



## Incorporating Construction Waste into Concrete Matrix: An Approach to Environmental Sustainability

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### KEY WORDS

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### ABSTRACT

This study investigates the mechanical performance of concrete incorporating construction and demolition waste materials as partial replacements for conventional fine and coarse aggregates. Both mixes were designed at a 1:2:4 ratio with a w/c of 0.6 (BS EN 12390-3:2019 and BS EN 12390-5:2019). A total concrete volume of 0.09075 m<sup>3</sup> was prepared for laboratory testing. The results showed that the compressive strength of conventional concrete increased from 10.40 N/mm<sup>2</sup> at 7 days to 15.31 N/mm<sup>2</sup> at 28 days, while the corresponding values for CWICM were 6.22 N/mm<sup>2</sup> and 10.00 N/mm<sup>2</sup>, respectively. Similarly, the flexural strength of CC improved from 2.56 N/mm<sup>2</sup> to 4.20 N/mm<sup>2</sup>, whereas CWICM recorded 1.98 N/mm<sup>2</sup> to 2.56 N/mm<sup>2</sup> across the same period. Regression analysis revealed that cube age and maximum crushing load are statistically significant predictors of compressive strength ( $p < 0.05$ ), with cube age showing the highest standardized coefficient ( $\beta = 0.941$ ). For flexural strength, cube age also exhibited the strongest influence ( $p = 0.008$ ), while density and compressive strength showed moderate but statistically insignificant effects. This research demonstrates the potential of reusing construction and demolition wastes as sustainable alternatives in concrete production.

## 10. INTRODUCTION

Use of construction waste in concrete matrices is a big step towards solving the currently existent and threatening issues of environmental degradation and depletion of resources. Construction waste that involves materials like concrete, bricks, wood, glass and metal are among the greatest contributors of the waste produced worldwide. The wrong management of such waste will not only contribute to the pollution of the environment but it will also lead to the wastage of valuable resources that can be reused (Sormunen & Kärki, 2019).

Being the most popular construction constituent in the entire world, concrete is the key constituent in the current development of the infrastructural systems. Nevertheless, its manufacturing process has severe environmental impacts. The separation of raw materials like sand, gravel, and limestone as well as the energy demanding nature of cement manufacturing all add to the level of carbon emission and depletion of the resources. Also, concrete production requires massive freshwater supplies, which complicates even the resource of water in the whole world. Such issues require new solutions to ensure that the production of concrete becomes more sustainable (Babor et al, 2019). The most promising way is incorporating the construction waste to concrete matrices. In this approach, crushed concrete, bricks and other waste materials under demolition are re-cycled to substitute natural aggregates in the process of concrete production. In this way, the construction sector will be able to decrease its use of virgin material, decrease the number of wastes deposited in

landfill, and cut the carbon footprint down on concrete manufacturing. As an example, the application of construction waste in form of recycled aggregates has proven useful in concrete materials that provide a viable solution to conventional material use [3].

The value of this strategy to the environment is large. Construction waste recycling decreases the need of the natural resources, saves the landfill and diminishes negative effects on the environment dependent on the standard procedure of making concrete. This is in line with the policy of the circular economy that focuses on utilizing resources efficiently and reducing waste. Also, with the recycled construction wastes used in concrete production, the emissions of greenhouse gases produced during the extraction and processing of raw material can be minimized (**Papamichael et al., 2023**). When construction waste is incorporated into concrete matrices, several advantages emerge. This approach can significantly reduce material costs in construction, while simultaneously fostering economic development through expanded opportunities in waste management and recycling industries. It also promotes the creation of green jobs, contributing to a more sustainable labor market. Moreover, sustainable construction practices have the potential to enhance community well-being by reducing environmental pollution, conserving natural resources, and supporting healthier living conditions (**Shukla et al., 2024**).

