Mechanical Performance Evaluation of Concrete with Waste Coarse Ceramic Aggregate

Hadee Mohammed and Shakeel Ahmed

Abstract This study aims to describe the experimental work to illustrate and evaluate the mechanical behaviour of concrete with waste ceramic (floor tiles) coarse aggregate. Concrete included the following materials natural fine aggregate (NFA), natural coarse aggregate (NCA) and waste ceramic aggregate (WCA). Concrete was prepared with WCA replacing in NCA in absolute volume percentage in of 0, 10, 20, 30, 50 and 100%. All the concretes were prepared with similarity aggregate size gradation and workability. In the hardened case, the concrete performance was evaluated by split tensile strength, compressive strengthen, flexural strengthen and combined flexural and torsion. The results show significant improvement in feasibility the partially replacement of NCA by WCA, in spite of the mechanical behaviour of concrete reductions with the rising replacement of NCA by WCA in case of compressive, tensile and flexure strength, whereas in case of combined flexural and torsion, it is increasing up to 20% replacement.

Keywords Coarse aggregate · Mechanical properties · Recycled aggregate · Concrete · Floor tiles · Ceramic waste aggregate

1 Introduction

Concrete, as construction material, has been applied in the construction industry for many different centuries. Approximately, one ton of concrete is applied per capita per year throughout the world. The following studies have carried out on the concrete strength with waste ceramic and evaluated by compressive strength, split tensile strength, flexural strength and combined flexural and torsion [1].

Lavat et al. [2] studied the recycling of ceramic waste tiles in the manufacture of blended cement. The researcher stated that the use of powdered roof tiles as Pozzolanic product in cement production. The wastes were listed as non glazed,

H. Mohammed (✉) · S. Ahmed (✉)
Department of Civil Engineering, Z. H. College of Engineering and Technology, Aligarh Muslim University, Aligarh, UP 202002, India

S. Ahmed et al. (eds.), *Smart Cities—Opportunities and Challenges*, Lecture Notes in Civil Engineering 58,
https://doi.org/10.1007/978-981-15-2545-2_49

natural and black-glazed tiles. The compressive strength of resulting models was measured. This result has approved that waste material is used to produce Pozzolanic cement.

The stone powder can be applied as fine aggregate and waste ceramic can be used as a coarse aggregate, this situation was studied by Reddy [3]. It was shown that the compressive strength increased due to use of stone powder as a fine aggregate, while decreased when using ceramic as a coarse aggregate. It was remarked that the strength of concrete increased in excess of 20%, and leads to decrease in excess of 20% below the standard mix. So in concrete, stone powder is more effectively to used as a fine aggregate Hence in concrete, a stone powder can be effectively used as fine aggregate instead of river sand and WAC can be used as a standard coarse aggregate up to 20%.

Medina et al. [4, 5] investigated reuse of sanitary ceramic waste as a coarse aggregate. These wastes were applied as recycling coarse aggregate in partially replacement (15, 20, and 25) % of NCA in the manufacturing of structural concrete. The result conforms that recycled, eco-efficient concrete resent superior mechanical performance compared to standard concrete.

The possibility of using lignite base bottom ash as fine aggregate was researched by Dhavamant et al. [6], and mix ratio consists 100% replacement of NCA by WCA. The result shows that compressive strength with ceramic coarse aggregate concrete was improved. This improvement in compressive strength refers to reduction in w/c ratio, whereas enhancement upto 85% at 28 day and 95% at 56 days for ceramic waste aggregate concrete.

Anderson et al. [7] study tested impact of using clean, waste ceramic floor tiles and wall tiles, on compressive, tensile and flexural strength of hardened concrete. Where test results showed that the clean tiles had little effect on compressive strength. The per cent which used in replacement of course by recycles ceramic aggregate from 20 to 100%. The result showed decrease in compressive strength in comparison to reference concrete as well as split tensile strength has improved over reference concrete while flexural strength has decreased over reference concrete. Gonzalez el al. [8] study aimed to use of industrial clay brick waste from inadmissible pieces in ceramic precast facilities to replace simultaneously NFA and NCA in the production of concrete for precast pre-stressed beams. Replacement percentage of (20, 35, 50, 70,100) %, respectively, were used. The final finding of this research is that decrease in compressive strength reaching to 23% for 100% replacement. None of the reviewed papers used any testing for waste aggregate concrete (WAC) under torsion.

