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Research paper

Study on Strength Properties of Concrete with Ceramic Waste Aggregate and Silica Fume Admixture

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Abstract

The ceramic waste is used as a coarse aggregate replacement in concrete is a two way beneficial process that involves minimization of resources for construction and processing of hazardous industrial wastes that cannot be recycled. The ceramic waste obtained from waste dismantled building were used as coarse aggregate 10%, 20%, 30%, 40% and 50% replacement. To improve the mechanical properties silica fume is added as admixture in the concrete. The optimum percentage replacement was obtained considering the strength as well as the objective of using ceramic waste aggregate. The compressive strength of concrete cubes were tested . The compressive strength of aggregate replaced concrete has been compared to that of conventional concrete and the results are evaluated.

Keywords: *Ceramic waste aggregate, silica fume and green concrete.*

1. Introduction

1.1. General

Ceramic formed by the action of heat is an inorganic non- metallic material which is used in the construction industry and also as day-to-day utility products in household. Every year, around 30% of ceramic products are being damaged during manufacturing, transportation and handling because of its fragile nature, which is considered as non- recyclable waste. Therefore, the most efficient way of processing the waste generated is by using as aggregates (coarse and fine) in concrete making it environmentally viable. Ceramics as coarse aggregates can be classified based on the surface texture as both sides smooth such as sanitary wares and one side smooth such as wall and floor tiles. Various researchers have studied the mechanical properties of ceramic aggregate based concrete involving both the variants of ceramic aggregate and it is found that ceramic has the potential to be used as aggregates. Numerous researches have also stated the environmental benefits like reduction in usage of aggregates, aggregate mining challenges and adulteration of landmass due to dumping of wastes. Ceramic tiles are hard having considerable value of specific gravity, rough surface on one side and smooth on other side, are lighter in weight than normal stone aggregate but the catastrophic nature of ceramic aggregate reduces the characteristic strength of concrete when compared to conventional concrete [1]. The ceramic waste aggregate does not interfere with the chemical reactions that occur during the cement hydration [2].The compressive, splitting tensile and flexural strengths of ceramic waste coarse aggregate concrete are lower by 3.8, 18.2 and 6% respectively when compared to conventional concrete, but ceramic waste coarse aggregate concrete possesses lower tensile to compressive strength ratio and is also observed thatreduction in water cement ratio resulted in increase of compressive strength for the ceramic waste aggregate concrete [3]. Thus, this study explores the possibilities of replacing the ceramic waste as coarse aggregate and also achieving higher strength. Hence, silica fume, a by-product of the silicon and

ferrosilicon alloy production is used to improve the strength characteristics. It is cementing material that improves the packing and the compactness of the concrete. The high specific surface area results in calcium hydroxide which released as a consequence of cement hydration imparts more compressive strength [4-7].

2. Materials and Methodology

2.1. Materials

Cement OPC 53 grade conforming to BIS specification IS: 12269-1987 was used. The physical properties of Cement is tested and calculated. The specific gravity of cement is 3.15.
Sand locally available river sand, grain size less than 4.75mm conforming to zone 3 as per IS: 383-1970, specific gravity 2.7 and fineness modulus 2.6.
Gravel natural surface dried crushed stone passing through 20mm sieve and retained in 12.5mm sieve of specific gravity 2.7 conforming to IS: 383-1970.

Table 1: Chemical Composition of Silica Fume

Chemical Composition	% Present
SiO_2	81.35
Al_2O_3	4.50
Fe_2O_3	1.40
CaO	0.75
MgO	1.52
SO_3	1.34
Loss on ignition	3.4

Ceramic waste aggregate obtained from a local construction site, broken by dropping hammer, passing through 20mm sieve and retained in 4.75mm sieve of specific gravity 2.35.

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Silica fume obtained from local manufacturing industry of specific gravity 2.22 and mean grain size 0.15µm appears to be in whitish grey in color. Refer TABLE 1 for chemical composition.



Fig. 1: Ceramic tile aggregate



Fig. 2: Silica Fume Powder

2.2. Mix Design

In this experiment conventional mix M20 grade was designed as per Indian Standard method IS 10262-2009 for extreme exposure condition as 1:1.5:3 with water cement ratio as 0.5 as reference sample. Coarse aggregate replaced concrete samples following the same mix design with 10%, 20%, 30%, 40%, 50% replacement of coarse aggregate with ceramic waste aggregate containing silica fume admixture of 10% by weight of cement.