As much as it offers a lot of benefits, construction waste in the concrete matrices is not without its difficulties. Issues pertaining the quality and performance of recycled materials have to be worked out to guarantee the endurance and the security of the corresponding concrete. The existence of regulatory barriers as well as the necessity to spread sustainable use of the construction waste constitutes a substantial impediment as well (**Badraddin et al., 2021**). Nevertheless, the improvement of the material science and the overall knowledge about the sustainability are trying to push the innovation into this direction and make the construction process more sustainable. The construction field is associated with numerous volumes of waste material with much of it being comprised of plaster wastes, waste concrete material form demolished buildings, waste mortar, waste rubbles, broken block material, broken tiles, iron byproduct (steel slag) and offcuts. Besides posing a threat to sustainable environmental management by resulting into increased landfilling and underutilization of resources, the disposal of this waste is a wasted opportunity in material management (**Alsheyab, 2021**). There is a dire need to use eco-friendly construction materials; however, the possibility of the use of such construction waste products in concrete matrices is still unexplored (**Abera, 2024**). Although this study is limited to evaluating mechanical properties, specifically compressive and flexural strength, the durability and overall performance of concrete incorporating recycled materials remain largely unexplored. This gap in knowledge presents a critical barrier to understanding the full potential of such applications in promoting environmental sustainability in the construction sector.

## **1.1 Waste Material as Aggregate Replacement**

### **1.1.1 Polyethylene Terephthalate (PET)**

Poly (Ethylene Terephthalate) also referred to as PET is a long chain polymer that falls under polyester. Pure terephthalic acid and ethylene glycol are the main ingredients of PET, and they are petroleum products. The processes of making polyester would also entail other chemicals which could be produced in form of polymerizing a mixture of a protein and an alkali together. PET is described as an amorphous glass. Concrete can also be made using PET waste, which would help conserve the environment. Yoon et al., (2005) tried to study the microstructure of PET monofilament light weight aggregates and examined how the granular slag of molten metal (GBFS) influenced the aggregates. The experiments showed that the density of concrete with PET aggregates grew by  $320\text{kg/m}^3$  ( $1940\text{kg/m}^3$ - $2260\text{kg/m}^3$ ) and between the cement paste and the particles of PET there was a bigger transition zone than the one between the cement paste and natural PET (**Akhtaruzzaman & Hasnat, 1983**). It was predicted that the grain of molten metal slag could increase the degree of PET with the minimal transition zone which promotes the reaction of calcium hydroxide. Other researches revealed that addition of PET to concrete is capable of increasing ductility and reducing shrinkage cracks (**Ling & Poon, 2012**).

**2. MATERIALS AND METHODS**

**2.1 Materials**

- i Waste/demolished concrete
- ii Steel slag (by-product/waste from iron production)
- iii Broken tiles
- iv Mortar waste
- v Plaster waste
- vi Broken block