2 Physical and Mechanical Properties

OPC 53 Grades conforming to IS: 8112-1989 [9] is applied in experimental study with physical properties as in Table 1. Setting time and the test of cement crushing value were performed according to IS: 4031-1988 [10], the procedure is shown in

Table 1 Physical properties of material

S. no.	Physical properties	Cement	Coarse aggregate	Fine aggregate	Waste ceramic aggregate
1	Normal consistency (%)	30	–	–	–
2	Specific gravity	3.6	2.55	2.6	2.35
3	Initial setting time	42 min	–	–	–
4	Final setting time	600 min	–	–	–
5	7 days compressive strengthen	21.1	–	–	–
6	Fineness modules	41.4	6.99	2.65	6.98
7	Max size	–	20 mm	–	20 mm
8	Dry compact density (kg/m^3)	–	1618	1319	1325
9	Water absorption (%)	–	0.25	1.6	4.5
10	Crushing value (%)	–	12.86	–	14.33
11	Impact value (%)	–	20.2	–	24.2

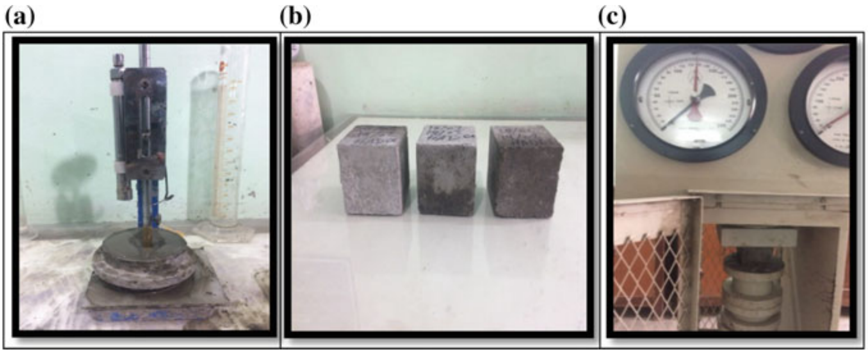

Fig. 1 **a** Setting time test for cement. **b** Cement cube specimens. **c** Testing of cement cube resistance to crushing

Fig. 1. The method which used to determine the relative strength of the cement tested by testing the resistance to crushing under compressive load was cement crushing value [7].

Coarse aggregate is locally prepared as a crushed stones according to a graded aggregate of normal size 10 and 20 mm as per IS: 383-1970 [11], applied in experimental work. Sieve analysis was used per IS 383:1970 [11] because the gradation of aggregate impacted for both hardened and fresh concrete as shown in Fig. 2a. Also some laboratory tests were made in order to find out the physical properties such as dry compact density (kg/m^3), fineness modules, water absorption, specific gravity, crushing value and impact value as per IS 2386-1963 [12] and are shown in Table 1.

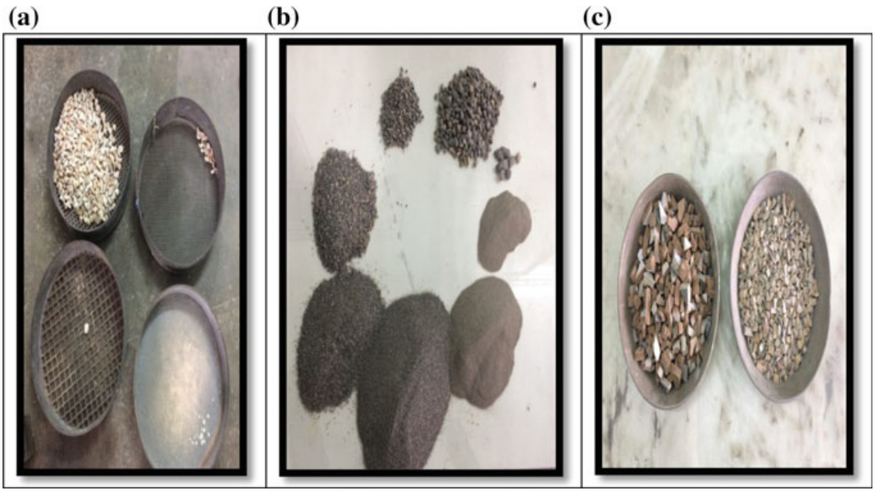

Fig. 2 **a** Coarse aggregate on sieve. **b** Fine aggregate after sieve analysis. **c** Waste ceramic coarse aggregate (20 mm, 10 mm) after sieving

