrete matrix and a weaker inner structure.

ACI 318-14 (ACI, 2014) suggests that the modulus of elasticity of normal-weight concrete is computed as follows:

$Ec = 4700 \sqrt{f'c}$ (4.1)

In order to explain these findings further, Fig. 4.9 demonstrates the impact of the broken tiles on the modulus of elasticity of concrete to be visualized in a better way.

Case	w/c	BTA replacement	Charge passed (C)	Penetrability class
1	0.45	0%	643.4613	Very Low
2	0.45	25%	547.83	Very Low
3	0.45	50%	555.1056	Very Low
4	0.45	75%	354.8916	Very Low
5	0.45	100%	374.724	Very Low
6	0.5	0%	1552.59	Low
7	0.5	25%	1440.2304	Low
8	0.5	50%	943.1199	Very Low
9	0.5	75%	909.1008	Very Low
10	0.5	100%	910.9044	Very Low

4.2.7 Rapid Chloride Penetration Test

Table 4.5 Chloride Penetration of Concrete Samples

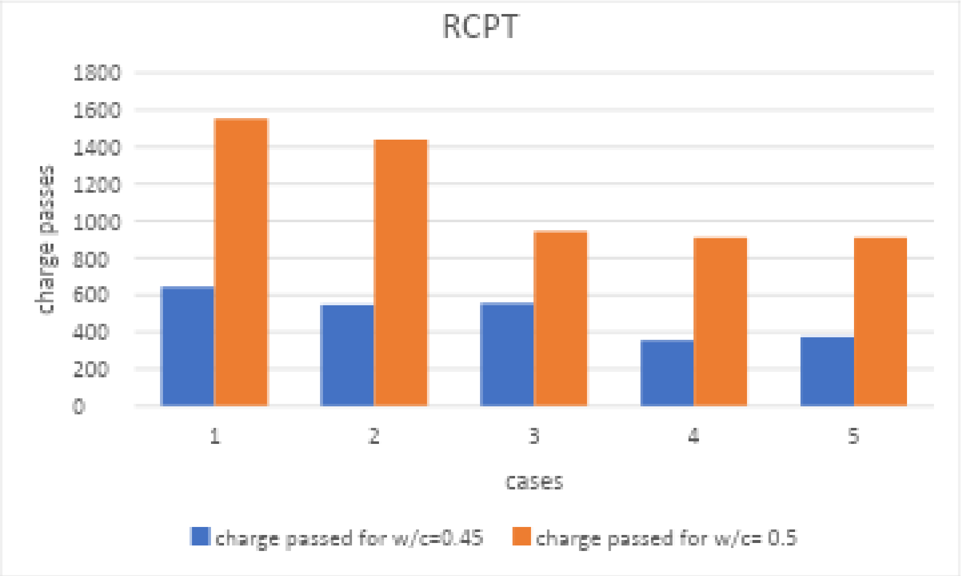


Fig 4.10 Charge passed through concrete for different cases

For w/c = 0.45, all mixes fell into the 'very low' penetrability class. For w/c = 0.50, the control exhibited 'low' penetrability while ≥50% BTA shifted performance to 'very low', indicating favorable resistance to chloride ingress at higher replacement levels in this series.