Figure 1: Collected plaster waste

Figure 2: Recycled plaster waste

Figure 3: Waste Demolished concrete

Figure 4: Recycled concrete

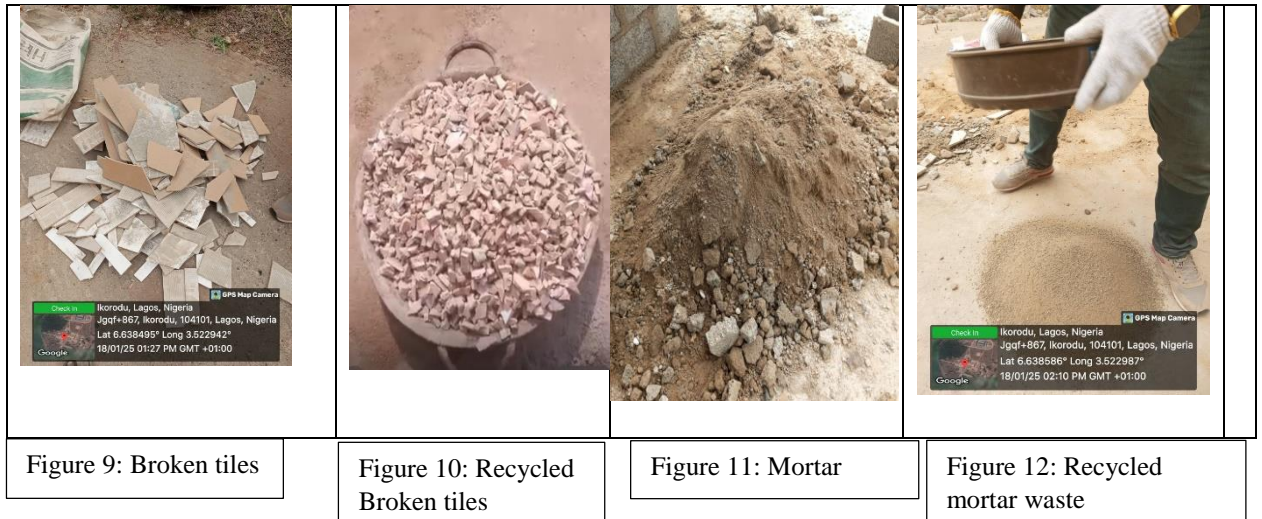


Figure 5: Steel slag

Figure 6: Recycled steel slag

Figure 7: Waste broken block

Figure 8: Recycled broken block



## 2.2 Methods

Construction and demolition waste materials, including demolished concrete, broken tiles, steel slag, mortar waste, plaster waste and broken blocks were collected around Lagos State University of Science and Technology (LASUSTECH), Ikorodu, Lagos and were manually crushed using a hammer and subsequently sieved to obtain usable aggregate fractions. While this approach is practical and accessible for laboratory-scale experimentation, it inherently introduces variability in aggregate shape, size distribution, and surface texture. Unlike industrial crushing methods that produce uniformly graded and angular aggregates, manual crushing can result in irregular particles with inconsistent grading and higher fines content. These inconsistencies may affect the packing density, interfacial bonding, and overall homogeneity of the concrete mix, potentially contributing to a reduction in mechanical strength. The recycled materials were categorised into coarse and fine aggregate as shown in Figure 1-12. The most common type of cement around Ikorodu is the Ordinary Portland Cement (OPC) of grade 42.5 (Dangote brand) it was used as concrete matrix according to BS EN 197-1:2011, For the conventional concrete, the aggregate used can be classified as fine and coarse, for the fine it is clean and dried river sand from Ogun River dredging site, while coarse aggregate is crushed granite stone with nominal size of 20mm from CICC TRADING LTD. Ikorodu was used. The water used was sourced from (LASUSTECH borehole) Concrete was prepared using construction wastes in concrete matrix (CWICM) and natural aggregates for conventional concrete (CC). To test the mechanical properties of the concrete two sets of 9cubes, 150×150×150mm and two sets of 3beam, 100×100×500mm beams was casted and kept in ambient condition for the first 24hours before loosen from mould and cured in the water for the period of 7,14 and 28days. Mechanical test was carried out in accordance with BS EN 12390-3:2019 to check average compressive strength and BS EN 12390-5:2019 for average flexural strength using a standard testing machine (UTM). The result of the construction waste in concrete matrix (CWICM) was compare to the result of conventional concrete (CC). Lastly, a multivariate regression statistical analysis model was used to examine the relationship between the characteristics of wastes and concrete performance.

## 3. RESULTS AND DISCUSSION

Conventional Concrete Materials includes:

- i Cement
- ii Water
- iii Fine Aggregate
- iv Portable Water

Construction and demolition wastes materials categorized based on composition for re-use

Recycled Waste/Demolished Concrete:	used as coarse aggregate
Recycled Broken Tiles:	used as coarse aggregate.
Recycled Steel Slag:	used as coarse aggregate.
Recycled Broken Block:	used as fine aggregate
Recycled Plaster Waste:	used as fine aggregate

Recycled Mortar Waste: used as fine aggregate  
 Volume of concrete required for laboratory work.  
 Cubes: 18 numbers of [150×150×150mm] = 0.06075 m<sup>3</sup>  
 Beams: 6 numbers of [500×100×100mm] = 0.03 m<sup>3</sup>  
 Total volume = 0.09075m<sup>3</sup>

Selection of water cement ratio:

Table 5(BS 8500-1:2015- BS EN 206) Maximum water cement ratio for 20mm aggregate = 0.65, exposure class (Dry).