The natural sand was used as a fine aggregate of the requirement of IS: 383:1970 [11], its divisions from 4.75 mm to 150 µm. The sieve analysis has done as per IS 383:1970 [11] as shown in Fig. 2b. Tests were made in order to find out it's physical properties like dry compact density (kg/m^3), specific gravity, water absorption and fineness modules as per IS 2386-1963 [12] and are shown in Table 1.

Waste ceramic coarse aggregates which used in experimental part were collected from many different ceramic stores in Aligarh. The collected waste ceramic coarse aggregates cleaned out of the dirty material and crushed by hammer into different particle size as shown in Fig. 2c. The result of sieving and other physical properties of ceramic waste as determined in the laboratory are shown in Table 1.

3 Mix Proportions

Concrete mix was designed as per IS10262-2009 [13] having a constant W/C ratio of 0.50. The concrete mixes of all specimen were made by definition proportion of (1:1.5:3) (Cement: Fine aggregate: Coarse aggregate), with the constant w/c ratio 0.5. Coarse aggregate was replaced with varying percentage with waste ceramic floor tiles which makes the concrete as most binder. Test increasing replacement ratios starting from 0% replacement (reference concrete) to 100% replacement were designed by aggregate replacement test. The named 25PC refers to reference concrete with (0%) replacement where 25 refers to M25 (grade of concrete) and PC refers to plain concrete. The replacement ratios test for the waste ceramic coarse aggregate series were 10%, 20%, 30%, 50% and 100%, were named 25WAC-10, 25WAC-20, 25WAC-30, 25WAC-50 and 25WAC-100, respectively. The number like 10 in the naming method denotes the replacement ratio, while W refers to waste ceramic, A refers to aggregate replacement and C refer to concrete.

4 Experimental Investigation

The Total of 72 test specimens were divided into six groups as shown below:

(1) **Group 1**: plain concrete

- 3 cubes, 6 beams, 3 cylinders

(2) **Croup 2**:10% replacement of NCA by WCA

- 3cubes, 6 beams, 3 cylinders

(3) **Croup 3**:20% replacement of NCA by WCA

- 3cubes, 6 beams, 3 cylinders

(4) **Croup 4**:30% replacement of NCA by WCA

- 3cubes, 6 beams, 3 cylinders

(5) **Croup 5**:50% replacement of NCA by WCA

- 3cubes, 6 beams, 3 cylinders

(6) **Croup 6**:100% replacement NCA by WCA

- 3cubes, 6 beams, 3 cylinders.

These specimens were casted in cube (150 * 150 * 150 mm), cylinder (length 300 mm * 150 mm diameter) and beam (100 * 100 * 500 mm) moulds and compacted on vibration machine, after 24 h the models were taken out from moulds and kept them in curing tank for 28 days. The concrete models were cured at 27 °C till the age of test. Four tests were conducted to determining compressive strengthen, split tensile strengthen, flexural strengthen and combined flexural and torsion for the optimal concrete mixes as mentioned in Fig. 3a–d for 10% replacement. All the tests were conducted as per IS 516–1959 [14].

