



## INFLUENCE OF RUBBER CRUMBS ON THE STRUCTURAL EFFICIENCY OF CONCRETE MADE FROM CERAMIC TILE AGGREGATES

A. Adetiloye<sup>1\*</sup>, J. O. Akinyele<sup>1</sup>, O. W. Adeoye<sup>1</sup> and J. O. Labiran<sup>2</sup>

<sup>1</sup>Department of Civil Engineering, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria.

<sup>2</sup>Department of Civil Engineering, University of Ibadan, Oyo State, Nigeria.

\*Corresponding author's email address: [adetiloyea@funaab.edu.ng](mailto:adetiloyea@funaab.edu.ng)

### ARTICLE INFORMATION ABSTRACT

Submitted 4 January, 2024

Revised 28 February, 2024

Accepted 25 March, 2024

#### Keywords:

Ceramic tiles

Tyre rubber crumbs

Granite

Sand

Cement.

The indiscriminate dumping of used tyres and construction waste like ceramic tiles has contributed to the present unclean environment. As part of the efforts in the recycling of these waste materials, they were both introduced to concrete, and the effect of these two materials on the structural properties of concrete was studied in this work. Crushed ceramic tiles were used to totally replace granite as the coarse aggregate, while crushed tyre rubber crumbs replaced sand as fine aggregate (0%, 5% and 10%), designated as C<sub>0</sub>, C<sub>5</sub> and C<sub>10</sub> respectively. The mix ratio was 1:2:2 for cement, fine and coarse aggregates at 0.5 water/cement ratio, concrete was cured for 7 and 28 days. 100 x 100 x 100 mm concrete cubes were used for the compressive and 100 x 100 x 750 mm beam was used for the flexural strength tests. The results obtained from both compressive and flexural tests showed a general reduction in strength, this was due to the ceramic tiles that absorbed excess water into the concrete. The ACI 209R-92 equations for the prediction of concrete strength were used to determine the one-year strength of the concrete samples. Statistical analysis showed that the R<sup>2</sup> of the strength within one year was 0.83 and 0.77 for the C<sub>0</sub> and C<sub>5</sub> samples respectively. The presence of rubber crumbs served as fillers, especially in the C<sub>5</sub> samples. It was concluded that crushed ceramic tiles and rubber crumbs could be used in structural concrete, but should not exceed 5% of rubber crumbs.

### 1.0 Introduction

Efforts are been made by different researchers in the introduction of alternative materials, especially the recycling of waste materials in concrete. It is believed that natural materials should be conserved, and waste materials should be recycled in concrete. In the past, several works have been done in the use of recycled materials in concrete. (Khaloo *et al.*, 2008) used both mechanical and non-destructive tests to determine the properties of rubberized concrete of varying rubber tyre particles. The research was able to reveal the behavior of concrete under compressive strain.

Many researches work such as (Karakurt, 2015; Mohammadi and Khabbaz, 2015; Thomas *et al.*, 2015; Thomas and Gupta, 2015) have used rubber in concrete as either fine or coarse aggregate with some very interesting results that has encouraged more research to be carried out on this subject. Akinyele *et al.* (2016) determined the influence of rubber crumbs on the chemical, mechanical and microstructural characteristics of concrete. The work resolved that rubber crumbs affected the strength of concrete negatively after about 8% replacement of fine aggregate. Gupta *et al.* (2015) investigated the use of crumb rubber as fine aggregates, and the

effect on concrete properties. Six replicate of rubber crumb fibers (0%, 5%, 10%, 15%, 20% and 25%) were used in the work. The study revealed that the durability and impact resistance of concrete can be improved upon by using rubber fiber in concrete.

Duarte *et al.* (2015) carried out numerical procedure using the split tensile test to evaluate the mechanical behavior of rubberized concrete. The results showed that rubberized concrete has higher ductility but lower strength and stiffness than normal concrete.

The usage of ceramic tiles as floor, walls and countertop tiles in buildings has become very popular, however, at the end of its use, it becomes a waste (Ray *et al.*, 2021). Various works have gone into the recycling of these materials in the production of concrete. Suvash *et al.* (2023) examined the mechanical durability and microstructural performance of concrete made with ceramic tiles aggregate at 0, 10, 20, 30, 50 and 100% in position of the normal coarse aggregate. The study showed that the more the amount of ceramic tiles used as aggregate, the more was the decrease in strength. However, a 10% addition of tiles as aggregate was recommended as the strength reduction at this point was relatively low.

