EXPERIMENTAL INVESTIGATION OF TENSILE AND FLEXURAL STRENGTH OF CERAMIC WASTE CONCRETE

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ABSTRACT: Different types of ceramics products are available in the market, which are being used for a wide variety of applications. Bricks, tiles, sanitary wares, sewer-pipes, pottery etc. are the common examples of ceramic products. The wastes generated from different products have constituted a serious adverse environmental impact in the societies. Therefore, use of ceramic waste as partially replacement material of any of constituents of the concrete, will not only control the product waste tactfully but will also economize concrete manufacturing cost. Moreover depleting sources of sand in Pakistan triggered the dire need of replacement of fine aggregate of the concrete. Experiment research was conducted to investigate the effect on compressive, tensile and flexural strength of concrete with the use of industrial ceramic waste as a partial replacement of fine aggregate in the concrete at the age of 28 days. Four types of concrete mixtures were tested in this research i.e. CC-0, CC-10, CC-15, and CC-20, where CC-0 stands for Reference Concrete and CC-10, CC-15 & CC-20 stand for concretes having 10%, 15% & 20% ceramic waste as sand replacement material respectively. Tests for compressive strength, modulus of rupture, split cylinder and double punch were performed. It revealed that the concrete produced with ceramic waste has more tensile strength, flexural strength and compressive strength when compared with reference concrete, which explicitly opened a door to use of industrial ceramic waste in concrete production.

Key words: Industrial ceramic waste, cement, compressive strength, flexural strength, splitting tensile strength, double punch tensile strength.

INTRODUCTION

Concrete is a combination of binding material which could be cement, mud, fly ash etc. and some ballast which could be natural or crushed gravel, or sand. With the passage of time, we are coming across a horrible situation that the concrete demand to meet the ever increasing construction projects is increasing day by day, resultantly, the amount of raw materials from natural resources are being consumed rapidly. Therefore, there is a dire need to explore other ways and sources of the replacement of the concrete constituents (Ahmed, 2011).

Experimental study showed that 25% replacement of cement by volume with silt and clay with water: cement ratio of 0.5 can develop durable concrete. Cement Replacement Materials (CRM) possess nature of pozzolanic material which can improve the characteristics of concrete. There are so many CRMs available in the market which may economize the concrete products e.g. Fly ash, Stone dust, Rice husk ash, Wheat straw ash, Brick powder etc. (Gabel and Tillman, 2005).

Pacheco and Jalali (2010) described that only in Europe amount of ceramic waste is touching 3 to 7 % of the global production. This ceramic waste in millions of tones has been using only for the landfill purpose. Therefore there is drastic need for the ceramic industry to explore the other ways and resources to use this ceramic waste. Though practice of reuse of ceramic waste is going on but this reuse amount is very negligible as compared to the annual production of the ceramic waste. It is only construction industry which can be considered as an end user of ceramic waste to resolve this issue. Without entering in dramatic change in application process, ceramic waste material can be used in construction industry. In such a way not only the cost to land fill with ceramic waste will reduce but also natural resources and raw materials will also be substituted ensuring a green environment. It would not be out of place to say that usage of ceramic waste as building materials render the construction industry more sustainable.

Nuran and MevluÈt (2000) made experimental investigation for the use of waste ceramic tiles as pozzolan. Pozzolonas do not present good binding properties when they are used alone. Scrap of waste glazed ceramic tiles has been used in this study. 25%, 30%, 35%, and 40% of waste ceramic tile was added into Ordinary Portland Cement by weight to check pozzolanic, chemical and physical properties of the cement. Test samples having 25%, 30%, and 35% ceramic tile waste showed sufficient strength whereas test sample having 40% ceramic tile waste showed good strength corresponding to 7 days but showed failure against 28 days strength. Addition of ceramic tile waste to the OPC found acceptable up to 35%.

Vejmelkova et al. (2012) studied properties of high performance concrete using finely ground ceramic waste as an Ordinary Portland Cement replacement material up to 60% of mass. For experimental investigation five types of the concrete were produced i.e. one reference mix concrete denoted by 'CR' and three ceramic mix concretes denoted by 'CB'. In ceramic concretes, Ordinary Portland Cement was substituted with the finely ground ceramic waste by 10%, 20% , 40% and 60% in weight to form four types of ceramic concrete CB-10, CB-20, CB-40 and CC-60 accordingly. The compressive strength tests after 7 and 28 days were performed in the laboratory on different concrete samples. The compressive strength results are summarized in the Table-1.