Minimum Cement - 260kg/m<sup>3</sup>

For Mix Ratio 1:2:4 Grade (M15) Water cement ratio is fixed at 0.6

Materials required for 1m<sup>3</sup> using Mix ratio 1:2:4 Grade (M15).

Cement: 316.8 kg /m<sup>3</sup>> 260kg/m<sup>3</sup> (minimum cement)

Fine Aggregate: 704 kg

Coarse Aggregate 1,425 kg

Water: 316.8x0.6 = 190.08kg

Quantity of materials required for laboratory work

Conventional Concrete (CC)

Cement: 0.0454 x 316.8 = 14.383 kg (Approx. 15 kg)

Fine Aggregate: 0.0454 x 704 = 31.962 kg (approx. 32 kg)

Coarse Aggregate: 0.0454 x 1,425 = 64.695kg (Approx. 65kg)

Water: 0.6x15 = 9kg

Construction waste in Concrete Matrix (CWICM)

Concrete matrix: Cement – 15kg

Fine Aggregate:

Recycled Broken Block: 33.3% of 32kg = 10.66 kg

Recycled Plaster Waste: 33.3% of 32kg = 10.66 kg

Recycled Mortar Waste: 33.3% of 32kg = 10.66 kg

Coarse Aggregate:

Recycled Waste/Demolished Concrete: 33.3% of 65 kg = 21.65 kg

Steel Slag: 33.3% of 65kg = 21.65 kg

Broken Tiles: 33.3% of 65= 21.65 kg

Water: 0.6 x 15 = 9kg

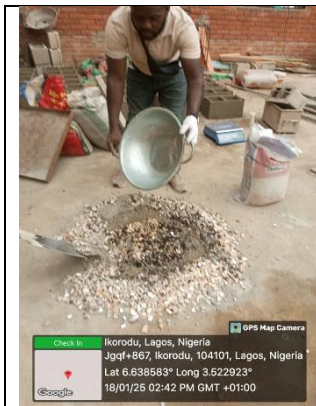


Figure 13: Concrete mixing



Figure 14: Slump



Figure 15: Cube and beam casting



Figure 16: Curing of concrete

### 3.3 Incorporation of Construction Waste Materials into Concrete Mixtures

The sorted construction waste materials were incorporated into concrete mixtures, and compressive and flexural strength tests were carried out on Cubes and Beam Using universal Testing Machine (UTM) As per BS EN 12390-3:2019 and BS EN 12390-5:2019 respectively to assess their mechanical properties for 7,14, and 28 days.

### 3.3.1 Compressive Strength Test Results Comparison between CC AND CWICM (7 days)

**Table 1: Compressive Strength Test Results Comparison (7 days)**

PARAMETERS	Conventional Cube	Conc.	Construction Cube	Waste
Area of Cube (mm <sup>2</sup> )	22500		22500	
Volume of Cube (mm <sup>3</sup> )	3375000		3375000	
Average Mass of Cube (Kg)	7.950		7.556	
Average Density of Cube (g/cm <sup>3</sup> )	2248		2238	
Average Max Crushing Load (KN)	230		140	
Average Compressive Strength (N/mm <sup>2</sup> )	10.40		6.22	

The average mass of the standard cubes is higher than that of the construction waste cubes, indicating a denser material composition. The average maximum crushing load for the standard cubes is significantly higher at **230 kN**, compared to **140 kN** for the construction waste cubes. The average compressive strength of the standard cubes is 10.40 N/mm<sup>2</sup>, while the construction waste cubes have an average strength of **6.22 N/mm<sup>2</sup>**. This Table provides a clear overview of the average performance differences between the two types of cubes in terms of mass, density, maximum crushing load, and compressive strength.

### 3.3.2 Compressive Strength Test Results Comparison (14 days)

The average mass (Table 2) of cubes in the standard condition is greater than in the construction waste condition, which means the material that makes up the cubes is dense.

