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Structural Behaviour of Crushed Fine Ceramic Tiles as Partial Substitute of Fine Aggregates In the Production of Concrete

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Abstract:- Ceramic tiles waste is generated from construction sites or factories where they are being manufactured. In the present construction world, the solid waste is increasing day by day from the demolitions of construction. Ceramic products are part of the essential construction materials used in most buildings. Construction industry can handle most of the ceramic waste produced from anthropogenic activities as well reduce rate utilization of quarried natural resources. Ceramic floor tiles collected from different location was dried, crushed and ground by mechanical grinding machine. The waste generated after grinding was passed through sieve size of 4. 75 mm. Particle size distributions was carried out on both fine and coarse aggregate in accordance to (BS 1377-2:1990), Workability test was also carried out on concrete. Specific gravity was carried out on cement, fine aggregate and cement. Concrete cubes were cast for each replacement (0%, 5%, 10%, 15% and 20%) with water cement ratio (W/C) of 0.5 and they were cured for 7, 14 and 28 respectively. Water absorption and consistency test were carried out on conventional and modified concrete .The result showed that Particle size distributions of the aggregates were well graded. The modified concrete exhibit true slumps. Specific gravity of cement, fine aggregate and crushed ceramic tile are 2.63, 2.65and 2.50 respectively. It was observed that 10% at 0.5w/c of replacement has higher water absorption rate of 1.14% and 5% at 0.5w/c of replacement has lower water absorption rate 0.88%. The compressive strength at 28days for modified concrete (5% and 10% replacement) with w/c of 0.5 were 27.33 N/mm^2 and 25.58 N/mm^2 compared to control (25 N/mm^2) at 28days.The study concluded that the modified concrete at 28days, having water-cement ratio of 0.5 at 5% and 10% crushed ceramic tile replacement have properties as a normal weight concrete.

Keywords:- *Ceramic tiles, Compressive Strength, Particle size distribution, Specific gravity, Water absorption*

I. INTRODUCTION

Concrete is a composite material and is mainly composed of aggregate, cement and water which are mixed in a particular proportion to get an actual strength. The contribution of Portland cement production worldwide to the greenhouse gas emission is estimated to be about 1.35billion tons annually or about 7% of the total greenhouse gas emissions to the earth's atmosphere [17].Concrete has a low coefficient of thermal expansion and its maturity leads to shrinkage. The first distinction between high-strength concrete and nominal-strength concrete refers to the relation of utmost resistance offered by compressive strength of the concrete sample for the application of any type of load. Though there is no correct separation between high-strength concrete and normal-strength concrete[4] demonstrated that 40 MPa (6,000 psi) high performance concrete for bridges could be economically made while increases gradients that will occur in a concrete placement can be predicted by procedures that provide data for this purpose.However, the composition of concrete may be changed to give desirable or achievable properties. In the present construction world, the solid waste is increasing day by day from the demolition of constructions as shown in figure 1 below. There is a huge usage of ceramic tiles in the present constructions is going on and it is increasing in day by day construction field.

Fig 1:- demolition of building with ceramic tiles (source: dreamstime.com)

Ceramic products are part of the essential construction materials used in most buildings. Some common manufactured ceramics include wall tiles, floor tiles, sanitary ware, household ceramics and technical ceramics. The need to sustain human development by using natural resources should also correspond to protection of natural environment in order to sustain its use in the present and future generation. The use of alternative materials from discarded waste or recycled material is propelled toward the fulfilment and reality of this need. Construction industries can handle most of the ceramic waste produced from originated activities as well reduce rate of utilization of quarried natural resources. Use of ceramic waste in concrete is not only economical but also it solves disposal issues. Ceramic waste can be divided in to two different categories which may vary in accordance with the sources of the raw materials. According to Torgal and Jalali (2018) the first one are all fired wastes generated by the structural ceramic factories that use only red pastes to manufacture their products, such as brick, blocks and roof tiles. The second one is all fired waste produced in stoneware ceramic such as wall, floor tiles and sanitary ware. These producers use red and white pastes; nevertheless, the usage of white paste is more frequent and much higher in volume. In each category the fired ceramic waste was classified according to the production process. This classification is as indicated in Figure 2 below