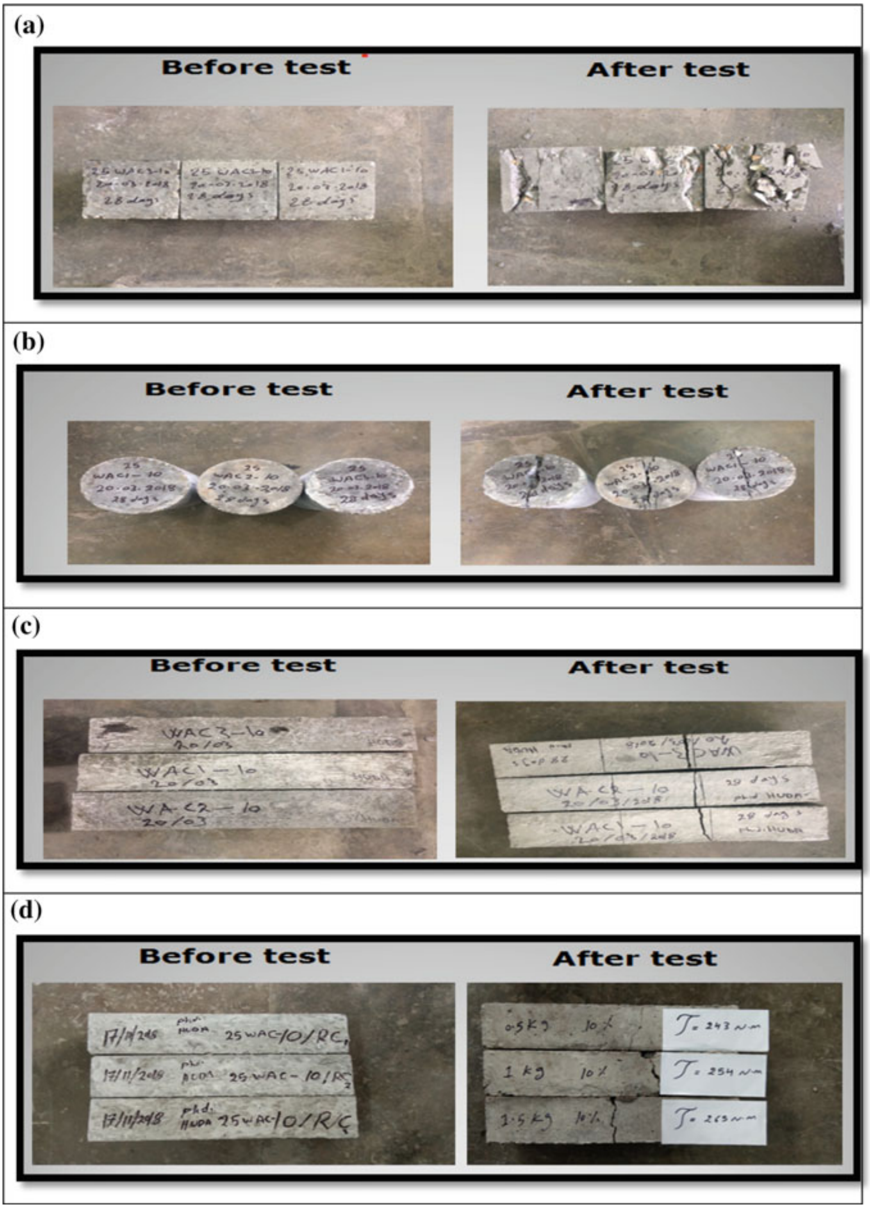

Fig. 3 **a** Compressive strength test: specimen before and after test. **b** Split tensile strength test: specimen before and after test. **c** Flexural strength test: specimen before and after test. **d** Combine flexural and torsion test: specimen before and after test

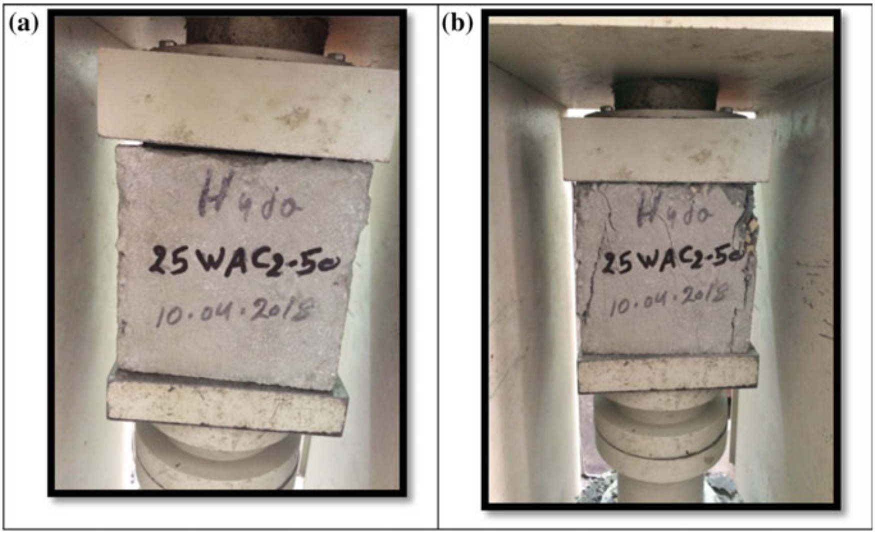

Fig. 4 **a** Sample in compression testing machine before fail **b** Sample in compression testing machine after fail