**Table 2: Compressive Strength Test Results Comparison (14 days)**

PARAMETERS	Conventional Cube	Conc.	Construction Cube	Waste
Area of Cube (mm <sup>2</sup> )	22500		22500	
Volume of Cube (mm <sup>3</sup> )	3375000		3375000	
Average Mass of Cube (Kg)	8.115		7.581	
Average Density of Cube (g/cm <sup>3</sup> )	2404		2246	
Average Max Crushing Load (KN)	253.33		180	
Average Compressive Strength (N/mm <sup>2</sup> )	11.23		8.00	

The average maximum crushing load taken by the conventional cubes is quite high, - 253.33 kN, while the construction waste cubes stood at 180 kN. Compressive strength comparison: The average Compressive Strength of the conventional cubes was 11.23 N/mm while the construction waste cubes was 8.00 N/mm<sup>2</sup>.

### 3.3.3 Compressive Strength Test Results Comparison (28 days)

The average mass (Table 3) of the standard cubes exceeds that of the construction waste cubes, which means that the standard cubes have a denser composition inscribed in the material.

**Table 3: Compressive Strength Test Results Comparison (28 days)**

PARAMETERS	Conventional Cube	Conc.	Construction Cube	Waste
Area of Cube (mm <sup>2</sup> )	22500		22500	
Volume of Cube (mm <sup>3</sup> )	3375000		3375000	
Average Mass of Cube (Kg)	8.290		7.657	
Average Density of Cube (g/cm <sup>3</sup> )	2456		2268	
Average Max Crushing Load (KN)	343.33		225	
Average Compressive Strength (N/mm <sup>2</sup> )	15.31		10.00	

Average Maximum Crushing Load: The mean value of maximum crushing load of the standard cubes is much more at 343.33 kN and the construction waste cubes is only 225 kN. The average

compressive strength of the standard cubes is 15.31 N/mm<sup>2</sup>, while the construction wastes cubes have average strength ranks of 10.00 N/mm<sup>2</sup>.

### 3.3.4 Comparison of Compressive and Flexural Strength

**Table 4: Strength Comparison of Conventional Concrete (CC) and Construction Wastes in Concrete Matrix (CWICM)**

AGE (Days)	Strength Type	Conventional Concrete(CC) (N/mm <sup>2</sup> )	Construction Wastes in Concrete Matrix (CWICM) (N/mm <sup>2</sup> )
7	Compressive Strength	10.40	6.22
14	Compressive Strength	11.23	8.00
28	Compressive Strength	15.31	10.00
7	Flexural Strength	2.56	1.98
14	Flexural Strength	3.65	2.48
28	Flexural Strength	4.20	2.56

At all ages, the compressive strength of Conventional Concrete is higher compared to that of Construction Wastes in Concrete Matrix. In the same manner, there is a greater flexural strength of Conventional Concrete than Construction Waste in Concrete Matrix. Table 5 shows the regression parameters that shall be applied to model the crushing strength of concrete as the dependent variable. The predictors involved are Cube age, Maximum crushing load and Density. Cube age and maximum crushing load all have significant contributions to the model ( $p < 0.05$ ) but the variable age of the cube has the highest standardized coefficient ( $\beta = 0.941$ ) and therefore the best predictor. The correlation with density is weak and also statistically insignificant ( $p > 0.05$ ). According to the model, compressive strength will also rise based on the age of the concrete and the weight it is supposed to support.

**Table 5: Sample Regression Coefficients (Dependent Variable: Compressive Strength)**

Predictor	Unstandardized Coefficient (B)	Standard Error	Standardized Coefficient (Beta)	t	Sig.
(Constant)	1.120	0.512	–	2.188	0.047
Age of Cube (Days)	0.260	0.034	0.941	7.647	0.001
Max Crushing Load (KN)	0.030	0.009	0.730	3.333	0.015
Density (g/cm <sup>3</sup> )	850	650	315	1308	225

Regression model predicts compressive strength based on cube age, crushing load, and density. The corrected case-wise diagnostics table shows the values of the observed and the predicted values of the compressive strength. It also contains the standardized residuals of each of the cases. All the residuals lie between -2 and + 2 standard deviations, and therefore there is no significant outlier and the model fits the data relatively well in all the cases.