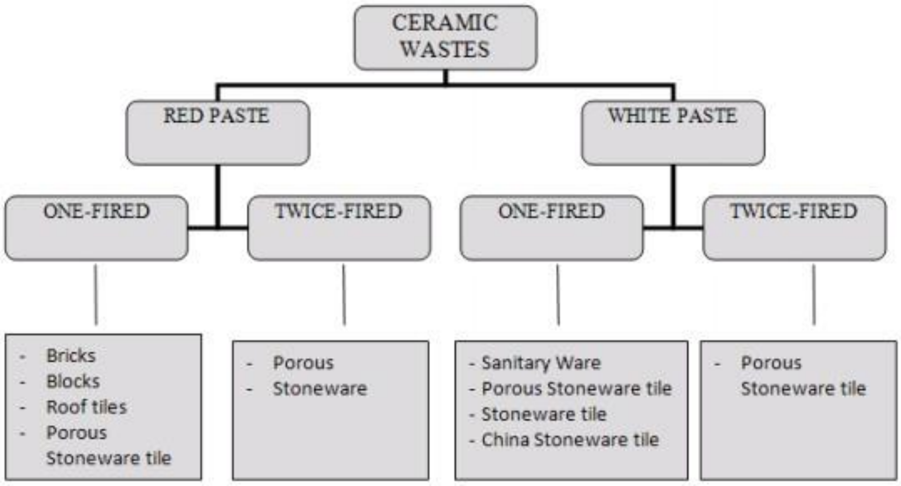

Fig 2:- Classification of ceramic waste by type and production process (Source : Torgal and Jalali, 2018).

[20] carried out "Experimental Study on Partial Replacement of Sand by Ceramic Waste in Concrete" said clearly that the ceramic waste can be used as replacement materials for river sand in concrete and it was observed that 10% and 20% replacement of ceramic waste satisfies the condition of M25 grade concrete and higher percentage of replacement beyond 20% reduced the strength of modified concrete. The tensile strength of 10, 20, 30% replacements at 14 days shows the consistency in attaining the required range of strength.[20], "A Study on Ceramic Waste Powder" The study showed that the addition of the industrial wastes improves the physical and mechanical properties. The Compressive Strength of M40 grade concrete increases when the replacement of cement with ceramic waste is up to 10% by weight of cement, and further replacement of cement with ceramic powder decreases the compressive strength.[3] carried out study on broken tiles at 0%, 15%, 20%, 25% and 30%. M20 grade concrete was adopted with water cement ratio of 0.48 is maintained for all the concrete mixes. The characteristics properties of concrete such as workability for fresh concrete. Compressive Strength and Split tensile Strength are found at 3, 7 and 28 days. The study suggested that the replacement of waste tile aggregate should be in the range of 5-30% and also it is suitable for ordinary mixes like M15 and M20. [18] used crushed waste tiles and Granite powder were used as a replacement to the coarse aggregates and fine aggregate. The combination of waste crushed tiles were replaced coarse aggregates by 10%, 20%, 30% and 40% and Granite powder was replaced fine aggregate by 10%, 20%, 30% and 40% without changing the mix design. M25 grade of concrete was designed to prepare the conventional mix. Without changing the mix design different types of mixes were prepared by replacing the coarse aggregates and fine aggregate at different percentages of crushed tiles and granite powder. The workability of concrete increased with increase in granite powder and it has been observed that the compressive strength is maximum at 30% of coarse aggregate replacement.[4] used crushed ceramic waste and pumice stone as a partial substitute for fine aggregates in the production of mortar and concrete, finding that the resultant product showed good compressive strength and abrasion resistance, together with less penetration by chlorides which could provide greater protection for the reinforcement used in reinforced concrete[1]. carried out experimental study on manually crushed and well burnt clay bricks as coarse aggregates and tested four grades of concrete made with crushed brick as aggregate to determine their physical and mechanical properties. The normal compressive strength ranged from 13.8 to 34.5 N/mm^2. [2] carried out experiment on tile waste based concrete, coarse aggregates were replaced by 20mm down size, tile wastes by 0% , 5%, 10%, 15%, 20% and 25% and also the cement is partially replaced by fly-ash. It was discovered that average maximum compressive strength