In another work, Ikponmwo and Ekhuenmen (2017) replaced coarse aggregate at 0, 25, 50, 75 and 100% and investigated the tensile and compressive strength tests at 90 days curing age. They observed that the two strengths were reducing as the percentage of ceramic tiles were increased. This reduction was attributed to the water absorption nature of the ceramic tiles in cured concrete. The work concluded that ceramic tiles could be used in concrete for structural and non-structural works, but should not exceed 75% replacement where strength is the major consideration.

This study aimed to investigate the influence of both tyre rubber crumbs and ceramic tiles wastes on the structural properties of concrete, such as the compressive, flexural, elastic modulus and structural efficiency of concrete.

## 2. Materials and Methods

### 2.1. Material Composition

The percentage of natural fine aggregates replacement by rubber crumb waste was chosen to be 0%, 5% and 10% by weight (designated as  $C_0$ ,  $C_5$  and  $C_{10}$  respectively). This percentage replacement was in agreement with Akinyele *et al.* (2016) where it was stated that “the systematic reduction of ultimate strength in tyre-rubber concrete might restrict its use in concentrations exceeding 8% for structural applications”, hence the restriction to 10% replacement. Crushed ceramic tiles were also used to completely replace the conventional coarse aggregate of granite stones. Figures 1 and 2 show the crushed tiles and rubber crumbs.



**Figure 1:** Crushed ceramic tiles



**Figure 2:** Crushed tyre rubber crumbs

### 2.2. Concrete Production

The design mix for concrete adopted in this work was 1:2:2 for cement, fine and coarse aggregates, respectively, with a water/cement ratio of 0.5 in accordance to BS 1881, (1993). Table 1 shows the mix proportion. 100 mm × 100 mm × 100 mm concrete cubes were cast in

steel moulds for the compressive strength test, cylinder size of 100 mm x 200 mm was used for the split tensile test, while 100 mm x 100 mm x 750 mm sized concrete beams was for the flexural strength test.

The inside of each mould was lubricated with black oil before usage, to prevent concrete from sticking to the mould after demoulding. Each mould was gradually filled with three layers of concrete, each layer was trampled using a tapping steel rod to prevent segregation, entrapped air and to allow full compaction of concrete.

**Table 1:** Mixture of concrete

Samples	Cement (kg)	Sand (kg)	Ceramic Tiles (kg)	Rubber crumb (Kg)	Water (kg)
C <sub>0</sub>	100	200	200	0	50
C <sub>5</sub>	100	190	200	10	50
C <sub>10</sub>	100	180	200	20	50

### 2.3 Density of Concrete

The BS 12350-6, (2000) was adopted for the density of hardened concrete at 28days. Concrete cubes were weighed after the curing period. The cured specimens were wiped dry before placement on a digital weighing machine, where their different masses were accurately measured. The volume of the samples were determined through the 100mm x 100mm x 100mm cube size that were used. The density was calculated as the ratio of their respective masses to their volume.

### 2.4 Compressive Strength Test

After the 7 and 28 days curing periods, the samples were removed from the curing tanks and the cubes were wiped with dry cloths to remove the dripping water. The samples were then transferred to a 2000 kN IMPACT compressive testing machine, where the cubes were placed between the top and bottom pressing plates as showed in Figure 3 at a rate of 180 kN/min. This was in accordance with BS 12390 -3, (2019). This test was carried out at the material laboratory of the Civil Engineering Department, Federal University of Agriculture, Abeokuta, Nigeria.



**Figure 3:** Compressive test on concrete sample.



**Figure 4:** Three-point flexural strength test

### 2.5 The Splitting Tensile Strength Test

This test is one of the significant properties of concrete, it was done according to ASTM C 496-96 standard, (2017). The purpose of the test was to determine the tensile resistance of concrete under sustained loading, this method is more preferred than the direct tensile test because of its simplicity of testing. This test was performed by using a cylindrical concrete samples of 100 mm diameter and 200 mm depth. The cylinder was laid on its side between the

loading plates of the 2000 kN IMPACT compressive strength testing machine and the loading was adjusted to a speed of 100 kN/min. until the crushing of the cylinder.

## 2.6 Flexural Strength Test of Beams

At the end of 7 and 28 days, the concrete beams were tested for its flexural strength. The ASTM C 78 standard, (2019) was adopted which has to do with the testing of the flexural strength of concrete using simple beam with third-point loading. The beam was positioned in the Universal Testing Machine (UTM) and subjected to gradual and continuous loading until failure occurred (Figure 4).