**Table 6: Case-wise Diagnostics**

Case	Observed Value (N/mm <sup>2</sup> )	Predicted Value (N/mm <sup>2</sup> )	Std. Residual	Outlier ( $\pm 2$ Std.)
1	6.22	6.50	-0.42	No
2	8.00	8.15	-0.25	No
3	10.00	9.60	0.40	No
4	10.40	10.00	0.52	No
5	11.23	11.50	-0.35	No
6	15.31	14.80	0.60	No

No significant outliers detected; all residuals within  $\pm 2$  SD. This correlation matrix indicates that there exist very positive correlations among all the variables. Interestingly, compressive strength is the most correlated variable with age ( $r = 0.985$ ) and max crushing load ( $r = 0.990$ ), which means that these three variables are very useful to predict compressive strength. Mass and density have a moderate positive relationship between them. The fact that the correlation between the variables is high is another factor that justifies why they should be used on the modeling regression.

**Table 3.7: Correlation Matrix**

Variable	Age (Days)	Mass (Kg)	Density (Kg/cm <sup>3</sup> )	Max Load (KN)	Compressive Strength (N/mm <sup>2</sup> )
Age (Days)	1.000	0.980	0.912	0.968	0.985
Mass (Kg)	0.980	1.000	0.926	0.951	0.973
Density (g/cm <sup>3</sup> )	912	926	1000	887	905
Max Crushing Load (KN)	0.968	0.951	0.887	1.000	0.990
Compressive Strength	0.985	0.973	0.905	0.990	1.000

**Note:** Strong positive correlation exists between compressive strength and max crushing load.

ANOVA table tests the significance of regression model as a whole. The F-test of 41.580 at a level of significance ( $p = 0.001$ ) shows that the regression model is found to be statistically significant and which explains a considerable amount of the variance in compressive strength. This confirms the significance of the predictors (age, the maximum load, and density) in the model.

**Table 3.8: ANOVA Summary for Regression Model**

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	72.143	3	24.048	41.580	0.001
Residual	2.893	5	0.579		
Total	75.036	8			

The regression model is statistically significant ( $p < 0.01$ ), indicating good model fit.

### 3.4 Analysis and Comparison of Mechanical Properties

Application of recycled construction wastes material as replacement for natural aggregates in concrete mixture has been checked repeatedly to determine the mechanical strength especially compressive and flexural strengths. The analysis based on the given data is presented in Table 9.

#### 3.4.1 Compressive Strength Comparison

**Table 9: Compressive Strength Test Results**

Age (Days)	Standard Cube (N/mm <sup>2</sup> )	Construction Waste Cube (N/mm <sup>2</sup> )
7	10.40	6.22
14	11.23	8.00
28	15.31	10.00

The compressive strength of both concretes is greater as it comes to age. The conventional concrete at all the ages is however superior to the construction waste incorporated concrete. Performance Gap: On the 28 days, the Conventional Concrete attains a Compressive strength of 15.31 N/mm<sup>2</sup> while the construction waste concrete has 10.00 N/mm<sup>2</sup>. This is a sign of a huge gap in performance which implies that the construction waste materials might not be as structurally sound as the traditional materials but at least would be able to perform well in the construction of some structural element that bear less load such as lintel, perimeter wall, bungalow etc. thus eliminating waste and enhances the socio-economic and environmental sustainability.

#### 3.4.2 Flexural Strength Comparison

**Table 10: Flexural Strength Test Results**

Age (Days)	Standard Cube (N/mm <sup>2</sup> )	Construction Waste Cube (N/mm <sup>2</sup> )
7	2.56	1.98
14	3.65	2.48
28	4.20	2.56

Like compressive strength, the flexural strength of both the concrete types rises with the age. All the ages possess a greater flexural strength in the conventional concrete. The flexural strength of standard concrete at 28 days is 4.20 N/mm<sup>2</sup> and 2.56 N/mm<sup>2</sup> for flexural strength of construction waste concrete. This further demonstrates the superior performance of conventional concrete not only in compressive strength but also for flexural strengths.

