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Structural Potential of Concrete Modified with Ceramic Tiles in The Production of Concrete

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Abstract

A sizeable unit of ceramic tiles that were broken while being employed as finishes on a construction site becomes waste and is mostly left unutilized, however it is occasionally used to tile retail spaces. This experiment attempts to partially replace cement and coarse aggregates in concrete by using recycled ceramic tiles as a replacement material. For the replacement of coarse aggregates and cement, respectively, in amounts ranging from 0 to 30% at intervals of 5%, ceramic tiles were broken into coarse and powdery forms. For each replacement (0-30%), The water cement ratio (W/C) of 0.4 was used to cast concrete cubes., and curing period was 7, 14, 21 and 28 days. This investigation, which followed British Standard, focused on the compressive strength of both normal and ceramically treated concrete. In comparison to control (25.77 N/mm^2), the compressive strengths of the modified concrete (5-30%) at 28 days were 22.38N/mm^2, 21.38N/mm^2, 23.69N/mm^2, 19.71N/mm^2, 17.51N/mm^2, and 14.82N/mm^2, respectively. Predictive model showed that flexural and spilt tensile strength fall within specified range for (2.53 -3.79N/mm^2) and (2.02-3.03N/mm^2) in accordance with ASTMC78 & C293 for flexural strength and ASTM C496 for spilt tensile strength. It may be inferred that ceramic tiles in powdery and coarse forms, respectively, can replace the combined cement and coarse aggregates up to 15% in concrete, with the resulting concrete possessing qualities equal to conventional concrete.

Keywords: Aggregate, Compressive Strength, Concrete, Ceramic tiles, Reuse

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Introduction

The second most often used material on Earth, after water, is concrete, which plays a role in influencing the built environment. Global production of concrete is thought to total 33 billion tons annually. This equals more than 1.7 billion truckloads annually, or roughly 6.4 million truckloads each day, or more than 3.8 tons per person annually (www.ecosmartconcrete.com/enviro_statistics.cfm) 2014.). Crushed ceramic waste and pumice stone were employed in mortar and concrete manufacturing by Binici, in 2007. The results showed that the completed product had great resistance to chloride attack, good compressive strength, and abrasion resistance. The goal of this study is to determine how using ceramic waste instead of cement, fine and coarse aggregate will have an impact on the crushing strength of the final product. Examined variables included physical traits, workability, compressive strength, and tensile strength. Understanding the combined behavior of ceramic materials with partial replacement of coarse aggregate and cement at different compositions is necessary for determining the acceptability of these crushed waste tiles and tile powder in concrete mixtures. All mixes are subjected to workability, ultrasonic, and compressive strength testing after 28 days. In 2015, Aruna et al. Concrete made from tile wastes was made with fly-ash in place of cement, and coarse aggregates were replaced with

20mm smaller, tile wastes with 0%, 5%, 10%, 15%, 20%, and 25%. The average maximum compressive strength of concrete made from roof tile aggregate is reached at a replacement rate of 25%. When 25% of the aggregate from roof tiles is used instead of regular concrete, the strength is reduced by 10% to 25%. The residual concrete made from roof tiles has moderate usefulness. Concrete can be used in place of tiles for straightforward structures.

Batriti & Marwein, (2016) The ceramic debris was made up of broken tiles. Ceramic waste concrete (CWC), created using these tiles, was produced in percentages of 0%, 15%, 20%, 25%, and 30%. All concrete mixtures are created using M20 grade concrete and a constant water-to-cement ratio of 0.48. At 3, 7, and 28 days, concrete's distinctive qualities, including its workability for new concrete and its compressive and split tensile strengths, are found. The study recommends replacing waste tile aggregate by 5–30%, and it is appropriate for popular mixes like M15 and M20.

Canbaz & Topçu. (2010) The waste generated by the tile industry is sufficient to serve as a substitute for rough(coarse) aggregate in the concrete. The environment and the bottom line both gain when leftover ceramic tile is used. By using tile aggregate, the concrete's self-weight is reduced by around 4%, boosting the structure's cost-effectiveness. The compressive and split tensile strengths of concrete are adversely affected when the aggregate is replaced with tile. However, the study concentrated on the largest fragments of tile debris that might be divided into smaller bits and used to produce concrete with ideal properties.