## 3. Results and Discussion

### 3.1. Density of Concrete Samples

The density of each concrete sample is shown in Figure 5. The pattern of the results revealed a general reduction in the density of samples with 10% rubber crumb having the lowest value at 2047 kg/m<sup>3</sup>. This reduction in density can be ascribed to the very light rubber crumb that was used to partially replace sand as fine aggregate. Density of sample C<sub>5</sub> was slightly higher than the control and this can be attributed to the fact that the rubber crumb acts as fillers to the voids within the concrete matrix in this particular sample, but the higher amount of rubber crumbs in samples C<sub>10</sub> made it to be lighter than the others. This result is comparable with the findings of Akinyele *et al.* (2016), where tyre rubber crumbs were used to substitute sand as fine aggregates up to 16% in concrete. The C<sub>0</sub> and C<sub>5</sub> concrete sample densities were above 2300 kg/m<sup>3</sup> and according to EN 206, (2000), this can be classified as normal weight concrete.

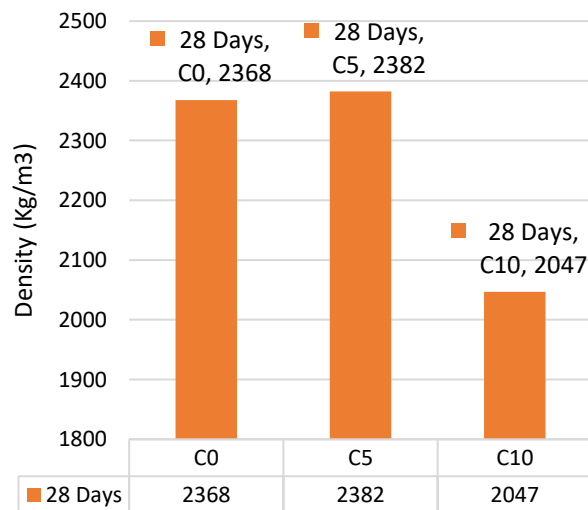


Figure 5: Density of concrete samples

### 3.2 Compressive Strength Result

The pattern showed by the concrete samples under crushing loads revealed the effect of rubber crumbs and ceramic tiles aggregates on the strength of the concrete samples. All the concrete samples showed general reduction in concrete strength between the 7<sup>th</sup> and the 28<sup>th</sup> days. This is understandable because the ceramic tiles that were used as the coarse aggregates did not have the same properties as the natural granite. At 7 days, the control (C<sub>0</sub>) sample attained 23.8 MPa, and at 28 days the strength reduced to 21.77 MPa, which is 8.5% reduction of the strength achieved at 7 days. The same reduction in strength was recorded for Sample C<sub>5</sub>, between the 7<sup>th</sup> and 28<sup>th</sup> days strength, while Sample C<sub>10</sub> performed very poorly, attaining a strength of 11.45 MPa at 28 days. The reason for this general reduction in strength was because of the water absorption capacity of the crushed ceramic tiles in the concrete matrix. Since the concrete samples were cured at room temperature, the ceramic tiles absorbed excess water within its surrounding inside the concrete matrix, this wouldn't have happened if the normal granite coarse aggregate was used. Although this does not hinder the hydration of cement in



the concrete, the more water the tiles absorbed, the lower the strength of the concrete samples from the observation in this study. The strengths above 28 days were predicted using the ACI 209R-92, (1997) equations for the predictions of concrete strength properties. Eqn. 1 was used to predict the strength at, 56, 90 and 365 days, and a graph was plotted to determine the  $R^2$  of the rate of strength reduction within one year. Figures. 7 and 8 showed the predicted strength and the rate of reduction in strength respectively.

$$(f'_c)_t = \frac{t}{\alpha + \beta t} (f'_c)_{28} \tag{1}$$

$(f'_c)_{28}$  = 28 days compressive strength,  $(f'_c)_t$  = predicted compressive strength,  $t$  = age of concrete in days,  $\alpha$  = a constant and  $\beta$  = a constant in days.