of roof tile aggregate concrete was obtained at a replacement of 25%. A reduction of 10-15% of strength was observed compared to conventional concrete at 25% of roof tile aggregate replacement. The workability of roof tile waste concrete was in the range of medium. The replacement of tiles in concrete is satisfactory for light constructions. [16] said the amount of tile waste generation is enough to use in concrete as a replacement to coarse aggregate. The use of ceramic tile waste has a positive effect on environment and cost implication. The intended use of tile aggregate, the self-weight of concrete is reduced about 4% which makes the structure to be safe and economical. Pertaining to the strength aspect, the tile aggregate replacement has a negative effect on both the compressive and split tensile strength of concrete if it used in larger percentage and the study focused on maximum replacements of tile waste which can be further divided into smaller percentages and can be utilized in concrete with desirable properties. [21] In this study, Ceramic tile waste were used in concrete as a replacement for natural coarse aggregate with 0%, 10%, 20% and 30% of the substitution and M20 grade concrete were used. The concrete moulds were casted and tested for Compressive Strength and Split Tensile Strength after a curing period of 3, 7 & 28 days. The results indicate that the maximum compressive strength was obtained for the 30% replacement of ceramic tile aggregate with natural coarse aggregate.

II. MATERIALS AND METHODS

This project work involved both Field and laboratory work. The Field work required sourcing for aggregates (Sharp sand and granite) and waste ceramic tiles. The laboratory experiments were carried out in Civil Engineering Concrete Laboratory Federal Polytechnic Ilaro, Ogun State, Nigeria.Waste ceramic tiles obtained from building demolition sites and left-overs from new building sites in Ilaro town, Ogun state were broken by hammer as shown in Figure 3 below then washed and dried and grinded to 4mm sizes particle at the grinding mill..It was later sieved through 4.75mm microns and then replaced by percentage dosage of 5, 10 , 15 and 20% weight of fine aggregates (sand).

Fig 3:- Ceramic tiles cushed by hammer.

Ordinary Portland Cement (OPC) was obtained from Dangote cement company, Ogun state, Nigeria with properties conforming to [7 & 8]. The fine and coarse aggregates were obtained from constructions site in Ilaro, and was allowed to pass through 4.75 microns and 19/20mmm sieve size respectively. Portable water was used for both mixing and curing. The concrete mix design of 1:2:4 and water cement ratio of 0.5 for control and other mixes. The fresh concrete was cast in mould for purpose of testing and curing. Concrete cubes were cured and compressive were carried out on cured cubes at 7, 14 and 28 days. Also 28 days water absorption tests were carried on concrete cube [13]. Cube (150mmx150mmx150mm) were tested for engineering properties in accordance to British standard. Batch weights of materials are shown in Table 1 below.

Materials	**0%**	**5%**	**10%**	**15%**	**20%**
Cement	11	11	11	11	11
F.A	22	20.9	19.8	18.7	17.6
C.A	44	44	44	44	44
CCT	0	1.1	2.2	3.3	4.4
Water	5.5	5.5	5.5	5.5	5.5