4.2.8 Scanning Electron Microscopy (SEM) Test

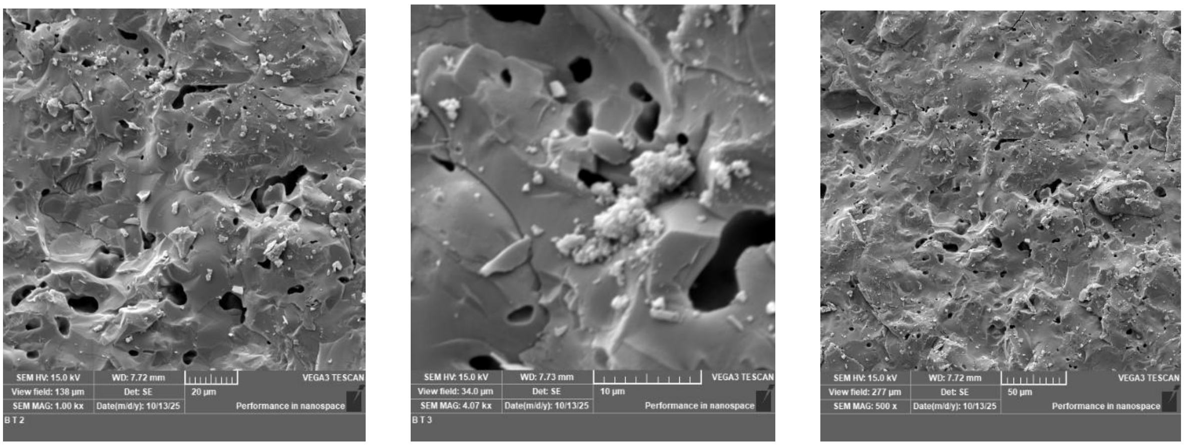


Fig 4.10 Microscopic view of broken tile aggregates

Here are the SEM analysed pictures of broken tiles coarse aggregates and fine aggregates. From the pictures we can see that the pores are negligible in the smoother side of the broken tile aggregates and pores tends to increase in the rougher side of the tile aggregates. Because of the pores the concrete is most likely to adhere to the rough and porous side of the broken tiles rather than the smoother side

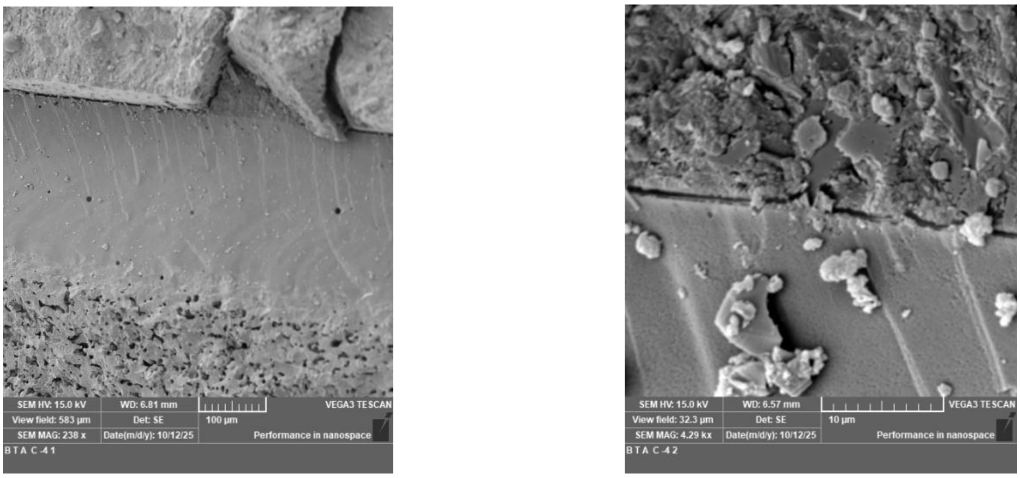


Fig 4.11 Case 4 concrete cylinder

The zone at the interface between broken tiles or natural aggregates and the cement paste is referred to as the ITZ. The zone is critical, as it tends to be more porous and have different microstructural characteristics, which influence the mechanical performance and durability of concrete. Some of the features that are typical of the ITZ can be observed in the first and third images (greater magnification):

Enhanced Brazing:

The porous areas that can be observed in the first image are definitely on the edges of aggregate particles. The bigger irregular voids and pores are concentrated near the borders, which is typical of ITZs where the surplus water is likely to accumulate during casting, ascending the ratio of water/cement locally.

The second picture (low power) gives a bigger picture and reveals:

Contrast in Density and Structure:

This is in accordance with the presence of an ITZ. There is a thin transition zone between the solid, less porous (aggregate) and more porous, microcracked cement paste, with different textural properties.

Continuous ITZ Band:

This is a fairly linear band that runs parallel with the aggregate surface, as is common with the ITZ in polished cross-sections of concrete.

4.3 Relationship between Compressive strength and Splitting Tensile Strength

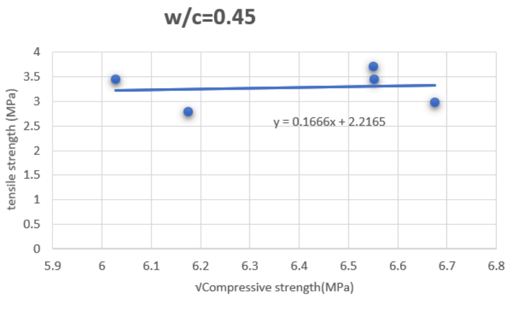
The variation of splitting tensile strength with compressive strength made with different water cement ratio is shown in figure xx. The tensile strength of concrete can be correlated with compressive strength by the following equations,

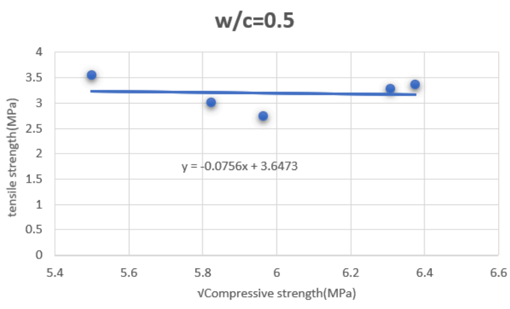
$$ft\ (w/c = 0.45) = 0.1666\sqrt{fc'}$$

$$ft\ (w/c = 0.5) = -0.0756\sqrt{fc'}$$

Where ft is the splitting tensile strength in MPa and fc' is the compressive strength of concrete in MPa.