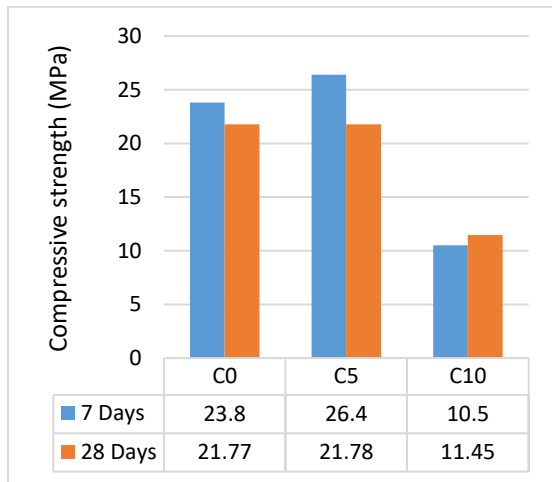


Figure 6: Compressive strength results

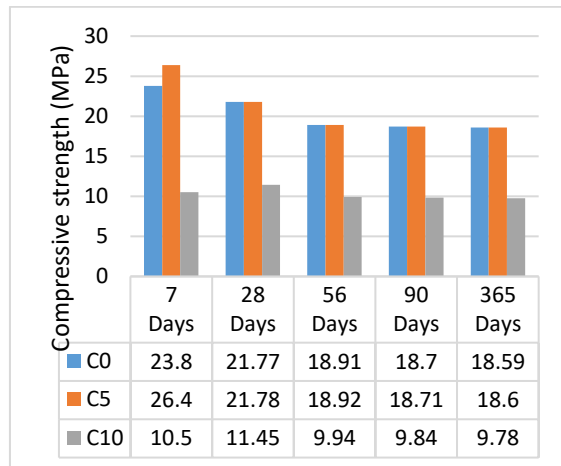


Figure 7: Predicted compressive strength above 28 days

Results from Figure 7 on the predicted compressive strength adopting Eqn. 1, have given insights into the strength characteristics of concrete samples made with ceramic tiles and rubber crumbs. While the ceramic tiles absorbed water, the rubber crumbs acted as fillers in the concrete, and the combination of these two inert materials contributed to the loss in strength over time. The reduction in strength over time will not encourage the use of these materials for high-strength concrete, except lightweight concrete structures. The statistical analysis from Fig. 9 showed that the  $R^2$  for the reduction in strength of sample  $C_0$  between 7 and 365 days was 0.83, when compared with the 0.77 value that was obtained for  $C_5$  sample, it can be concluded that the  $C_0$  samples performed better.

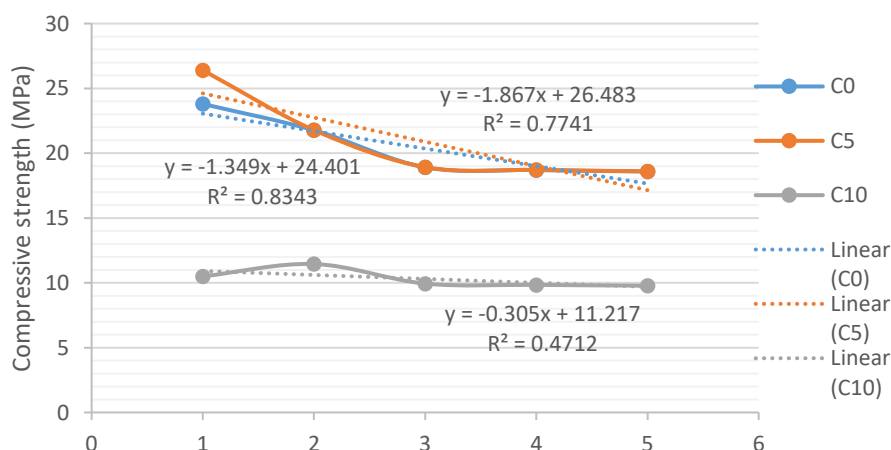


Figure 8: Rate of decrease in compressive strength between 7 and 365 days.

### 3.3 Split Tensile Strength Results

The resistance to tensile forces in the concrete samples were determined in this particular test. The split tensile strength test results showed that the control samples had the highest strength when compared with the two other samples at both seven and twenty-eight days. The split test showed different results when compared to both the compressive and flexural strength. There was a general increase in split tensile strength between the 7<sup>th</sup> and 28<sup>th</sup> days test. The slight increment in strength can be ascribed to the adhesive forces that were holding the cement paste and the two aggregates together. Although this force is not strong, it increased as the age of the concrete samples increased.