5 Hardened Concrete Properties

5.1 Compressive Strength

Compression testing machine was used for this test. Load was shedded gradually till the model fail as shown in Fig. 4a, b. The results in Fig. 5 show a typical hardened concrete sample after failure under compression loading test, showing the effect of WCA content into concrete mix on the 28 days compressive strength into the hardened concrete for same W/C ratio. The decrease in compressive strength in all models was noticed, where percentage error for 10% replacement is equal to 7.4% and for 100% replacement is equal to 30.73%. The final results are shown in Table 2. One reason for decreasing compressive strength of samples when increasing the percentage of aggregate replacement because of the increasing in the flaky aggregate, where waste ceramic aggregates have different sizes and shapes. Second reason may be low hardness and abrasion value of waste ceramic aggregate for decrease of strength.

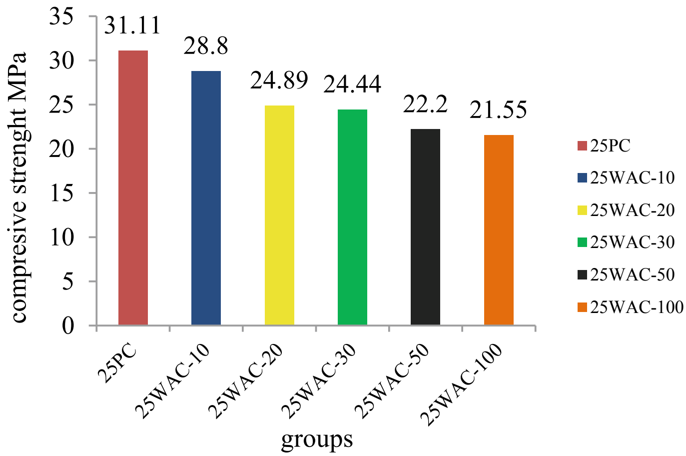

Fig. 5 Compressive strength test result

Table 2 Compressive, tensile, flexural, combined flexural and torsion test result

S. no.	S. name	Compressive strength 28 days (N/mm^2)	Split tensile strength 28 days (N/mm^2)	Flexural strength 28 days (N/mm^2)	Ultimate stress under torsion 243 N m (MPa)	Ultimate stress under torsion 254 N m (MPa)	Ultimate stress under torsion 265 N m (MPa)
1	25PC	31.11	3.69	6.08	3.25	3	2.75
2	25 WAC-10	28.8	3.37	6	4.25	4	3.75
3	25 WAC-20	24.89	3.25	5.6	3.25	3	2.75
4	25 WAC-30	24.44	3.18	5.13	3	2.75	2.5
5	25 WAC-50	22.2	3.14	4.75	2.25	2	1.75
6	25 WAC-100	21.55	2.95	4.67	2	1.75	1.5

5.2 *Split Tensile Strength*

This test has done by fixing cylindrical model horizontally between the load surface of compression test machine and the load was shed gradually until fail of cylinder along the height which is shown in Fig. 6a, b. The results in Fig. 7 show decrement in split tensile strength in all specimens, where percentage error for 10% replacement is 8.6% and for 100% replacement is 20.05%. The final output result is listed in Table 2. The lower performance of ceramic waste aggregate concrete in compared to plain concrete is possibly due to the intrinsic properties of the adhered mortar and its low adhesiveness to ceramic.