Both plots relate split-tensile strength to compressive strength for two mixes.
For **w/c = 0.45**, the fitted line rises slightly (slope ≈ +0.17). This is consistent with a denser paste and a stronger ITZ at lower w/c, so small gains in compressive strength tend to carry into tensile strength.
For **w/c = 0.50**, the line falls slightly (slope ≈ −0.08). The higher w/c introduces more capillary porosity and microcracking, which depresses tensile capacity even when compressive strength varies mildly. Given the very narrow range of compressive strengths, minor specimen-to-specimen variability can flip the local slope, so both trends should be read as weak. ft is the splitting tensile strength in MPa and fc' is the compressive strength of concrete in MPa.





4.4 Relationship between Compressive strength and UPV

The variation of UPV with compressive strength made with different water cement ratio is shown in the figure . The UPV can be correlated with Compressive strength by the following equations:

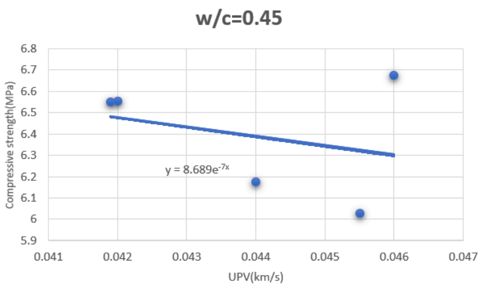
$$fc'\ (w/c=0.45) = 8.689\ e^{-7(UPV)}$$

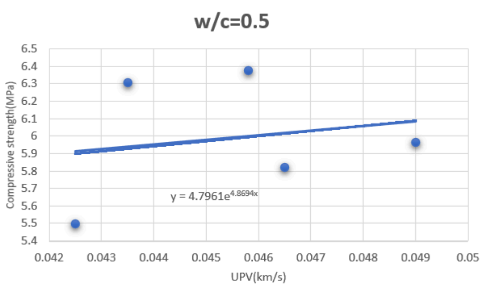
fc' (w/c=0.5) = $4.7961e^{4.8694(UPV)}$

w/c = 0.45 — slight negative trend.
As UPV increases, compressive strength falls a little. At this lower w/c the paste is dense; UPV becomes highly sensitive to **moisture state, aggregate path continuity, and micro-cracking in the ITZ**. Specimens that are a bit **wetter** or have stiffer wave paths can show **higher UPV** without being stronger, and any drying-shrinkage microcracks reduce tensile/compressive capacity more than they slow the wave. With the **very narrow strength range** and few points, that decoupling gives a weak **downward** slope.

w/c = 0.50 — slight positive trend.
Here the matrix has more capillary porosity, so both properties respond to the same feature: void content/degree of hydration. Lower porosity → higher UPV and higher compressive strength, yielding the expected weak upward slope.

fc' is the compressive strength of concrete in MPa and UPV is the Ultrasonic Pulse Velocity in km/s.





4.5 Relationship between Modulus of Elasticity and UPV

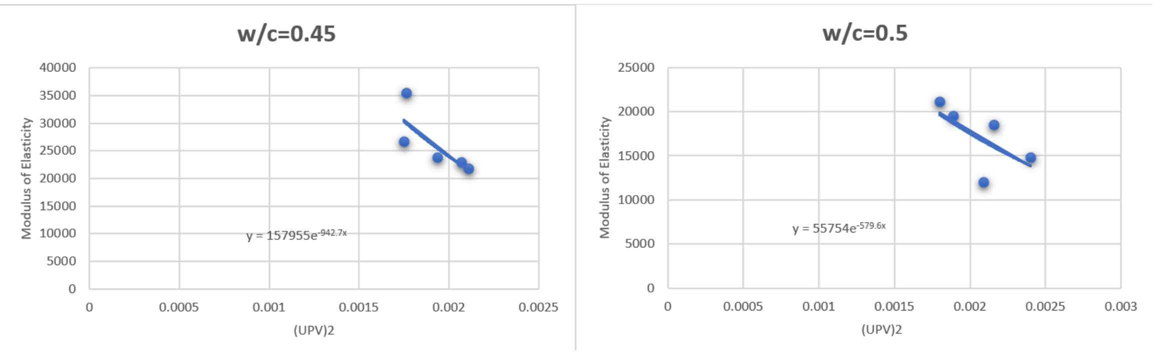
The variation of Modulus of Elasticity with UPV made with different water cement ratio is shown in the figure . The tensile strength of concrete can be correlated with compressive strength by the following equations:

Ec (w/c=0.45)= $157955e^{-942.7 (UPV)2}$

Ec (w/c=0.5)= $55754e^{-579.6 (UPV)2}$

w/c = 0.45. The points show a clear **downward** trend: specimens with higher measured $(UPV)^2$ have **lower static modulus**. At this low w/c the paste is dense, so small microcracks from drying or restraint lower the modulus, while a slightly wetter or better-coupled specimen can still give **higher UPV**. Because UPV is very sensitive to moisture and coupling, it can rise even when stiffness falls. With few samples and a tight range, this produces the observed negative slope.

w/c = 0.50. The trend is also **negative**, but milder. The higher w/c mix has more capillary pores; modulus varies with microcracking and pore structure, while UPV again responds strongly to moisture and path continuity. When moisture differences dominate, UPV can increase without a matching increase in static modulus, giving the slight decline



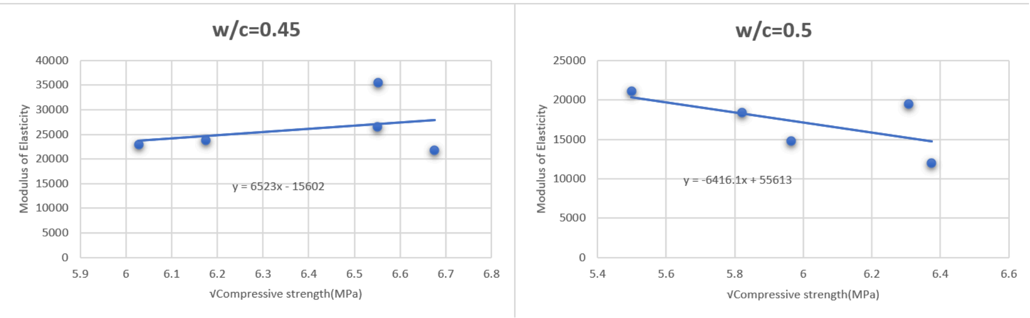
4.6 Relationship between Modulus of Elasticity and Compressive Strength

The variation of Young’s Modulus with compressive strength made with different water cement ratio is shown in the figure . The tensile strength of concrete can be correlated with compressive strength by the following equations:

Ec (w/c= 0.45) = 6523√fc'

Ec (w/c= 0.5) = -6416.1x √fc'

Where, Ec is the Young's modulus and fc' is the compressive strength of concrete in MPa



Chapter 5: Conclusion and Recommendations

5.1 General

This chapter provides the conclusions based on the experimental research on the use of broken tiles as a partial and complete substitute to natural coarse and fine aggregates in the concrete. Fresh properties, mechanical strengths, and the modulus of elasticity are analyzed to come up with the conclusions. Moreover, this chapter offers recommendations to be applied in practice and indicates future research paths that can be used to further develop these findings.

5.2 Conclusions

The conclusions are made based on the results of experiments which were conducted through different tests and observations and include:

The material properties of broken tiles are as follows:

- Broken tile aggregates contain less specific gravity (2.19, 2.17, course, fine) than natural aggregates (2.7, 2.65 course, fine). The implication of this is that concrete that is made using tile aggregates will be light.

- The absorption capacity of coarse aggregate broken tile (10percent) is much greater than the absorption capacity of natural coarse aggregate. This property has a direct impact on the fresh concrete behaviour demand and mix design water demand.

Fresh Concrete Properties:

- Slump test showed that the workability of concrete continued to decline with the increase in the percentage of tile aggregates in both w/c ratios. This is explained by the fact that the high water absorption and the angular and irregular geometry of the tile particles.

- Water-reducing chemical admixtures (superplasticizers) should be used to achieve the desired workability to be applied in practice, in particular, the replacement level should be more than 25%.