Tavakoli et al. (2013) The usage of ceramic tile in concrete has been researched. Coarse aggregate is used in place of fine aggregate in the range of 0 to 40%. With 10% substitution, slump, water absorption, and unit weight all decrease by 10%, 0.1 percent, and 2.29 percent, respectively, but compressive strength rises by 5.13 percent. On the concentration of industrial ceramic waste, research was conducted in Spain. The concrete was made in accordance with Spanish concrete code, and the recycled ceramic aggregates complied with all technical requirements specified by the appropriate Spanish law (EHE-08). Up to 100% of the coarse aggregate can be replaced with ceramic aggregate. The appropriate experiments were run in order to compare the mechanical properties of the novel concrete to those of conventional concrete. Concrete made with ceramic ware aggregate shares many of the same properties as concrete made with regular gravel.

According to Naveen Prasad et al. (2016), waste crushed tiles were substituted for coarse aggregate at replacement levels of 10%, 20%, 30%, and 40%, and granite powder was substituted for fine aggregate at replacement levels of 10%, 20%, 30%, and 40%. For the standard mix, the M25 concrete grade was developed. By substituting crushed tiles and granite powder at different percentages for coarse and fine aggregates, several mixes were created without changing the mix design. Experiments are employed in research. Concrete became easier to deal with as the amount of granite powder increased. With a 30% substitution of coarse aggregate, the highest compressive strength was discovered.

Parminder & Rakesh Kumar (2015) research on the application of ceramic tiles generated from industrial waste. A partial substitute for coarse aggregate is under investigation. On three distinct grades of concrete, testing has been done. Even though the results contradict conventional wisdom, it is advocated that ceramic tile aggregate be used in concrete because of its strength properties. Ultimately, it was determined that 20% of ceramic tile is the right amount to use in M20 grade concrete.

In 2016, Awoyera investigated the utilization of ceramic tiles in concrete. Ceramic fine and coarse aggregates from construction sites in Ota, Lagos, and Nigeria are substituted for both coarse and fine aggregates in various ratios. By using ceramic fine and coarse particles as a replacement, the strength properties of traditional concrete are investigated. Last but not least, it asserts that employing ceramic waste in place of conventional concrete greatly boosts the concrete's strength.

Rajalakshmi et al. (2016). Utilizing ceramic waste will be a productive step in improving the properties of concrete and protecting the environment. Concrete produced with ceramic wastes rather than aggregates will benefit the environment.

According to Shruthi et al. (2016), ceramic tiles were taken from industries, construction sites, and demolition sites, causing pollution. Using crushed tile as a coarse aggregate in concrete would also be cost-effective. In the study, M20 grade concrete was employed, and ceramic tile waste was substituted for natural coarse aggregate at percentages of 0%, 10%, 20%, and 30%. After being cured for 3, 7, and 28 days, concrete molds' compressive and split tensile strengths were measured. The results show that when utilized as a 30% substitution for ceramic tile aggregate, natural coarse aggregate generates the highest compressive strength.

The Ceramic tiles were allegedly taken from businesses, construction sites, and demolition sites, producing pollution, according to Shruthi et al. (2016). Additionally economical would be the use of crushed tile as the coarse aggregate in concrete. Ceramic tile waste was used in the study as a replacement for natural coarse aggregate at percentages of 0%, 10%, 20%, and 30%. M20 grade concrete was used throughout. Concrete moulds' compressive and split tensile strengths were assessed after curing for 3, 7, and 28 days. The findings indicate that natural coarse aggregate can replace ceramic tile aggregate by 30%. Saswat & Vikas (2016) claim that fine aggregate in stiff pavement has been partially replaced by ceramic and construction waste. They discovered that stiff pavement built of ceramic and demolition waste can save 40% of natural fine aggregate. The compressive strengths of demolition and ceramic debris were also found to be up to 20% greater than those of the reference materials. According to Saswat & Vikas. (2016), fine aggregate in cement concrete can be replaced to the extent of 30% with ceramic waste powder without affecting the concrete's compressive strength. Additionally, they found that, in comparison to regular concrete, just about 1% of the split tensile strength is lost.