Table-1: Compressive strength (MPa) from Vejmelkova E. et al. (2012)

Material	7 days	28 days
CR	63.3	62.0
CB-10	65.2	65.7
CB-20	47.8	60.2
CB-40	37.9	42.6
CB-60	21.3	22.5

So it was found that very finely ground ceramic waste can be safely recommended to be used as supplementary cementitious material for the fabrication of high performance concrete.

Masahiro Suzuki et al. (2009) focused on early age cracking in High Performance Concrete (HPC). Ordinary Portland cement (OPC) with 10 silica fume (SF) were used in the experiments. Porous Ceramic Coarse Aggregate (PCCA) was used as an internal water curing system. Two control mixtures and four mixtures having PCCA were prepared. Coarse aggregate were partially replaced by PCCA with four proportions i.e. 10 %, 20 %, 30 % and 40 % by volume. Tests for compressive strength were performed after 1, 3, 7 and 28 days. The obtained compressive strength after 28 days are shown in the Figure-1.

It can be observed that by the addition of PCCA, there has been no significant improvement in the compressive strength of the concrete from 1 to 3 days. The positive effect of addition of PCCA resulted after 28 days.

Pincha Torkittikul et al. (2010) experimentally investigated the feasibility of utilization of ceramic waste and fly ash to cast concrete. Lignite fly ash has been used in this study as cement supplementary material at 30% by weight. The results of compressive strength of concrete at the age of 7 and 28 days are obtained and drawn in the Figure-2.

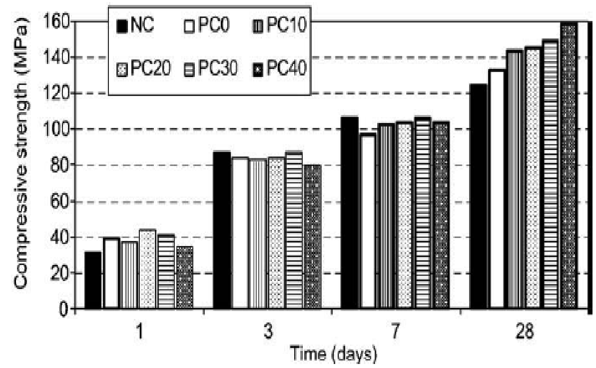

Figure-1: Effect of the addition of the PCCA on compressive strength from "Masahiro Suzuki et al. (2009)"

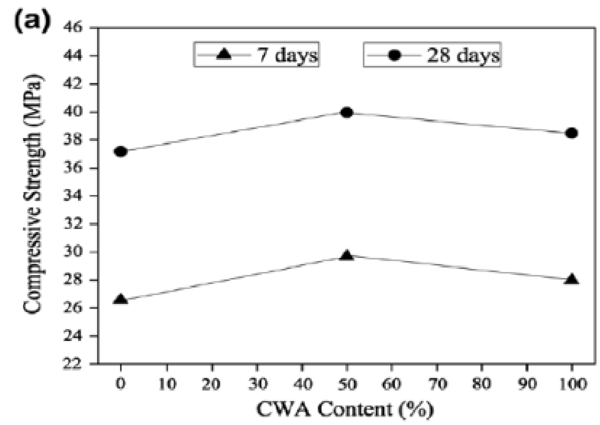

Figure-2: The effect of CWA replacement on Compressive strength of concrete from "Pincha Torkittikul et al. (2010)"

From the graph it can be assessed that at the age of 7 days maximum strength was achieved equal to 29.5 MPa using CWA content at 50 %.

Senthamarai and Devadas (2005) focused on the usage of industrial ceramic waste as replacement of natural coarse aggregate. Experiments made in this study include compressive, splitting tensile and flexural strengths of the concrete made with the ceramic coarse aggregate. After the execution of the tests it was found that compressive strength of the concrete varied from 51 to 30 MPa. The splitting tensile strength of concrete varied from 4.5 to 3.2 MPa. The splitting tensile strength of ceramic concrete was found less than that of the conventional concrete. The ratio of tensile to compressive strength was also calculated and found lower for ceramic concrete when compared to the conventional concrete. The flexural strength was also calculated and observed that it varied from 6.9 to 4.7 MPa.