**Table 11: Summary of Mechanical Properties**

PARAMETERS	Standard Cube	Construction Waste Cube	Performance Gap (%)
Average Mass (Kg)	8.29	7.66	7.64
Average Density (g/cm <sup>3</sup> )	2456.00	2268.00	7.65
Average Max Crushing Load (KN)	343.33	225.00	34.47
Average Compressive Strength (N/mm <sup>2</sup> )	15.31	10.00	34.68
Average Flexural Strength (N/mm <sup>2</sup> )	4.20	2.56	39.05

Looking at the mechanical properties, it is observed that Conventional Concrete (CC) always performs better than Construction Wastes in Concrete Matrix (CWICM) on all the parameters tested. The large discrepancies between compressive and flexural strengths reveal that construction waste materials can be used in concrete mixtures, but for structural element that bear less load. This implies the need to carry out further study to improve the mechanical properties either by adding additives or increase the ratio of the matrix.

**Table 12: Sample Regression Coefficients (Dependent Variable: Flexural Strength)**

Predictor	Unstandardized Coefficient (B)	Standard Error	Standardized Coefficient (Beta)	t	Sig.
(Constant)	0.892	0.274	–	3.257	0.044
Age of Cube (Days)	0.064	0.010	0.980	6.400	0.008
Density (g/cm <sup>3</sup> )	950	422	672	2250	92
Compressive Strength (N/mm <sup>2</sup> )	0.110	0.056	0.640	1.964	0.130

The table below is the summary of the regression coefficient of the predictive model of flexural strength, which is an average of cube age, density, and compressive strength of these cubes. The age of the cube reveals the strongest influence and is statistically significant ( $p = 0.008$ ), whereas density and compressive strength are moderate but do not reach the statistical significance ( $p = 0.085$  and  $0.147$  respectively). The regression indicates a positive relationship between flexural strength and age, and the other two values which are density and compressive strength of the concrete.

**Table 13: Case-wise Diagnostics**

Case	Observed Value (N/mm <sup>2</sup> )	Predicted Value (N/mm <sup>2</sup> )	Std. Residual	Outlier ( $\pm 2$ Std.)
1	1.98	2.00	-0.12	No
2	2.48	2.45	0.14	No
3	2.56	2.60	-0.08	No
4	2.56	2.60	-0.08	No
5	3.65	3.55	0.19	No
6	4.20	4.10	0.15	No

The case-wise diagnostics table compares observed versus predicted flexural strength values and assesses model residuals. All standardized residuals fall well within the  $\pm 2$  standard deviation threshold, confirming that the model predictions are accurate and free from influential outliers.

**Table 14: Correlation Matrix**

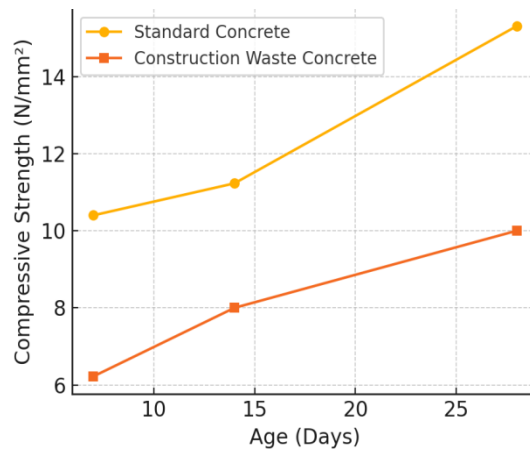
Variable	Age (Days)	Density (Kg/cm <sup>3</sup> )	Compressive Strength (N/mm <sup>2</sup> )	Flexural Strength (N/mm <sup>2</sup> )
Age (Days)	1.000	0.944	0.980	0.986
Density (g/cm <sup>3</sup> )	0.944	1.000	0.925	0.942
Compressive Strength	0.980	0.925	1.000	0.975
Flexural Strength	0.986	0.942	0.975	1.000

The correlation matrix indicates strong positive correlation among all the variables that are captured in the table. It is important to note that there is a strong correlation of the flexural strength with age ( $r = 0.986$ ), compressive strength ( $r = 0.975$ ), and density ( $r = 0.942$ ). These functions attest to the reliability of predicting flexural strength in terms of other mechanical properties and cube age.