In addition, Hemanth et al. (2015) investigated the viability of substituting used ceramic tiles for both coarse and fine aggregate in concrete. 10% and 20%, respectively, of the fine and coarse aggregate in the trial were replaced with waste crushed tiles. They found that broken tiles may only substitute 10% of coarse material. Ceramic tile waste (CWT) as an aggregate in concrete was studied in 2016 by Shruti, et al. In their experiment, M20 grade concrete was used, and waste ceramic tile was substituted for natural coarse aggregate in the concrete at varying percentages (0, 10%, 20%, and 30%). The concrete moulds were cast after cure durations of 3, 7, and 28 days, and their compressive and split tensile strengths were assessed. The findings demonstrate that when ceramic tile aggregate is 30% substituted for natural coarse aggregate, the highest compressive strength is reached.

Topcu & Canbaz (2007). The effects of replacing crushed tile with various amounts of natural aggregate at various percentages (0%, 50%, and 100%) were studied. The tests in terms of mechanics and physics are complete. When compared to control concrete, the strength and weight per unit of concrete with crushed tile aggregate were lower. There was an improvement in the capillary and absorption coefficients comparing to the non-modified concrete Ikponmwosa & Ehikhuenmen. (2017). It was examined how the strength properties of concrete were altered by coarse aggregate derived from ceramic waste. The study, according to the American Journal of Civil Engineering and Architecture, showed that while ceramic waste might be used for both structural and non-structural reasons, it shouldn't be used in concrete projects where achieving high strength is the main objective.

Reddy & Reddy (2007) furthermore shown that using ceramic scrap in place of standard coarse aggregates (10% and 20%) won't affect the structural integrity. The slump of all fresh concrete modified with broken ceramic tiles, according to Adeala & Omisande (2016), ranged from 1mm to 2mm. Mix design ratio of 1:2:4 was adopted, modified concrete has a higher potential than conventional concrete for 28 days compressive strength, as evidenced by the compressive strengths of modified concrete with replacement levels ranging from 5% to 20% being larger than 25N/mm2. Broken ceramic concrete performs similarly to regular concrete and is allowed by law to be between 2300 and 2500 kg/m^3. The amended concrete appears to match the criteria for excellent concrete, with water absorption ranging from 0.89 to 3%, according to the Concrete Society of the United Kingdom. Lastly, in both developing and wealthy nations, recycling broken ceramic waste tiles can replace coarse aggregates in concrete production by up to 20% Adeala & Omisande (2016).

De Brito et al. (2005) looked into the mechanical properties of non-structural concrete made using recycled ceramic aggregates and used for the creation of 50 mm thick pavement slabs. In addition to mechanical properties including compressive strength, flexural strength, and abrasion resistance, the specific density of ceramic aggregate concrete was also evaluated in various fresh concrete tests. The Portuguese factory employed waste ceramic in the study, which was used to create 50 mm thick pavement slabs by crushing the waste ceramic in place of the customary coarse aggregate. The study focused on four different concrete compositions with various replacement proportions of common aggregate, namely 0, 1/3, 2/3, and 3/3 by mass.

Materials and Methods

The materials used in this study were broken waste ceramic tiles recovered during renovation in the Federal Polytechnic Ilaro (Fig.1) and were further broken down into smaller usable sizes using hand held hammer. Some of the broken ceramic tiles were milled fine into powdery form as shown in (Fig.2) using power milling machine.

Broken ceramic tiles were let to pass through a 20 mm to a 150 m sieve as aggregate to replace coarse aggregates, while powdered ceramic tiles were passed through a 75 m sieve (Fig. 3). Cement was also purchased from a Dangote cement retail outlet in Ilaro. Coarse aggregates with a maximum size of 19mm and fine aggregates were purchased in Ilaro, Ogun state. The Federal Polytechnic Ilaro's Material Testing Laboratory supplied portable water. Both coarse and aggregate sizes were subjected to sieve examination. Cement and coarse aggregates were replaced, respectively, with powdery ceramic tiles and crushed ceramic tiles, at 5%, 10%, 15%, 20%, 25%, and 30%. Seventy-two (72) cubes in total were combined with a water cement ratio of 0.4, cast, and cured in water for 7, 14, 21, and 28 days as depicted in Fig. 4, and then crushed.