MATERIALS AND METHODOLOGY

For experimental investigation four types of the concrete were fabricated and tested i.e. one Reference Concrete and three Ceramic Waste Concretes. In Ceramic Waste Concretes, fine aggregate was replaced with the fine ceramic aggregate by 10%, 15% and 20% by weight to prepare three types of concretes CC-10, CC-15 and CC-20 respectively. Reference Concrete was prepared as yard stick to compare the results of other mixtures of Ceramic Waste Concrete. After casting the concrete specimens, these were cured for 28 days. Subsequently tests were performed to determine compressive strength (ASTM C39), tensile strength (ASTM C 496) and flexural strength (ASTM C 78-02) of the specimens to arrive at a conclusion.

Cement: In this experimental study ASTM Type I normal Portland cement (PC 42.5 MPa) with a specific gravity of 3180 kg/m3 has been used as a binding material having brand "Pioneer". Following main tests were performed amongst others to ensure whether the cement was meeting with the required standards or otherwise.

- Consistency of cement paste
- Setting Time (Initial and final setting time)
- Fineness of cement

Initial and final Vicat setting times of the cement were 140 and 215 min, respectively. Fineness of cement was 86.6%.

Aggregate: For coarse aggregate dry & clean Margala Crush was used having size 12.5 mm down. For fine aggregate Lawrencepur sand has been used in this research. Sieve analysis results of fine aggregate (Lawrencepur sand) having FM 2.54 and coarse aggregate (Margala Crush) having FM 8.16 is presented in Figure-3 & 4.

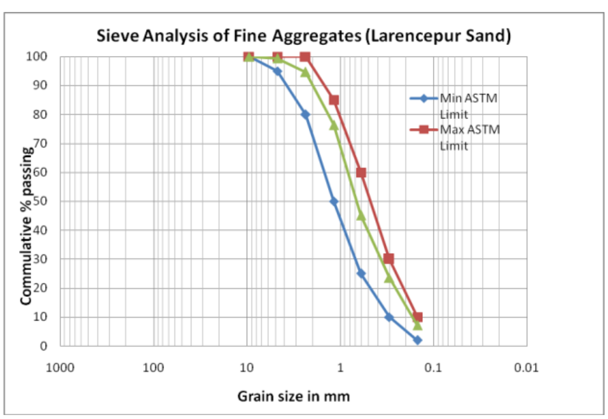

Figure-3: Grading Curve of Lawrencepur Sand

The above figures show that the grading of fine aggregate (Lawrencepur sand) and coarse aggregate (Margala crush) is suitable for concrete production.

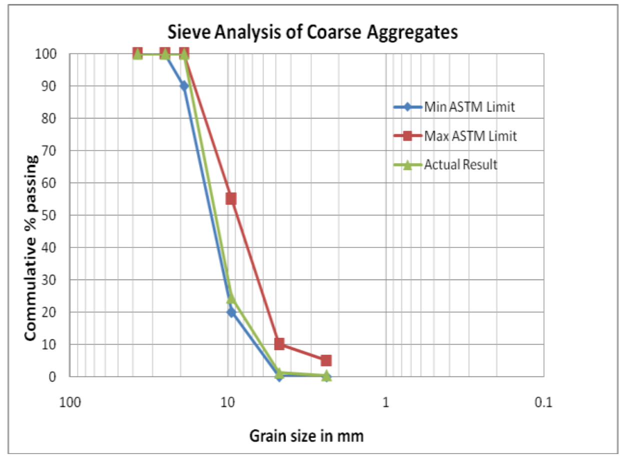

Figure-4: Grading Curve of Coarse Aggregate

Crushed Ceramic as fine aggregate: 25 kilograms ceramic waste was collected from the local ceramic industry and transported to the Concrete Laboratory of Department of Architectural Engineering & Design, University of Engineering & Technology, Lahore. Sieve analysis results of ceramic waste having FM 3.90 is presented by Figure-5 which shows that grading of ceramic waste is suitable for concrete production.