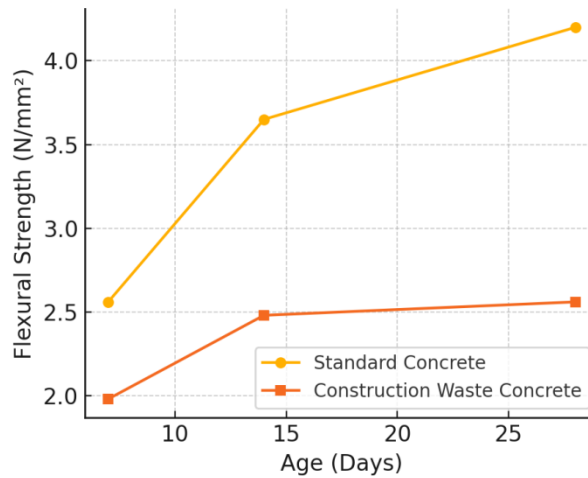
**Table 15: ANOVA Summary for Regression Model**

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	8.129	3	2.710	30.990	0.006
Residual	0.437	5	0.087		
Total	8.566	8			

ANOVA findings reveal that the statistical significance of the regression model employed to make predictions of the average flexural strength is significant ( $p = 0.006$ ). The F value is very high; hence, there is a good fit between the model and therefore the independent variables (age, density, and compressive strength) explain a large amount of the variation in flexural strength.

**Figure 17: Compressive Strength vs. Age**

This graph shows the increase in compressive strength over time for both standard concrete and concrete made with construction waste. The standard mix consistently shows higher strength at each curing period.



**Figure 18: Flexural Strength vs. Age**

This graph depicts the development of flexural strength over time for both concrete types. The conventional concrete outperforms the construction waste concrete in all curing durations, showing better bending resistance.

#### 4. CONCLUSION

Based on the results obtained the following conclusions can be drawn;

The study established that incorporating recycled construction waste materials into concrete mixtures results in a moderate reduction in compressive and flexural strengths compared to conventional concrete. However, both strengths increased with curing age, reflecting adequate hydration and material bonding development. At 28 days, conventional concrete achieved 15.31 N/mm<sup>2</sup>, while CWICM reached 10.00 N/mm<sup>2</sup>, representing a 34.7% reduction. The regression and correlation analyses confirmed that compressive strength is highly dependent on cube age ( $r = 0.985$ ) and maximum crushing load ( $r = 0.990$ ), with minimal influence from density. The flexural strength of CWICM was consistently lower than that of conventional concrete, with a 39.05% performance gap at 28 days. Statistical modeling indicated that cube age strongly influenced flexural strength ( $\beta = 0.980$ ;  $p = 0.008$ ), confirming the critical role of curing in strength development. The regression models for both compressive and flexural strengths showed strong fits (ANOVA  $p$ -values  $< 0.01$ ), no significant outliers (residuals within  $\pm 2$  SD), and high inter-variable correlations, confirming their predictive reliability. While CWICM may not be ideal for heavily loaded structural elements, it is suitable for light construction works where sustainability, cost efficiency, and waste reduction are priorities. Its use supports circular economy principles by converting waste into valuable construction resources.

#### Recommendations

Future studies should investigate the inclusion of supplementary cementitious materials (e.g., fly ash, silica fume, or cassava peel ash) and chemical admixtures to enhance the bonding and strength characteristics of recycled aggregate concrete. Durability tests under various environmental conditions are also recommended to evaluate long-term performance.

#### NOMENCLATURE

kg/m<sup>3</sup>                      Kilogram

## Abbreviations

CC	Conventional Concrete
CWICM	Construction Waste In Concrete Matrix

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