Figure 1: Broken Ceramic Tiles

Figure 2: Crushed Ceramic Tiles after milling.

Figure 3: Sieved powdery tiles

Figure 4: Mixing and casting of concrete

Table 1 shows batch weights of materials used for the research work. The percentages of the substitutes for both Powdery ceramic tiles (PCT) and broken crushed ceramic tiles (BCCT) were as shown in Table 1.

Table 1: Batch weight of materials in (kg) with 0.4 water-cement ratio

Materials	0%	5%	10%	15%	20%	25%	30%
Cement	11.00	10.45	9.90	9.35	8.80	8.25	7.70
F. A	22.00	22.00	22.00	22.00	22.00	22.00	22.00
C.A	44	41.8	39.6	37.4	35.2	33.00	30.80
PCT	0	0.55	1.10	1.65	2.20	2.75	3.30
BCCT	0	2.20	4.40	6.60	8.80	11.00	13.20

Results

The result of the sieve analysis carried out in accordance to BS 1377 on the coarse aggregates is as depicted in Fig. 5. The Cu of the aggregates lies between 1 and 3 while the finesse moduli are between 2 and 4 for both coarse (conventional and modified) and fine aggregates as shown in fig.5 and fig.6 below.

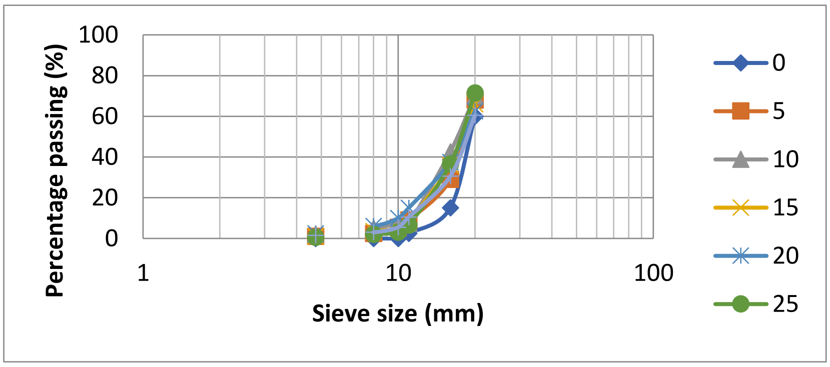

Figure 5: Grading Curves for Conventional and Modified Coarse Aggregates

According to BS 1377, 2: 1990, it was noted that both typical and modified coarse aggregates are adequately graded.

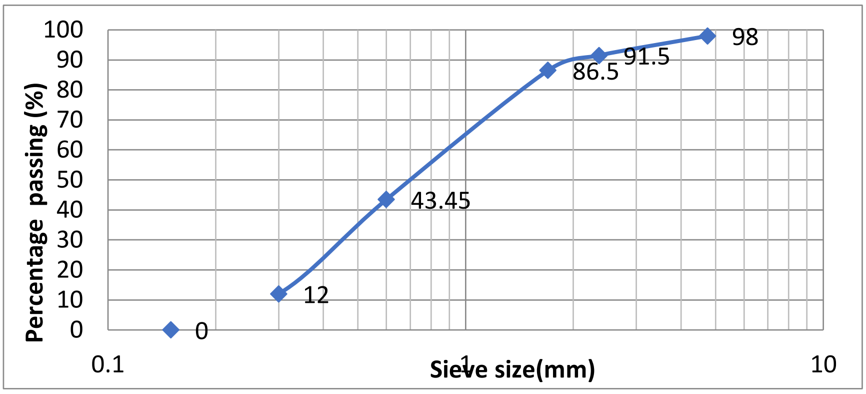

Figure 6: Grading Curve for fine Aggregates

According to BS 1377, 2: 1990, fine aggregates were found to be properly graded.

A. **Unit Specific Gravity**

The ratio of a liquid's unit weight to the weight of water, the reference liquid, is measured by its specific gravity. The fine aggregate's specific gravity was measured to see if it could be used to produce concrete.

Table 2: Unit Specific gravity of cement binder.