Table 2: Detailed Mix Design of All the Samples

Description	M20	10%	20%	30%	40%	50%
Cement (kg/cum)	380	380	380	380	380	380
Fine Aggregate (kg/cum)	570	570	570	570	570	570
Coarse Aggregate (kg/cum)	1140	1026	912	798	684	570
Ceramic Waste Aggregate(kg/cum)	-	114	228	342	456	570
Silica fume(kg/cum)	-	38	38	38	38	38
W/C ratio	0.5	0.5	0.5	0.5	0.5	0.5

2.3. Methodology

The methodology of work involves obtaining materials and casting containers according to the desired grade size and shape followed by preliminary testing of the obtained materials. Based on the mix design, 12 nos. of 100mm cubes, two of each combination was casted for 7 days and 14 days testing and 6 nos. of 150mm cubes, one of each combination was casted for 28 days testing of compressive strength to determine the optimum combination. Two reinforced concrete beams (conventional concrete and optimum combination) of dimensions 1100mm x 100mm x 150mm was casted for 28 days testing towards flexure. The beam consists of 4 nos. of 12mm dia bars of length 1000mm, two in the compression zone and two in the tension zone and stirrups of 6mm dia 150mm spacing.
The casted samples were kept for curing in the water under normal room temperature. After sufficient curing the samples were tested for compressive strength and flexural strength. Based on the test results the conclusions were drawn.

2.4. Experiments

Table 3: Physical Properties: Gravel vs. Ceramic Tile Aggregate

Particulars	Gravel	Ceramic Tile Aggregate
Shape	Angular	Flaky
Texture	Rough	All sides rough except the top face
Specific gravity	2.7	2.35
Water absorption	1.5%	14.4%
Impact value	17%	21%
Crushing strength	20.5%	24.7%
Fineness modulus	2.3	2.23

2.4.1. Testing of Materials

The preliminary testing of materials was carried to determine some of the basic properties required for the mix design and also to know the quality and grading of the material. The specific gravity of sand, fine aggregate, gravel and ceramic waste

aggregate was tested by prescribed methods of testing. Coarse aggregate was graded based on IS: 383-1970(clause 4.1 and 4.2) and the nominal size of aggregate were found to be 20mm and fine aggregate under clause 4.3 of IS: 383-1970 were found to be of grading zone 3. The fineness modulus of sand was found to be 2.6 and that of coarse aggregate was found to be 2.3 for gravel and 2.23 for ceramic waste aggregate. A few more tests were conducted to validate the replacement of coarse aggregate by ceramic waste aggregate. There wasn't much pressure in finding the properties and chemical composition of silica fume. The chemical composition was given by the industrial associate based on industrial laboratory report and it was also verified by comparing with the literatures. The water absorption of ceramic waste aggregate is much more than naturally occurring gravel (ref. TABLE 3) which is the reason to adapt a water-cement ratio of 0.5 in the mix design.

2.4.2. Testing of Fresh Concrete

The consistency and workability of fresh concrete was tested by using slump cone method. Slump cone test offered the knowledge to know if the mix was made properly. All the combinations of fresh concrete mix were tested in a slump cone of dimensions 300mm height and dia 100mm in the top and 200mm in the

bottom. The cone was filled in three layers. Each layer is tamped 25 times with rod. The concrete at the top of the cone was struck off. The mould is lifted without disturbing the concrete. The slump height is measured using meter scale.

2.4.3. Testing of Compressive Strength of Concrete

Compressive Strength of concrete is one of the important properties of concrete that influences all other mechanical properties of concrete. It is defined as the load at which not more that 5 percent of the concrete fiber fails under gradual loading in the compressive testing machine. Twelve cubes of six combinations, that is normal m20 mix, 10%, 20%, 30%, 40% and 50% were casted in a wooden mould of dimension 100mm x 100mm x 100 mm connected by 18mm dia bolts, lubricated well with oil for easy removal of mould after 24 hours. Six cubes of six combinations were casted in a wooden mould of dimension 150mm x 150mm x 150mm connected by bolts, well lubricated and separated by wooden planks. All the cubes were manually compacted with tampering rod conforming to IS: 516-1959 and finished using trowel to maintain a flat surface on all the sides. The cubes were labeled by making an impression using trowel with the combinations labeled as NC- normal M20 mix, 10, 20, 30, 40 and 50 for 10%, 20%, 30%, 40% and 50% replacement of ceramic waste aggregate respectively. The cubes were de-moulded after 24hrs of casting. The de-moulded cubes were kept inside the water tank for curing under room temperature.100mm cubes were tested for a curing period of 14 and 28 days.150mm cubes were tested for a curing period of 7 days. After the period of curing the cubes were dried under the sun for 24 hours. The dried cubes were tested in the compressive testing machine conforming to IS: 14858-2000 and calibrated with an accuracy of ±1% as per the requirement of 1828(class 1) and compressive strength of cubes was obtained. .