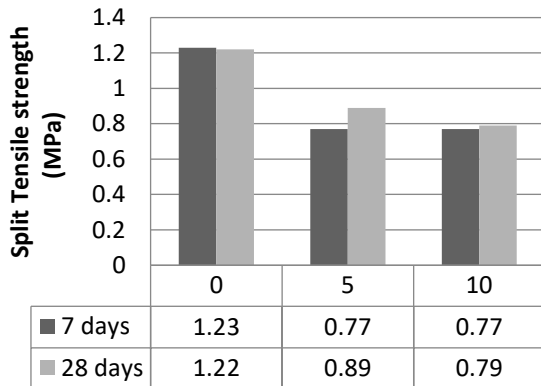


Figure 9: Split tensile test results

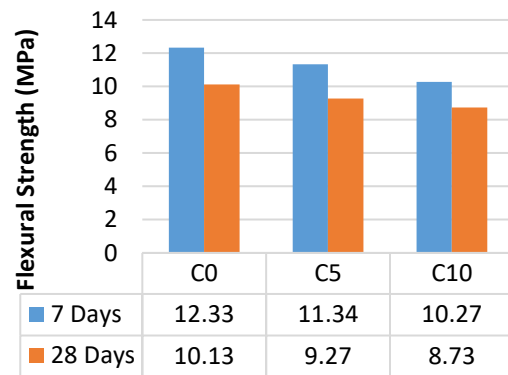


Figure 10: Flexural strength results

### 3.4 Flexural Strength Results

The flexural strength or modulus of ruptures for each concrete sample were determined. This is the amount of stress in the beams before it yielded under flexural loading. The results followed the same pattern as the compressive strength in which the 7-day strength test was higher than the 28-day test, based on the explanations discussed above under compressive strength. The results revealed that Sample C<sub>0</sub> had a higher ability to resist flexural loads, under sustained loading in the tensioned zone of the beam. The effect of rubber crumbs in reducing flexural strength as more crumbs were added to the sample was very conspicuous, and this is also in accord with the findings of Akinyele *et al.* (2016).

### 3.5 Structural Characteristics of Concrete Samples

The structural characteristics of the concrete samples showed in table 2 were determined and compared with each other. Properties such as Modulus of elasticity was determined using Equation 2 which was adopted from the ACI 209R-92 reports, (1997), while the structural efficiency is the ratio of compressive strength to the density of the concrete materials (Akinyele *et al.*, 2019).

$$E_{ct} = g_{ct} [w^3 (f'_c)_t]^{1/2} \quad (2)$$

Where:  $g_{ct}$  is a constant (0.043),  $w$  is the unit weight of concrete,  $f'_c$  is the characteristic strength of concrete at 28 days.

It should be observed that the Modulus of elasticity obtained for all the concrete samples in this research are very low when compared to the standard elastic modulus of concrete which is 29 MPa for a grade 20/25 concrete, and 30.5 for a grade 30/35 concrete (Hurst, 2017). This can be ascribed to the negative effects of the crushed rubber crumb and ceramic tiles that are present in the concrete used in this study. The modulus of elasticity of sample C<sub>5</sub> is higher than that of C<sub>0</sub>, probably due to the rubber crumbs in the concrete samples when compared with the control that had no rubber crumbs in it.

The structural efficiency is the capacity of the concrete to withstand compressive load in relation to its unit weight. Despite sample C<sub>0</sub> having a marginally low compressive strength when compared to C<sub>5</sub>, it had a higher structural efficiency than C<sub>5</sub>. This is a positive advantage because it can support heavier load with its low density when compared to the C<sub>5</sub> sample.

**Table 2:** Structural Properties of concrete samples

Samples	Modulus of Elasticity (10 <sup>3</sup> N/mm <sup>2</sup> )	Structural Efficiency (x10 <sup>-3</sup> m)
C <sub>0</sub>	23.12	9.19
C <sub>5</sub>	23.33	9.14
C <sub>10</sub>	13.48	5.60

#### 4. Conclusion

The influence of crushed tyre rubber crumbs and ceramic tiles on the properties of concrete has been investigated in this work. There was a generally reduction in concrete strength as the concrete ages, and also the more the addition of rubber crumbs above 5% replacement, the more was the reduction in strength. The general reduction in strength was because of the absorption of water by the ceramic tiles in the cured concrete. Only 8.5% reduction in strength of the concrete was observed for the C<sub>0</sub> sample, which is the control at 28 days, but this does not rule out the use of this type of concrete for structural work. The R<sup>2</sup> for the C<sub>0</sub> sample at the predicted reduced strength for one year was 0.83, while that of C<sub>5</sub> was 0.77, the implication of this is that the reduction in strength overtime will be minimal when compared with the first 28 days, hence the strength of the concrete sample will stabilize as the concrete ages. The modulus of elasticity of the C<sub>5</sub> sample was the highest and was about 80% of the standard modulus of elasticity for grade 20/25 concrete. The structural efficiency of the C<sub>5</sub> sample was about 99% of the control sample. It can be concluded that the use of crushed ceramic tiles in place of granite and the addition of rubber crumbs at 5% into the concrete can be used for structural works.