Percentage Replacement (%)	Unit Specific gravity
0% powdery ceramic Tiles+ 100% Cement binder	2.430
5% PCT +95% Cement binder	2.350
10% PCT + 90% Cement binder	2.600
15% PCT +85% Cement binder	2.120
20% PCT+80% Cement binder	2.580
25% PCT + 75% Cement binder	2.050
30%PCT +70% Cement binder	3.010

The unit specific gravity of control has value of 2.43, getting to 5% replacement of powdery ceramic tiles it decreased to 2.35,when additional of 5% powdery ceramic tiles was added specific gravity was accelerated to 2.60,on reaching 15% there drawn down to 2.12, 20% substitute there was improve in specific gravity to 2.58, on utilization of 25% substitute of powdery ceramic tiles it beveled down to 2.05 and finally to 30% there was huge differential increase of 0.95 over 25% replacement. It is evident that 10%,20% and 30% substitute of powdery ceramic tiles still have positive influence on the cement.

B. Time of setting of cement paste

Time of initial and final setting of cement paste was carried in accordance to BS 12, 1978.

Table 3: Setting time of cement paste

Sample composition	Time of Initial setting	Time of Final setting
0%powdery ceramic Tiles+ 100% cement binder	110mins	165mins
5% PCT +95% Cement binder	145mins	180mins
10% PCT + 90% Cement binder	157mins	195mins
15% PCT +85% Cement binder	165mins	262mins
20% PCT+80% Cement binder	175mins	268mins
25% PCT + 75% Cement binder	184mins	275mins
30%PCT +70% Cement binder	202mins	285mins

It is satisfactory adequate in accordance with BS 12, because time of initial and final setting fall between 45mins and 10 hours.

C. Workability

Slump is a measure of hold-ability and mixing of fresh concrete. It is carried out in accordance to BS EN 12350-2.

Table 4: **Slump values of fresh concrete**

Percentage (%)	Slump Height (mm)
0	4
5	2
10	5
15	6
20	4
25	6
30	0

Fig.7 below showed that at 0% replacement the slump height was 4mm and decreased to 2mm and at 10% it was accelerated to 5mm then later increased by difference of 1mm at 15%. It was observed that at 20% measured 4mm slump and increased to 6mm at 25% and decreased drastically to 0mm at 30% substitute.

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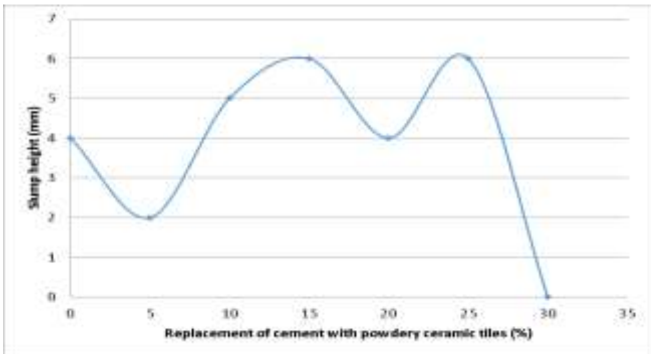

Figure 7: Graph of slump against the concrete replacement.

D. Water Absorption of concrete

Water absorption is quantity of water the concrete specimen takes in after 7,14,21 and 28days. This research paper focused on 28 days and it was carried out in accordance to BS813-2: 1995. At 0%, the water absorption yields 1.09%, which declines to 0.28 at 5%, increases to 0.80 at 10%, decreases to 0.59 at 15%, and then increases slightly to 0.85 at 20%, 0.64 at 25%, and finally 0.85 at 30%. According to the Maritime Code BS 6349, water absorption shouldn't go beyond 3% in critical

situations like exposure to very aggressive chlorides or freeze-thaw conditions. It demonstrates that the modified concrete absorbs less water than the standard concrete, suggesting that it would have fared better in an environment with more water. The water absorption in the specimen is more precisely shown in Fig. 8 below.