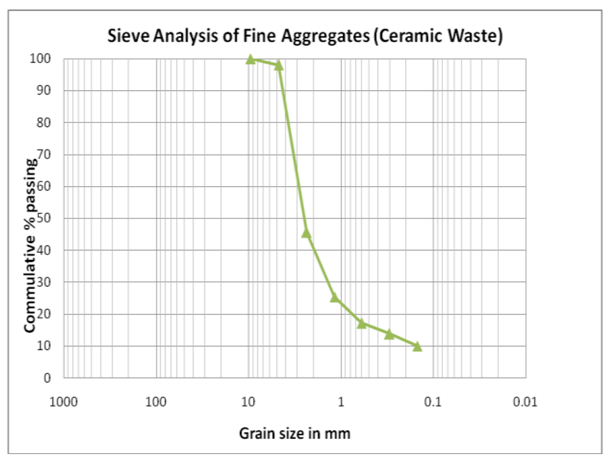

Figure-5: Grading Curve of Ceramic Waste

Ceramic waste was chemically analyzed at Process Lab of Chemical Engineering Department, University of Engineering & Technology, Lahore for identification and quality control monitoring of ceramic products. Various ceramic products are available in market like bricks, tiles, sewer pipes, pottery etc. in most of ceramic materials/products, chemical analysis involves the determination of LOI CaO, MgO, SO4, Al2O3, Fe2O3, Cr2O3, SiO2 etc. Chemical composition of the ceramic waste used in this study is shown in the Table-2 in weight percent:

Table-2: Chemical Analysis Results

Sr. No.	Elements	Mass in %age
1	CaO	8.60
2	MgO	1.88
3	SO4	1.10
4	Al2O3	9.10
5	Fe2O3	1.90
6	Cr2O3	0.50
7	LOI	1.61
8	SiO2	75.4

The composition of ceramic material may vary from place to place & influence the chemical properties of ceramic product. The properties of ceramic product entirely depend upon the chemical composition of raw material of the ceramic.

The extent of carbonation of ceramic aggregate was determined by Process Lab of Chemical Engineering Department, UET Lahore. Freshly exposed surface of the ceramic waste tile was selected and it was sprayed with 1% phenolphthalein solution. With the application of this controlled spray the color of calcium hydroxide changes to pink while the carbonated portion of sample is uncolored. Since color of sample of ceramic tile changed to pink subsequent to spray of 1% phenolphthalein solution, therefore this sample was found un-carbonated.

Figure-6: Ceramic Fine Aggregate Sample

Concrete Mixture Proportion: Since in most of the building construction projects, a common mix proportion of Cement: Fine Aggregate: Coarse Aggregate = 1: 2: 4 is being used, therefore same mix proportion has been adopted in this research work with water/cement ratio of 0.6 for 28-days cylindrical compressive strength for reference/control concrete. The same mix has been adopted for the preparation of ceramic waste concrete by replacing 10 %, 15 % and 20 % of the sand with fine aggregate of ceramic waste by weight.

Concrete mix design and sampling detail is illustrated by the Figure-7.

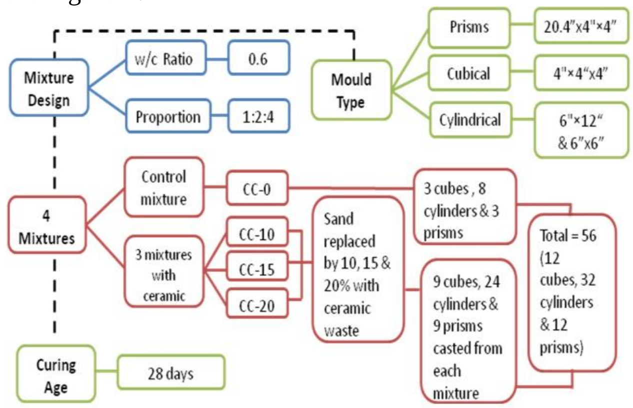

Figure-7: Concrete mix design and sampling

Concrete Samples: Quantities of the concrete materials used for the all concrete mixtures are shown in the Table-3. Four types of concrete mixes were prepared in order to carry out the this research. Details of these concrete mixes are appended below:

- 1st concrete mix "CC-0" without fine aggregate of ceramic waste.
- 2nd concrete mix "CC-10" containing 10% replacement of sand with fine aggregate of ceramic waste.
- 3nd concrete mix "CC-15" containing 15% replacement of sand with fine aggregate of ceramic waste.
- 4th concrete mix "CC-20" containing 20% replacement of sand with fine aggregate of ceramic waste.