Table 1:- Batch weight of materials in (Kg) with 0.5 water-cement ratio

III. RESULTS AND DISCUSSIONS

A. Particle Size distribution of aggregates

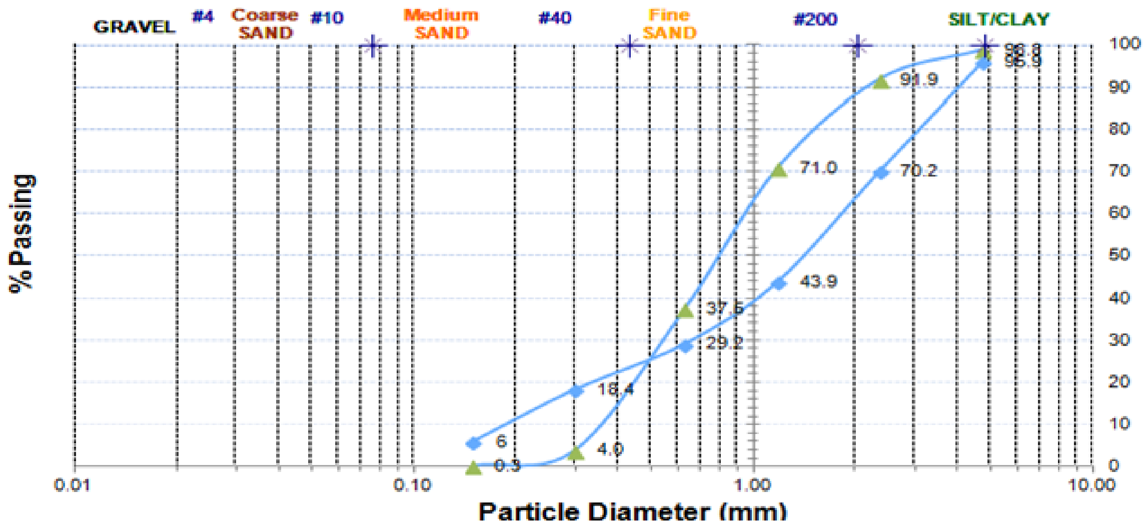

Fig 4:- Particle Size distribution curves for fine aggregates and crushed ceramic tiles.

From the above curves for fine aggregates and crushed ceramic tiles

Co-efficient of uniformity (C_U) is given as $\frac{D_{60}}{D_{10}}$ = 2.64

Co-efficient of curvature (C_Z) is given as $\frac{D_{30}^2}{D_{60}D_{10}}$ = 0.82

For fine aggregates (sand)

Co-efficient of uniformity (C_U) is given as $\frac{D_{60}}{D_{10}}$ = 9.47

Co-efficient of curvature (C_Z) is given as $\frac{D_{30}^2}{D_{60}D_{10}}$ = 1.31

Since, C_Z for both aggregates lies between 1 and 3 so it well graded and C_U for fine aggregates is less than 4 and greater than 4 for crushed ceramic tiles which is also opened well and closed well graded respectively in accordance to BS 1377-2: 1990.Finess modulus of fine aggregates is 3.96 and crushed ceramic tiles is 4.36 which means fall between 3.6 and 6.9 which is good for concrete work.