Fig. 3: Compressive strength test

2.4.4. Testing of flexural strength of concrete

Flexural strength of concrete was computed taking experiment conducted using a Self Balancing Loading Frame weighing 1000 kN with a service load of 250 kN. Beams of Dimension 1100mm x 150mm x 100mm were cast representing two variations, conventional mix [CB] and 30% of coarse aggregate replaced by ceramic tile aggregate [30B]. The reinforcement consisted of 2 nos. of 12mm dia (tension zone) and 2 nos. of 8mm dia (compression zone), Fe 500 thermo mechanically treated bars and stirrups made of 6mm dia bars of the same grade. The beams experienced water curing at room temperature for 56 days.
After arranging the beam according to flexural loading conditions, load was gradually applied on to the loading frame using a hydraulic jack system which was transferred to the I-section supported by rollers at the one third of span points on the beam causing a 4-point loading setup. Deflection was measured using a linear variable differential transducer (LVDT) at the mid span. The major observations were the cracking load and the ultimate load along with the corresponding deflection.

3. Results and Discussions

3.1 Slump Test

The workability of various combinations of concrete in use has been tested. The Slump value of the corresponding mixes are calculated by measuring the decrease in the height of the concrete from that of the cone i.e. the height of the concrete after the cone is taken.

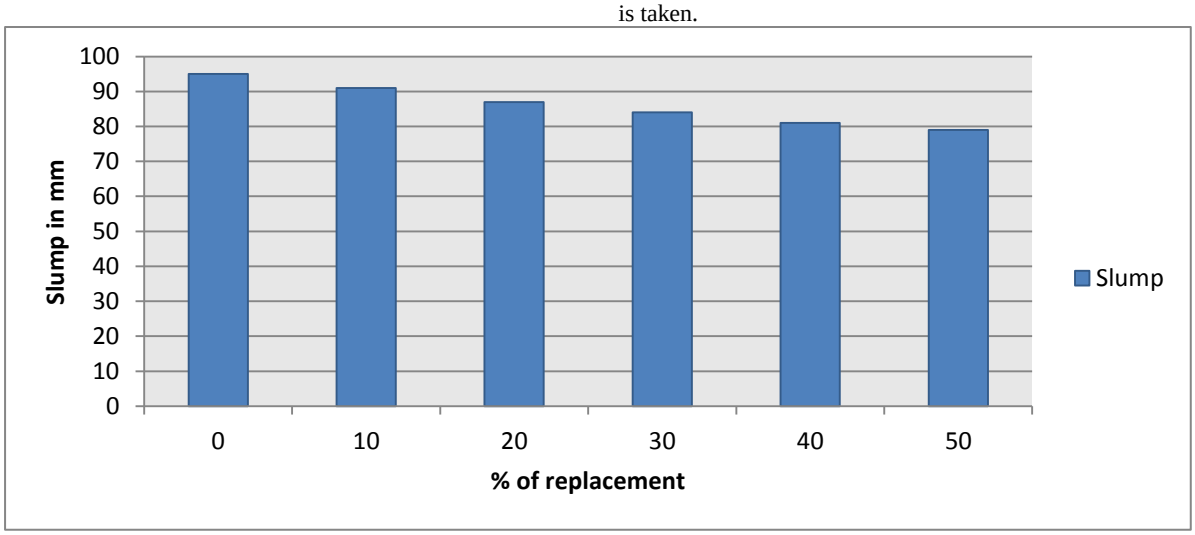


Fig. 4: Bar Chart representing the Slump test values of various percentage of replacement.

The workability of normal concrete was found to be greater than that of ceramic waste aggregate replaced concrete. As the percentage of replacement increases, the slump value reduces ranging between 91mm - 79mm accordingly. The slump value of reference concrete was found to 95mm.

3.2 Compressive Strength Test

Cubes of dimension 100mm x 100mm x 100mm were tested for a curing period of 7 and 14days and that of dimension 150mm x 150mm x 150mm were tested for a curing period of 28 days. The results of the compressive strength are graphically represented in FIGURE 5.