Table-3: Quantities of Concrete Materials

Concrete Code	Cement	Fine Aggregate		Coarse Aggregate	Water
		Sand	Ceramic Waste		
	Kg	Kg	Kg	Kg	Kg
CC-0	24.189	48.378	0	96.756	14.513
CC-10	24.189	43.548	4.838	96.756	14.513
CC-15	24.189	41.121	7.257	96.756	14.513
CC-20	24.189	38.702	9.676	96.756	14.513
Total	96.756	142	21.771	387.024	58.052

All of above concrete mixes were produced by keeping cement content, water/cement ratio, type and quantity of coarse aggregate constant and changing the proportions of fine aggregate with fine aggregate of ceramic waste.

Concrete samples as illustrated by Table-4 were fabricated to carry out the required experimental investigation in the laboratory.

Table-4: Description of concrete samples

Sr. No	Type of Test	Description of Specimen		Type of Concrete	No of Samples
		Type	Dimension		
1	Compressive Strength	Cube	Length =4” Width =4” Height =4”	CC-0 CC-10 CC-15 CC-20	12
2	Flexural Strength	Prism	Length =20.4” Width =4” Height =4”	CC-0 CC-10 CC-15 CC-20	12
3	Splitting Cylinder Tensile Strength	Cylinder	Diameter =6” Height =12”	CC-0 CC-10 CC-15 CC-20	12
4	Double Punch Test	Cylinder	Diameter =6” Height =6”	CC-0 CC-10 CC-15 CC-20	12
5	Modulus of Elasticity	Cylinder	Diameter =6” Height =12”	CC-0 CC-10 CC-15 CC-20	8

RESULTS AND DISCUSSION

Compressive strength: Concrete cubes of 4”x4”x4” size were fabricated in this test to determine the compressive strength of samples made of different concrete mixtures. Compression tests were performed at the age of 28 days on specimens made of Reference Concrete and three types of Ceramic Waste Concretes i.e. CC-10, CC-15 and CC-20. Concrete having no ceramic waste CC-0 has a compressive strength of 16.78 MPa at an age of 28 days. But at the same age, the ceramic waste concretes having 10, 15 and 20 % ceramic waste (by weight) as sand replacement material and designated by CC-10, CC-15 & CC-20 achieved the compressive strength of 25.11, 25.17 & 18.05 MPa respectively. Test results obtained from these tests is graphically represented in the Figure–8.

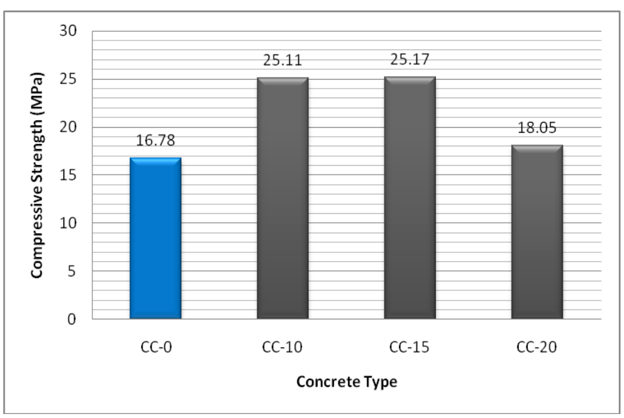

Figure-8: Compressive Strength results for Reference and Ceramic Waste Concretes at 28 days

It is depicted from the test results that the compressive strength of the ceramic waste concrete increased with the increase of quantity of ceramic waste in the concrete as partial replacement of sand. Taking the strength of reference concrete (i.e. 16.78 MPa) as base value, it is analyzed that the compressive strength of Ceramic Waste Concretes i.e. CC-10, CC-15 and CC-20 is 49.62%, 50.00% and 18.05% higher than compressive strength of Reference Concrete (CC-0) respectively.

Flexural strength: Two Point Loading Test was performed at the age of 28 days on specimens made of Reference Concrete (CC-0) and three types of Ceramic Waste Concretes i.e. CC-10, CC15 and CC-20. Concrete having no ceramic waste has a flexural strength of 3.65 MPa. But ceramic waste concretes having 10, 15 and 20 % ceramic waste (by weight) as sand replacement material and designated by CC-10, CC-15 & CC-20 achieved the flexural strength of 3.92, 3.12, 1.94 MPa respectively. A comparison of flexural strength results obtained from these tests is graphically represented in the Figure-9.