Compressive Strength:

- Compressive strength of concrete showed a non-linear and complicated relationship with the level of replacement. One of the findings is determination of an optimum replacement level at 25 percent that produced 28-day compressive strength of 43.88 MPa when using w/c=0.45 and 39.70 MPa when using w/c=0.50 that was higher than the control concrete. This indicates possible filler effect and enhancing of the interlock of the matrices at this percentage.

- In the case of lower w/c ratio (0.45) the compressive strength was considerably decreasing when the percentage of replacement was more than 50 percent, probably because at high volumes, the porosity was high and the Interfacial Transition Zone (ITZ) was weaker and dominated the matrix.

Splitting Tensile Strength:

- The splitting tensile strength tended to follow a downward pattern with the rise in the content of tiles, and was more sensitive to the bond between the aggregate and paste than compressive strength.

- Unlike when the same is observed with some other recycled materials, the concrete with the lower w/c ratio (0.45) tended to be stronger tensilely than the concrete with the higher w/c ratio (0.50) mixes which is consistent with the known behavior of conventional concrete where a denser matrix would enhance tensile capacity.

Ultrasonic Pulse Velocity (UPV):

- The value of the UPV of all mixes was in the range of good and excellent quality as described in the normal classifications. Although there was an overall reduction in UPV with an increase in tile content, the 100% replacement mixture of w/c=0.50 had a comparatively high UPV indicating that a continuous and dense skeleton aggregate could be formed, which is desirable in the propagation of waves.

Modulus of Elasticity:

- The modulus of elasticity was found to be lower when the level of broken tiles replacement was increased. This signifies that fragmented aggregates of tile render the concrete less tough and more flexible to the pressure, which is a result of the increasing porosity and micro-cracking possibilities within the ceramic particles and the ITZ.

Rapid Chloride Penetration:

- The chloride ion penetrability of all the concrete mixes was very low to low with aggregates of broken tiles. It is interesting to note, that in w/c=0.50, 50% and more tile replacement mixes experienced enhanced resistance (all Very Low) relative to the control mix (Very Low). This suggests that broken tiles may increase the resistance of concrete to the ingress of chlorides, probably by increasing the tortuosity of the ionic transport.

Proposed Relationships:

- A correlation between compressive strength and splitting tensile strength, UPV, and modulus of elasticity was determined in both w/c ratios. The suggested coefficients and trends did not necessarily coincide with the usual codes, and it was the behavior of concrete with broken tile aggregates. The negative or even weak associations in certain relationships (e.g., Ec vs. UPV) serve as the reminder of the intricate interaction of the microstructure, moisture condition, and mechanical properties of this composite material.

Overall Feasibility:

All the test findings and observations point to the fact that it is possible to replace natural aggregates with broken tiles up to 50% and use it in practice. The degree of replacement provides workability of satisfactory level (with admixtures), competitive compressive and tensile strength, and may even be enhanced in chloride penetration durability. The replacement level of 25 percent is determined as being the best in attaining improved mechanical performance.

5.3 Future Work Recommendations.

Based on this research, it can be said that it is possible to utilize up to 50 percent of natural aggregates to broken tiles. The identification of limitations can be used to find the possible ways of optimizing the performance and maximizing the viable percentage of replacement in the future.

- Reducing Water Absorption: The main problem is that tile aggregates have a great absorption capacity. Further research must explore the pre-saturation methods or the application of superior superplasticizers to achieve a superior control of workability without affecting the water-cement ratio.

- Particle Size Optimization: The shape and size of tile aggregates determine the performance of the tile aggregates. Future studies may emphasize the optimal design of the crushing and grading operation to result in an optimum particle size distribution that produces the highest possible packing density at the lowest possible detrimental effects on workability and strength.

- Alternative Binders and Mix Designs: This paper relied on the ordinary Portland cement. To enhance the ITZ and the density of the total matrix, it may be possible to consider the use of supplementary cementitious materials (e.g. fly ash, silica fume) or high-strength cement. Moreover, exploration of a broader scope of w/c ratios and s/a (sand to aggregate) ratios might be beneficial to tune the balance of mixes.

- Processing of Tile Waste: The tiles that were applied in this experiment were not treated. Improved performance could be achieved in the future by having a pre-treatment step like washing to eliminate impurities, magnetic separation to eliminate metallic contaminants and a more controlled crushing to eliminate internal micro-cracks.

- Extended Duration and Long-term Investigations: The study was concerned with the major mechanical and chloride penetration qualities. Other durability elements that should be explored in the future include sulfate resistance, acid attack, drying shrinkage, and long term creep behaviour. A life-cycle analysis assessing the environmental advantages and economic viability of the utilization of broken tile aggregates in massive building would also be of great use.

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