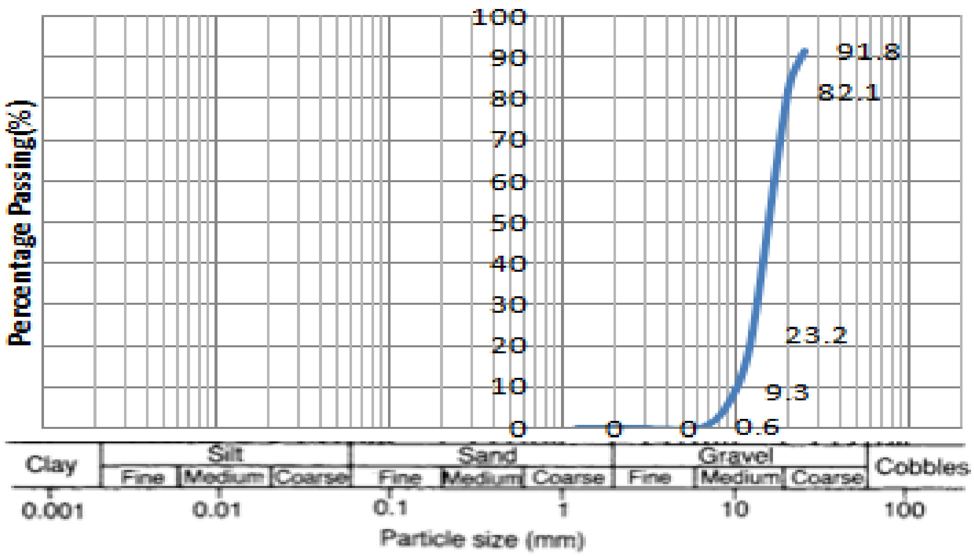

Fig 5:- Particle size distribution of coarse aggregates.

C_u and C_z for coarse aggregates are 1.06 for each which is opened well graded and has finess modulus of 3.9 which also falls between 3.6 and 6.5 which is good for concrete work and the higher the finess modulus the more coaser the aggreagate will be.

B. Specific gravity

Specific gravity was carried out on materials and result was presented in Table 2 below

Specific gravity = Mass of substance/Mass of water

Specific gravity was carried out in accordance to [9]

Materials	Specific gravity
Cement	2.63
Crushed Ceramic Tiles	2.50
Fine aggregate	2.65

Table 2:- Specific gravity of materials.

It was observed that specific gravity of cement was 2.63 compare to 3.15 for conventional cement then specific gravity for both crushed fine ceramic tiles(CFCT) and fine aggregates (FA) i.e sand were 2.50 and 2.65 respectively. Comparing specific gravity of CCT and FA , it can be deduced that sand is more denser than CCT which means the weight density of concrete produced by CCT will be little lighter than concrete produced by sharp sand by ratio 1: 1.06 that is the weight density of CCT concrete will be 94,3% of the weight density of conventional concrete.

C. Workability

It is the property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished' (ACI, 1990).Workability was carried out on both fresh concrete was carried by slump method in accordance [10] and the result is presented in figure 5 below

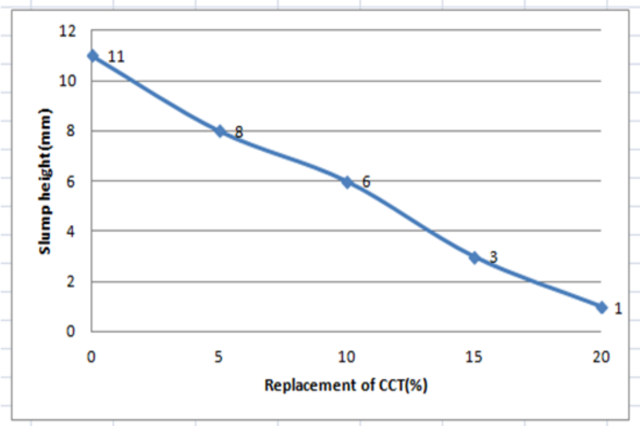

Fig 6:- Slump height against percentage replacement of CFCT.

From fig.5 above, it was observed that the conventional concrete produced 11mm slump height, on proceeding to 5% replacement of CCT the slump gradually reduced to 8mm, on getting to 10% height of slump dropped to 6mm and on replacing 15% of CCT with sharp sand the height drastically reduced to 3mm and substituting with 20% the slump reduced abruptly to 1mm.All these slump calibrated were classified as true slump which falls within the range of 0 and 50mm. As the CCT increases the slump height also reduces which the amount water im the concrete matrix decreases though the concrete can be easily be handled and placed.

D. Standard Consistency

Standard consistency test was carried out on cement in accordance to [6].The result obtained is presented in table 3 below

Vicat apparatus	Cement
Needle penetration	5
Needle with collar	6
Needle without collar	5

Table 3:- Standard consistency of cement

It can be deduced from table 3 above, that needle penetration was between 5 to 7mm which is satisfactory in accordance to [6].