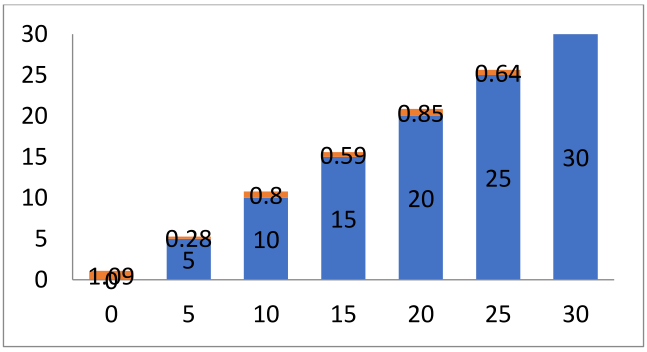

Figure 8: Water absorption test of concrete for 28 days

E. Density of concrete

Density is mass per unit volume and it's measured in Kg/m^3.

Table 6: Density of specimen for 28days

Percentage Replacement (%)	Density (Kg/m^3)
0	2341
5	2311
10	2282
15	2311
20	2252
25	2222
30	2193

The density of conventional concrete falls between 2300 to 2500Kg/m^3. At 0% it was observed that concrete had density of 2341kg/m3 and decreased gradually to 2311kg/m^3 at 5% replacement and 10% reduced to 2282kg/m^3, at 15% increased to 2311kg/m^3 and fell drastically to 2252kg/m^3 at 20% and maintain the tempo reduced to 2222kg/m^3 at 25% then finally slipped down to 2193kg/m^3 at 30%. It can be deduced that concrete 25 and 30% replacement of these substitutes (PCT and BCCT) did not fall within the range of conventional concrete thereby not applicable to normal weight concrete where reinforced concrete will be used.

F. Compressive Strength

Compressive strength was carried in accordance to BS EN 12390-3:2009It was observed that at 28days curing the concrete attained strength of 25.27MPa then at 5% the strength reduced to 22.38MPa and on getting to 10% replacement the concrete developed 21.38 MPa, immediately it reached 15% the strength climbed up to 23.69MPa. At 20% it declined drastically to 19.71MPa, on getting to 25% it dropped to 17.51MPa and finally decreased to 14.82MPa at 30% substitute. All others specimen followed the same trend for 7,14,21days curing days as illustrated in fig.9.

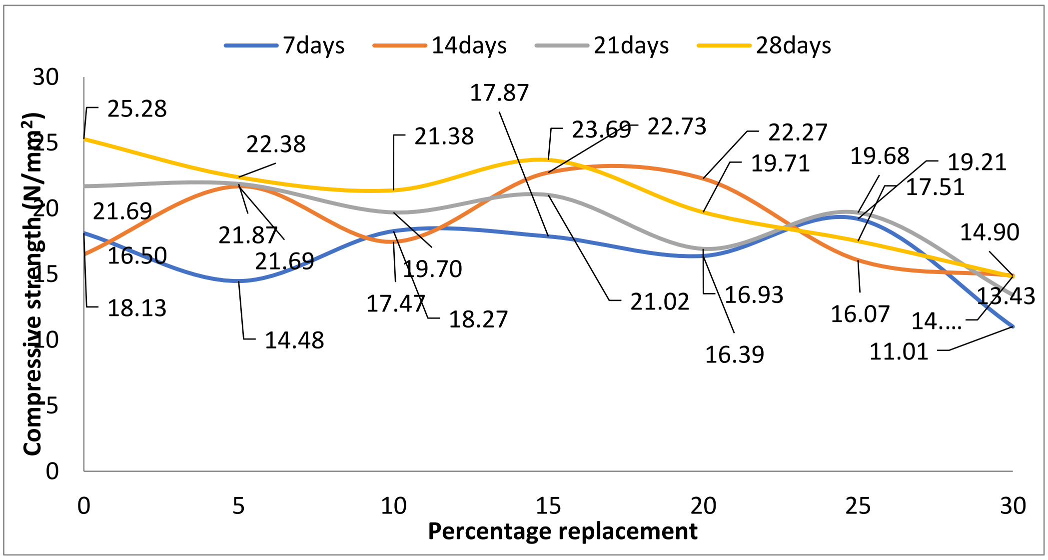

Figure 9: Compressive strength development against percentage substitution.

G. Regression analysis between crushing strength and percentage replacement

The % replacement and the compressive strength have a significant correlation since R^2 = 0. 828.It means there is strong correlation between crushing strength of concrete and percentage replacement.