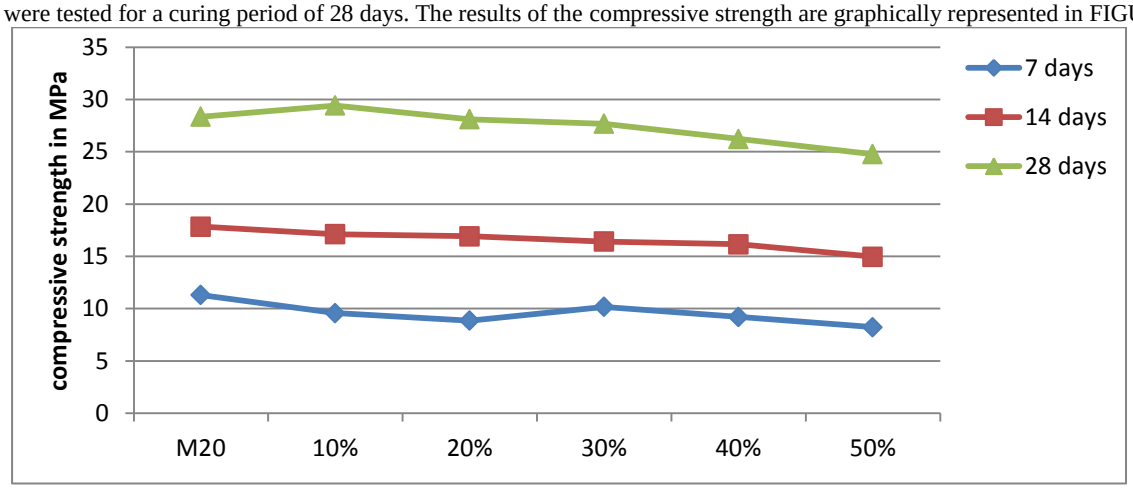


Fig. 5: Compressive Strength

Based on the results from the compressive strength test, it is evident that all the combinations have attained the target mean strength. The compressive strength of cubes replaced with 10% of ceramic waste aggregate proves to hold the maximum strength after 28 days of curing period. It is found that the cubes replaced with 20% and 30% of ceramic waste aggregate has attained a compressive strength of 28.1 MPa and 27.6 MPa respectively, which is not very less compared to the conventional concrete. Cubes with 40% and 50% replacement have fallen in the bottom most places when arranged in descending order with compressive strength of 26.2 MPa and 24.78 MPa.

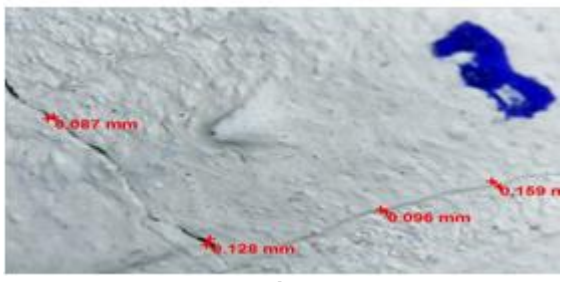
3.3. Flexural Strength Test

The beams were tested under flexural loading conditions after 56 days of curing in water. FIGURE 7 represents the graph of load VS deflection at mid span. It is observed that both the beams experience permissible deflection in the elastic zone. However, the ultimate load and the cracking load of 30B were found to be higher than CB. Refer table 4 for the essential test results.

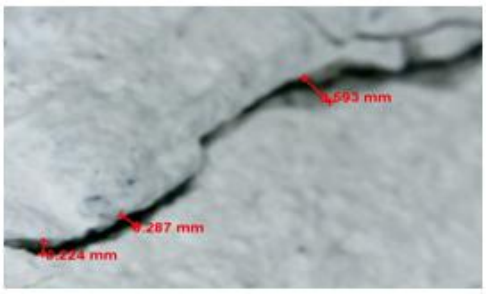
Table 4. Flexural strength test results

Description	Cracking load(kN)	Ultimate load(kN)	Cracking moment (kN)	Max deflection
Conventional beam	47	66.2	21.15×10^{-3}	7.6
30 % aggregate replaced beam	55	71.5	24.75×10^{-3}	8.5

Both the beams experienced flexural crack as their first with the 30B cracking at 17% higher load when compared to CB. Some interesting cracking pattern and the width of the cracking is represented by FIGURE 6A -6D. The average crack width of all main cracks fall under the serviceability conditions stated by IS 456:2000.