It can be noted that the flexural strength of the ceramic waste concrete increased with the increase of quantity of ceramic waste in the concrete as partial replacement of sand. Taking the strength of reference concrete (i.e. 3.65 MPa) as base value, it is analyzed that the flexural strength of CC-10 concrete is 7.52% higher than flexural strength of Reference Concrete (CC-0) where as flexural strength of CC-15 & CC-20 concretes is 14.60% and 46.90% lower than flexural strength of Reference Concrete (CC-0) respectively.

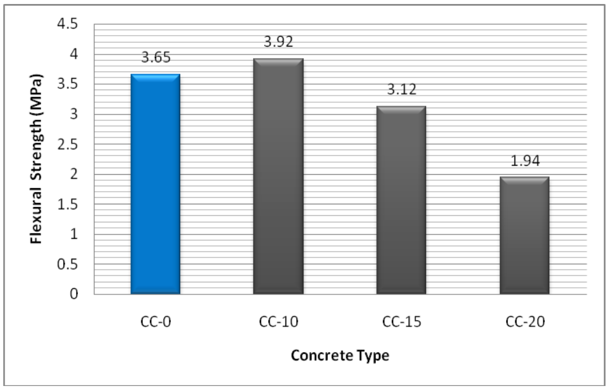

Figure-9: Flexural Strength results for Reference and Ceramic Waste Concretes

Split cylinder test: According to guidelines of ACI 318-05, split cylinder strength should be within the range of $0.507\sqrt{fc'}$ and $0.675\sqrt{fc'}$ MPa for normal weight concrete. If we calculate the required ranges with 20 MPa characteristic strength concrete using these specified ACI relations then it should be within 2.27 and 3.02 MPa. From the experimental results it is found that in split cylinder tests the tensile strength of the ceramic waste concrete is reduced with the increase of quantity of ceramic waste as sand replacement material in the concrete. The experimental results with respect to splitting tensile strength test are graphically represented in the Figure-10.

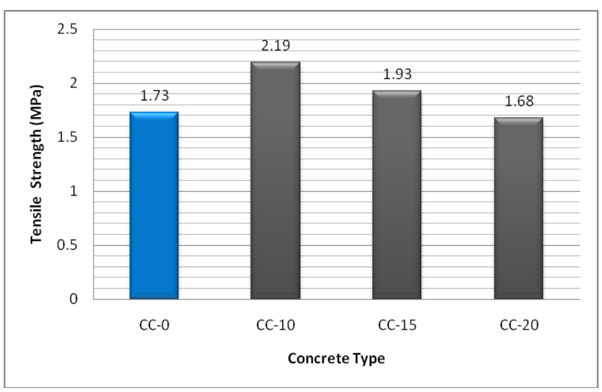

Figure-10: Split Cylinder Tensile Strength results for Reference and Ceramic Waste Concretes

It is clear from the test results that CC-10 concrete has the greatest splitting tensile strength, whereas CC-20 concrete has the lowest splitting tensile strength.

Double punch test: Tensile strength of the concrete can also be found out with the help of "Double Punch Test" which is an indirect tensile strength test method. It is found that the results of double punch test are quite similar to the results of split cylinder tensile strength test. Results obtained in Double Punch Test depicts that the tensile strength of the concrete is gradually reduced with the increase of contents of ceramic waste fine aggregate as partial replacement of sand. The results of Double Punch Test are graphically represented in the Figure-11.

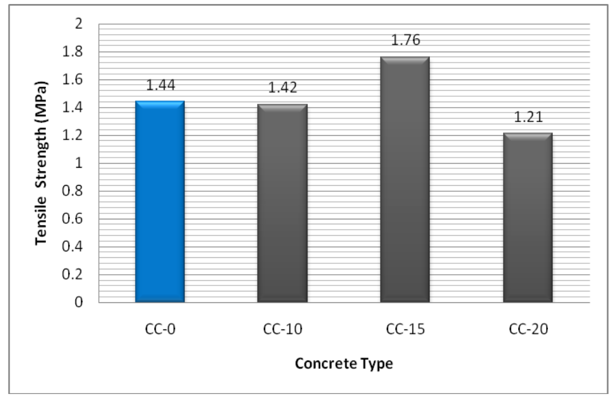

Figure-11: Double Punch Tensile Strength results for Reference and Ceramic Waste Concretes

It is clear from the test results that CC-15 concrete has the greatest tensile strength whereas CC-20 concrete has the lowest tensile strength. The tensile strength of CC-15 concrete is 22.67% higher than Reference Concrete (CC-0) while the tensile strength of CC-10 and CC-20 concretes is 1.33% and 16.00% lower than Reference Concrete (CC-0) respectively.