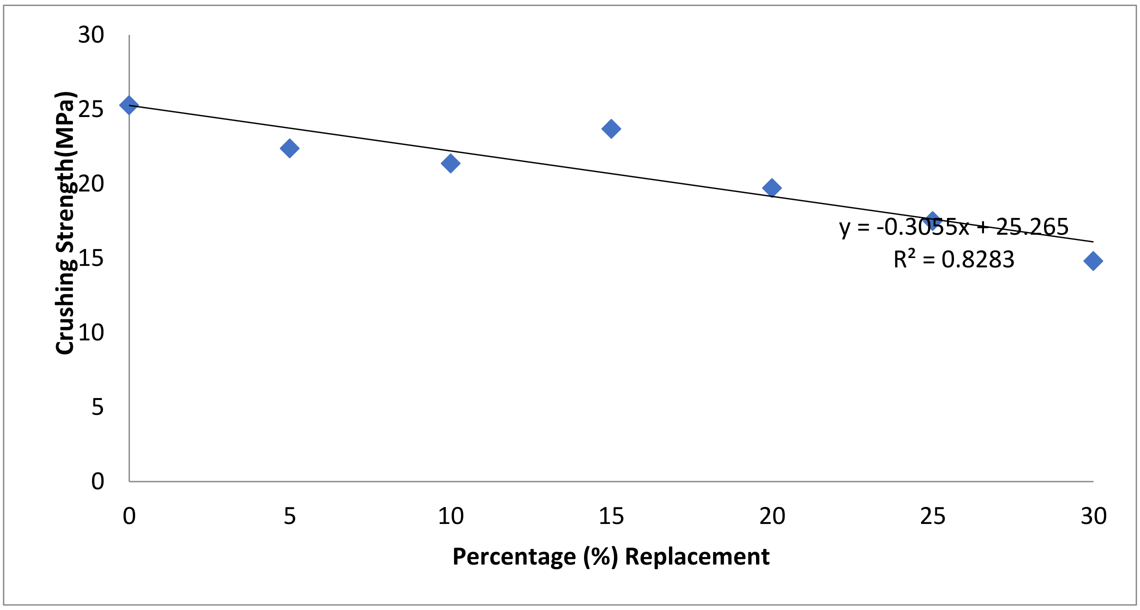

Figure 10: A regression analysis showing the relationship between compressive strength

H. Predictive mathematical model of flexural strength (Bending stress)

The mathematical model of flexural strength, which demonstrated the same trend of strength drop as the compressive strength$f_{ft} = 0.62 f_{ck}^{\frac{1}{2}}$,ACI 318 (2014) indicated that maximum modified concrete strength was achieved at 5% replacement and that strength gradually decreased up to 30% modified concrete. The mathematical expression connecting the compressive strength f_{ck} of concrete to its flexural or bending strength f_{ft} was used to generate the model as shown in fig.11 below. Since flexural strength of concrete with grade 25MPa has its strength from 2.76N/mm^2 to 4.83N/mm^2 and all the replacement of waste ceramic tiles fall within this stipulated range except 30% substitute especially for 28 days flexural strength while the maximum strength of 2.96 N/mm^2 was obtained at 15% for 28days curing.

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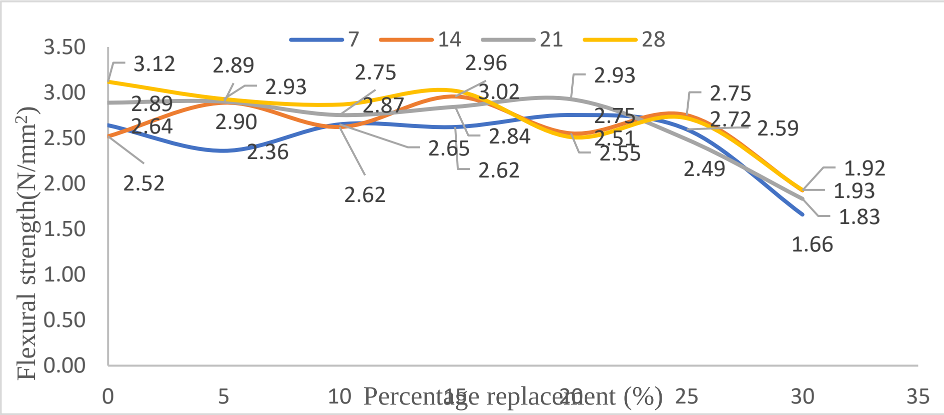