A



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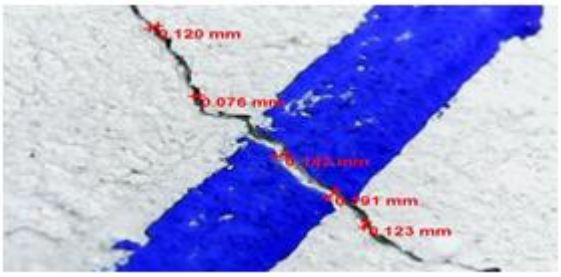

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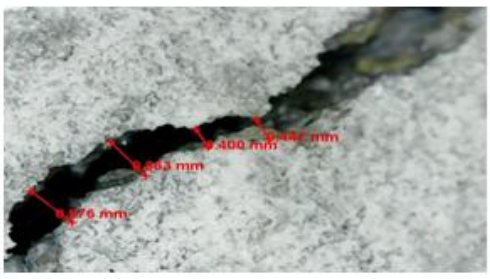

D

Fig. 6: The crack pattern of 30 % aggregate replaced beam (A,B) and the crack pattern of Conventional beam(C,D).

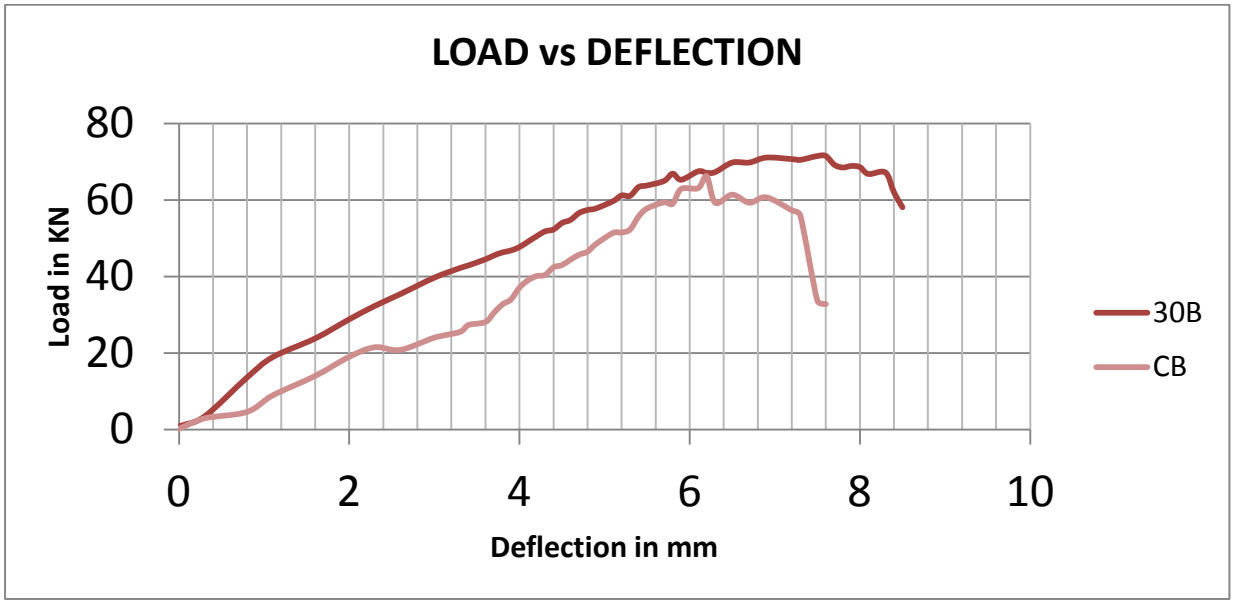

Fig.7: Load VS Deflection curve of 30B and CB.

Based on the flexural test results the beam consisting 30% of ceramic tile aggregate has considerably performed quite a notch better than the conventional beam by attaining an ultimate load of 71.5 kN which is almost 8 % higher. However, both the beams fall under the serviceability conditions provided by IS Codes.

4. Conclusions

Based on the results obtained from the experiments conducted with the various combinations of concrete containing ceramic waste as coarse aggregate and silica fume admixture, the following conclusions are drawn:

- The workability of concrete reduces with the increases in percentage of replacement of ceramic waste aggregate.
- The compressive strength of concrete containing 10% of ceramic waste was found to be 3.7% higher than conventional mix.
- Concrete containing 20% and 30%of ceramic waste have almost the similar strength to that of conventional mix whereas the strength reduces marginally in 40% and 50% replacement.
- RCC beam containing 30% ceramic waste aggregate has attained an ultimate load of 71.5 KN which is 8% higher than conventional beam.
- The deflection experienced by the beam at one particular load is less in the 30B when compared to CB.

- The use of silica fume as an admixture has played a significant role in helping the concrete mixes made with ceramic waste in attaining the target strength.
- Therefore the optimum percentage of use of ceramic waste aggregate would be 30% considering the environmental benefits in processing the non-recyclable waste as well as minimizing the use of natural resource.

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