Modulus of elasticity test: This test was performed to find out the variation in the Modulus of Elasticity in four different types of the concrete mixtures, one reference concrete and three ceramic waste concretes with substitution of sand with fine aggregate of ceramic waste at different proportions. The test results of Modulus of Elasticity (MOE) corresponding to each concrete mixture are graphically represented in the Figure-12.

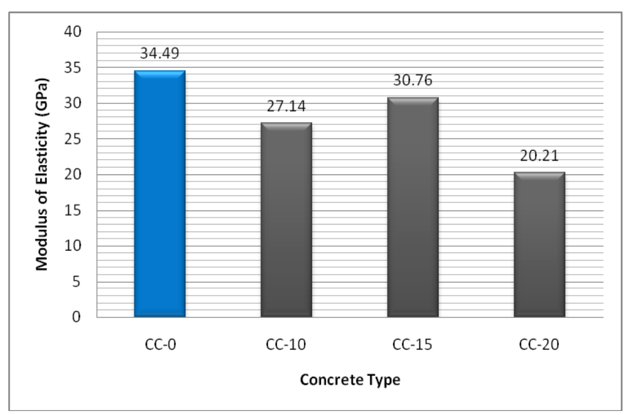

Figure-12: Modulus of Elasticity results for Reference and Ceramic Waste Concretes

From the test results it is found that modulus of elasticity (Ec) of the concrete is reduced with the increase of contents of ceramic waste as fine aggregate. It is clear from the test results that CC-0 concrete has the highest value, CC-15 concrete has the second highest value and CC-20 concrete has lowest value of Ec. Concrete with lower quantity of ceramic waste aggregate is showing better results than concrete with high quantity of ceramic waste aggregate. Ec of CC-10, CC-15, CC-20 concretes is 21.33%, 10.82% and 41.41% below the Ec of CC-0 concrete respectively.

Conclusions: Following are the conclusions drawn on the basis of results of different types of laboratory tests undertaken in this research work:

- The workability of all the three concrete mixtures increased slightly with the addition of fine aggregate of ceramic waste as partial replacement of sand.
- All the three concrete mixtures attained the compressive strength more than the compressive strength of reference concrete. Compressive strength of concrete gradually increased with the increase of quantity of fine aggregate of ceramic waste. There is maximum 50% increase in compressive strength for CC-15 concrete.
- The flexural strength of the ceramic waste concrete increased with the increase of quantity of ceramic waste in the concrete. The flexural strength of CC-10 concrete is 7.5% higher than flexural strength of CC-0 concrete. However, flexural strength reduced by 14.6% & 46.9% for CC-15 & CC-20 concretes respectively. There is increase in flexural strength up to 10% but beyond this limit, the flexural strength reduced.
- The greatest splitting tensile strength was observed for CC-10 concrete and the lowest for CC-20 concrete. The tensile strength of CC-20 concrete is 3.23% lower than CC-0 concrete while CC-10 concrete attained the highest tensile strength i.e. 26.45% more than the CC-0 concrete.
- CC-15 concrete achieved the greatest Double Punch tensile strength whereas CC-20 concrete attained the lowest Double Punch tensile strength. The tensile strength of CC-10 and CC-20 concretes is 1.33% and 16% lower than CC-0 concrete respectively while tensile strength of CC-15 concrete attained the highest tensile strength i.e. 22.67% more than the CC-0 concrete.
- Reference Concrete (CC-0) achieved the greatest Modulus of Elasticity (MOE) whereas CC-20 concrete attained the lowest Modulus of Elasticity (MOE). Modulus of Elasticity kept on decreasing with the increase in contents of ceramic waste in the concrete.
- All the concrete mixtures with ceramic waste are depicting satisfactory results so it is recommended to use industrial ceramic waste as partial replacement of fine aggregate up to 15% in concrete production.

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