Figure 11: Mathematics Predictive model of Flexural Strength curve

I. Predictive mathematical of strength of spilt test

The split tensile strength test's mathematical model predicted that the strength would fall similarly to how compressive strength and flexural strength did. When 5% of the original concrete was replaced, the modified concrete's strength reached its peak, and it then gradually decreased until it reached 30%. The equation linking compressive strength to spilt tensile strength $f_{st} = 0.56fck^{0.5}$ (ACI 318-99 (2005) used to develop the model. Fig.12 provides an illustration of the description. At 28 days curing the spilt tensile strength were predicted to be 2.82,2.65,2.59,2.73,2.64N/mm^2 at 0%,5%,10%,15%,20% which lied between 2.5N/mm^2 and 3.5N/mm^2 but 25% and 30% strength of concrete predicted or forecast fell below the range as shown in fig.12.

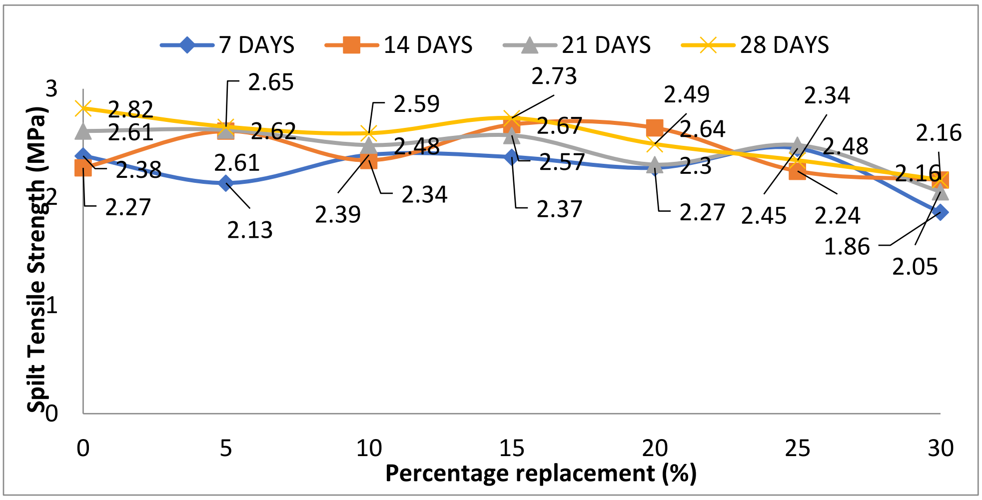

Figure 12: Mathematics Predictive model of Spilt Tensile Strength curve

Conclusion

It was observed that specific gravity of modified concrete with waste ceramic has the lowest and highest specific gravity at 25% and 30% substitute with 2.05 and 3.01 respectively

It was found that setting was satisfactory and adequate in accordance with BS 12, because time of initial and final setting lied between 45mins and 10 hours with its minimum and maximum initial setting time were 1 hour 50minutes and 3 hours 22 minutes respectively and minimum and maximum final setting time were 2 hours 45minutes and 4 hours 45minutes. All fell within 45 mins and 10 hours. Workability of fresh concrete has minimum slump of 0 at 30% and maximum slump of 6mm at 25%.

Control at 28 days Water absorption has highest value of 1.09%. Modified concrete has the lowest water absorption of 0.28% at 28 days and 0.85% at the same curing days

It was found that using finely crushed ceramic tiles for 28 days in place of cement and coarse aggregates in the manufacturing of normal weight concrete can substitute for 15% of the cement and coarse aggregates, respectively. The percentage substitution of powdered ceramic tiles (PCT) and broken crushed ceramic tiles (BCCT) showed a substantial correlation with compressive strength, it was also discovered. Its density at 15% was 2311Kg/m^3 which fall within the range of 2300 to 2500Kg/m^3 of conventional concrete. Predictive model was used to predict behavior of concrete when subjected to flexure (flexural strength) and split tensile strength which both lied within specified range.

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