#### References

- Khaloo, AR., Dehestani, M. and Rahmatabadi, P. 2008. Mechanical Properties of Concrete Containing a High Volume of Tire–Rubber Particles. *Waste Management*, 28(12): 2472–2482.
- Karakurt, C. 2015. Microstructure Properties of Waste Tire Rubber Composites: An Overview. *Journal of Material Cycles and Waste Management*, 17: 422–433.
- Mohammadi, I. and Khabbaz, H. 2015. Shrinkage performance of Crumb Rubber Concrete (CRC) prepared by water–soaking treatment method for rigid pavements. *Cements and Concrete Composite*, 62: 106–116.
- Thomas, BS., Gupta, RC. and Panicker, VJ. 2016. Recycling of waste tire rubber as aggregate in concrete: durability related performance. *Journal of Cleaner Production*, 112 (1): 504–513.
- Thomas, BS. and Gupta, RC. 2015. Long term behavior of cement concrete containing discarded rubber.” *Journal of Cleaner Production*, 101: 78–87.
- Thomas, BS. and Gupta, RC. 2016. A comprehensive review on the applications of waste tyre rubber in cement concrete. *Renewable and Sustainable Energy Reviews*, 54: 1323–1333.
- Akinyele, JO., Salim, RW. and Kupolati, WK. 2016. Effect of rubber crumb on the microstructural properties of concrete. *African Journal of Science, Technology, Innovation and Development*, 8(5-6): 467-474.
- Gupta, T., Sharma, RK. and Chaudhary, S. 2015. Impact resistance of concrete containing waste rubber fiber and silica fume. *International Journal of Impact Engineering*, 83: 76–87.

Duarte, APC., Silva, BA., Silvestre, N., de Brito, J. and Julio, E. 2015. Mechanical characterization of rubberized concrete using an image-processing/XFEM coupled procedure. *Composites Part B*, 78: 214–226.

Ray, S., Haque, M., Sakib, MN., Mita, AF., Rahman, MM. and Tanmoy, BB. 2021. Use of ceramic wastes as aggregates in concrete production: a review. *Journal of Building Engineering*, 43: 102567.

Suvahs, CP., Samrat, AUF., Adewumi, JB. and Md, JF. 2023. Eco-friendly concrete with waste ceramic tile as coarse aggregate: mechanical strength, durability, and microstructural properties. *Asian Journal of Civil Engineering*, 24: 3363-3373.

Ikponmwo, EE. and Ehikhuenmen, SO. 2017. The effect of ceramic waste as coarse aggregate on Strength properties of concrete. *Nigerian Journal of Technology (NIJOTECH)*, 36(3): 691 – 696.

Akinyele, JO., Salim, RW. and Kupolati, WK. 2016. Production of lightweight concrete from waste tire rubber crumb.” *Engineering Structures and Technologies*, 8(3): 108-116.

BS 1881, Part 108. 1993. Method for making test cubes from fresh concrete. British Standard Institution, London.

BS 12350, Part 6.2000. Method for Determining of Density. London: British Standards Institution. London.

BS EN 12390-3.2019. Testing Hardened Concrete. Compressive Strength of Test Specimens. British Standard Institution, London.

ASTM C496-96M–17.2017. Standard test method for splitting tensile strength of cylindrical concrete specimens. ASTM international, West Conshohocken PA, USA.

ASTM C78.2019. Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). ASTM international, West Conshohocken PA, USA.

BS EN 12390-5.2019. Testing Hardened Concrete: Flexural Strength of Test Specimens.” British Standard Institution, London.

EN 206 part 1.2000. “Specification, performance, production conformity.” European Standard. Brussels.

ACI-209R-92.1997. Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures. ACI Committee Report.

Akinyele, JO., Akinwande, OM. and Igba, UT. 2019. The use of PET pellet in cement stabilized compressed earth bricks. *Advances in Engineering materials, Structures and systems: Innovations, Mechanics and Applications*. (Ed Zingoni). Taylor & Francis Group, London, pp. 1631-1635.

Hurst, MK. 2017. *Prestressed Concrete design*. 2<sup>nd</sup> Edition. Pg. 31, CRC Press, Rutledge. New York and London.