E. Setting time of cement paste.

This is a measure of initial and final setting time of cement paste and was carried ot in accordance to [6].The initial and final setting time of cement paste used in this research study was presented in table 4 below.

Sample	Initial setting time	Final setting time
Cement	1hour 30mins	2hours 45mins

Table 4:- Standard Consistency for cement paste.

From table 4 above it was observed that the initial setting time and final setting time of cement were 1 hour 30mins and 2 hours 45 mins respectively which is satisfactory in accordance to [6] which states that the minimum initial setting time for cement paste is 45mins and maximum final setting time is 10 hours.

F. Density

The weight of each concrete cubes were obtained prior to testing to ascertain the density. This was done in accordance with [11].

Density = Mass/Volume.
The result was presented in table 5 below

W/C	**CFCT REPLACEMENT %**	**WEIGH (Kg)**	**DENSITY (Kg/m^3)**
0.5	0	8.388	2,486
	5	8.244	2,442
	10	8.097	2,399
	15	8.227	2,437
	20	8.124	2,407

Table 5:- Density of CFCTC concrete at 28days

Referring to table 5 above, the density of control specimen was 2486kg/m^3 and at 5% CCT replacement, it decreased to 2442 kg/m^3 and later proceeding to 10% substitute of sharp sand with CCT it reduced to 2399 and getting 15% the density increased to 2437 and which later dropped to 2407 kg/m^3 at 20% replacement..It was observed that density falls within the range of 2300 to 2500 kg/m^3 which fall within the range of density of conventional concrete. In term of density, CFCTC has stinking similar characteristic of conventional concrete.

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G. Water Absorption

The weight of the cubes were weigh after demoulding and also 28 days curing in water in order to ascertain water absorption and which was carried in accordance with [14].

Water absorption rate = (Final weight of cubes after curing - Initial weight of cubes before curing) / Initial weight of cubes before curing.

W/C	REPLACEMENT	WEIGHT BEFORE (g)	WEIGHT AFTER (g)	WATER ABSORPTION (%)
0.5	0%	8287.17	8388.66	1.22
	5%	8172	8244	0.88
	10%	8006.33	8097.33	1.14
	15%	8137.33	8227	1.10
	20%	8051	8123.66	0.90

Table 6:- Water absorption at 28 days

The concrete cubes at 28days curing were weighed after demoulding. It was observed that the 0% crushed ceramic tiles has water absorption of 1.22% and that 5% level of replacement the concrete cube has water absorption rate of 0.84% while 10% has 1.14%, 15% and 20% has water absorption of 1.10% and 0.90 % respectively. It was shown that increase in CCT led to decrease in water absorption of concrete as shown in Table 7. The water absorption for all concrete cubes were all good according to concrete Society, United Kingdom, concrete quality is classified as good if the saturated water absorption is between 0.89% and 3%. In conclusion, the replacement levels from 5 to 20% of concrete with CFCT were all good.

H. Compressive Strength

The cubes were cured in water for 7days, 14 days and 28 days. The compressive strength was carried on 150mm x150mm cubes after days of curing in accordance with [12].

Compressive strength = Compressive Force/ Cross section Area (N/mm^2 or MPa)

Curing days	PERCENTAGE REPLACEMENT (%)				
	0	5	10	15	20
7	20.96	15.25	18.19	17.71	11.52
14	22.03	15.66	19.77	18.7	15.01
28	25	27.33	25.58	22.18	18.26

Table 7:- Curing days of CCTC with compressive strength development.

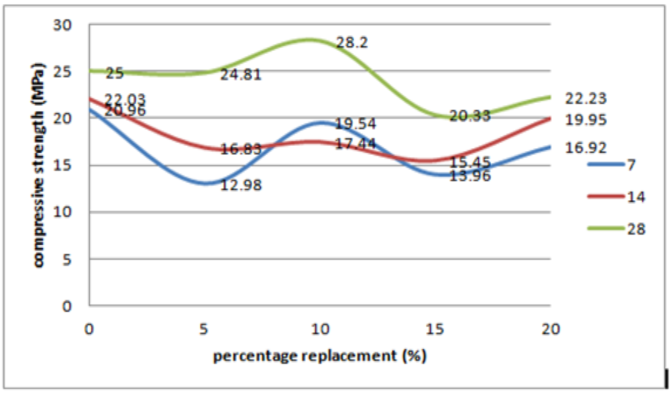

Fig 7:- Curing days with compressive strength development.

The compressive strength at 28 days for convectional concrete is 25MPa. For the modified concrete, at 5% replacement, it decreases to 24.81MPa. Proceeding to 10% it increased to 28.20MPa, on getting to 15% substitute it decreased to 20.33MPa. At 20%, it gain strength to 22.23MPa. It can be deduced from above explanation that the modified concrete attained optimum strength at 10% replacement which means to get maximum strength of 28.20Mpa 10 % of CCT must be substituted for 10% sharp sand in matrix of concrete.

I. Mathematical Model of Flexural Strength

The flexural strength is expressed as Modulus of Rupture (MR) in(N/mm^2) or (MPa) and is determined by standard test methods third-point loading (ASTM C 78) or centre-point loading (ASTM C 293).

Mathematical model was developed for flexural strength at 7, 14 and 28 days using the relationship between compressive strength (F_{ck}) and flexural strength (F_{st})

$F_{st} = 0.7\sqrt{F_{ck}}$

The result was presented in table 8 below

PERCENTAGE REPLACEMENT (%)	NO. OF DAYS		
	7DAYS	14DAYS	28DAYS
0	3.2	3.29	3.5
5	2.52	2.87	3.49
10	3.09	2.92	3.72
15	2.62	2.75	3.16
20	2.88	3.13	3.3

Table 8:- Mathematical model of flexural strength

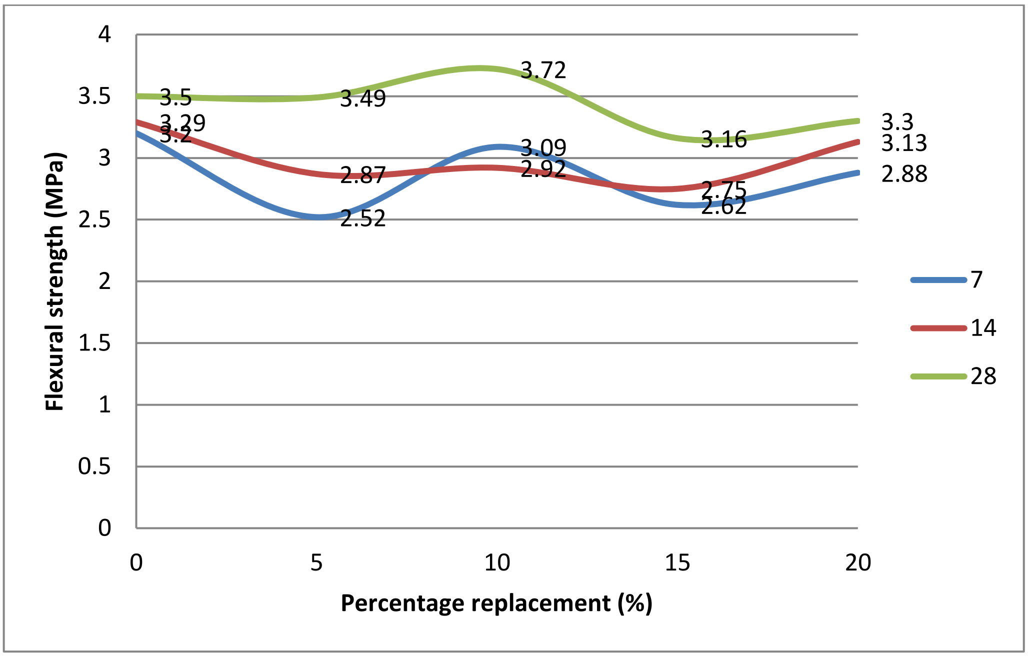

Fig 8:- Flexural Strength against percentage replacement of CFCT

From figure 8 above, The flexural strength at 28 days for convectional concrete is 3.5MPa and at 5% replacement of CCT, it decreased to 3.49MPa. At 10%, it increased to 3.72MPa. At 15%, it decreased to 3.16MP and at 20%, it increased to 3.3MPa. It can be deduced that the modified concrete attained optimum strength at 10% replacement of CCT with sharp sand in concrete matrix.

J. Statistical Modelling of compressive strength at 28 days

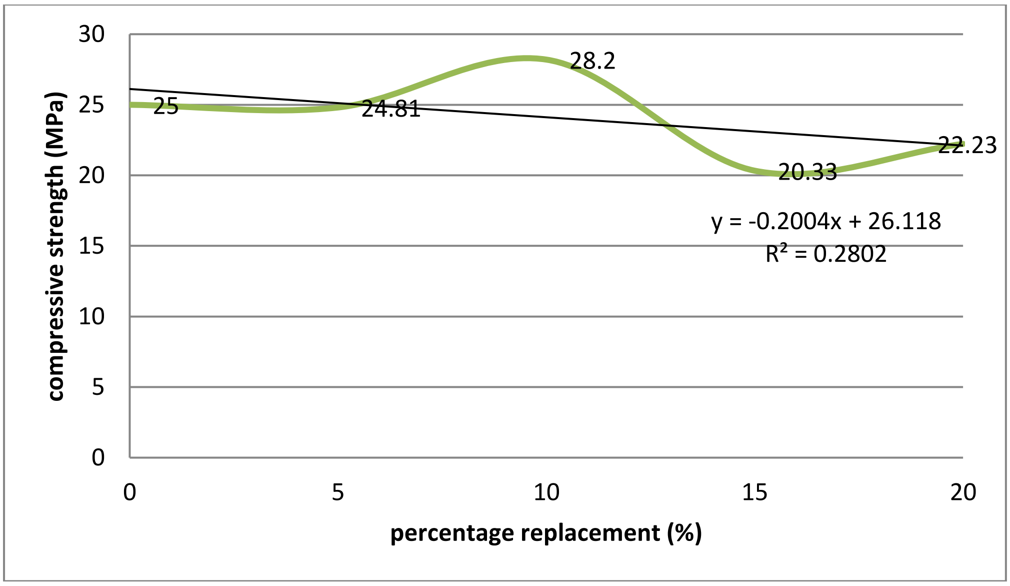

Fig 9:- Regression analysis showing relationship between compressive strength and percentage replacement of CFCT.

Regression analysis showing relationship between compressive strength and percentage replacement of CCT in concrete matrix showed that there is poor correlation between compressive strength of modified concrete and replacement level of CCT in composition of concrete with $R^2 = 0.2802$.

To produce strength of 25MPa, the percentage level of CCT that can be used to replace sharp sand (fine aggregates) can be determined from regression equation Fct = -0.2004x + 26.118. Assuming target strength to be 25Mpa.

$25 = -0.2004x + 26.118$
X = 5.6% of CCT can replace fine aggregates to produce compressive strength of 25MPa of 1: 2: 4 mix.

IV. CONCLUSIONS

The experimental study showed that there is striking similarities with conventional concrete. The CCTC posses true slump, the densities of CCTC varies from 2300 to 2500 kg/m3 which has the same density similar to conventional concrete. Water absorption of modified concrete varies from 0.88 to 1.14 which classified as good.10% substitute of CCT in concrete matrix produced maximum strength of 28.2MPa as seen in fig.8 i.e CCT can be substituted for sharp sand up to 10% in concrete production.

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