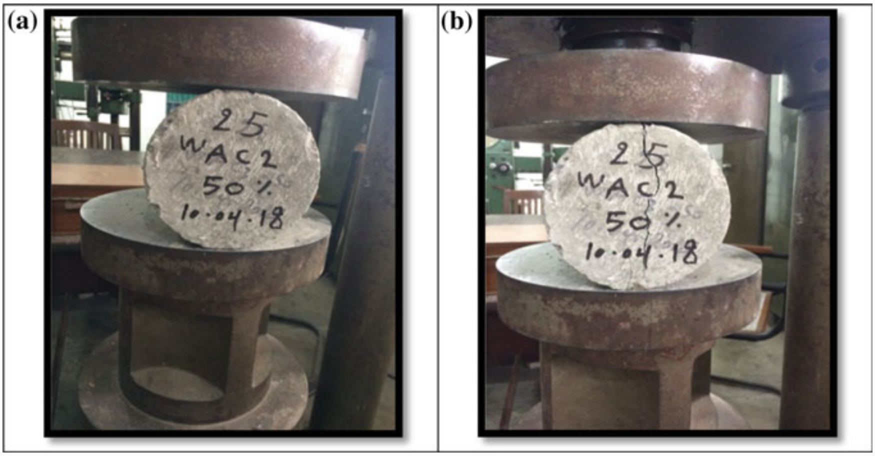

Fig. 6 **a** Sample in split tensile machine before fail. **b** Sample in split tensile machine after fail

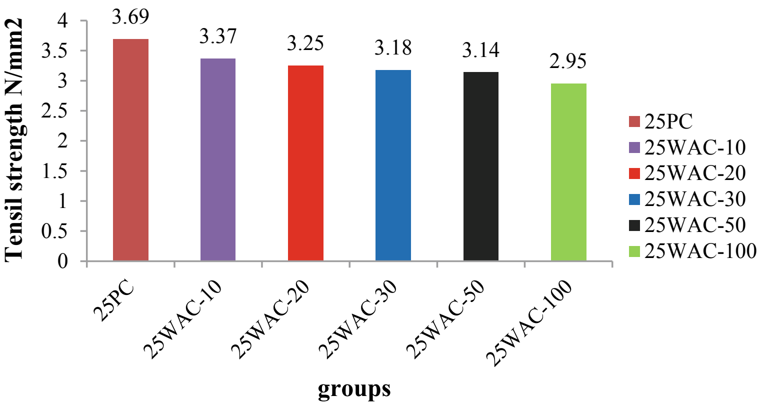

Fig. 7 Split tensile result

5.3 *Flexural Strength*

This test was used to determine the flexural strength of the models. Two-point load system was chosen as an effective span while testing the specimen. The load is employed until the failure of specimen takes place which is shown in Fig. 8a, b. The results are shown in Fig. 9 noted decrease in flexural strengthen in all models, where percentage of error for 20% replacement is equal to 7.89% and for 100% replacement is equal to 23.19%. The final results are shown in Table 2. The flexural strength decrease may be due to weak-bond formation in waste ceramic coarse aggregate.

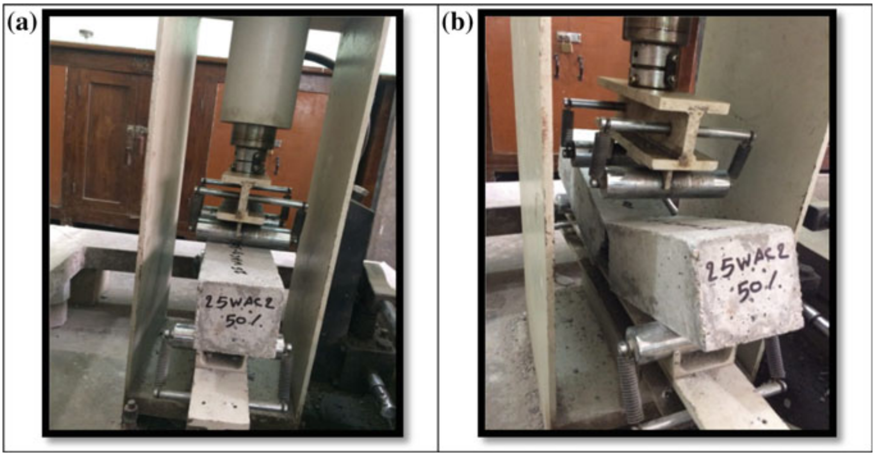

Fig. 8 **a** Sample in flexural machine before fail. **b** Sample in split flexural machine after fail

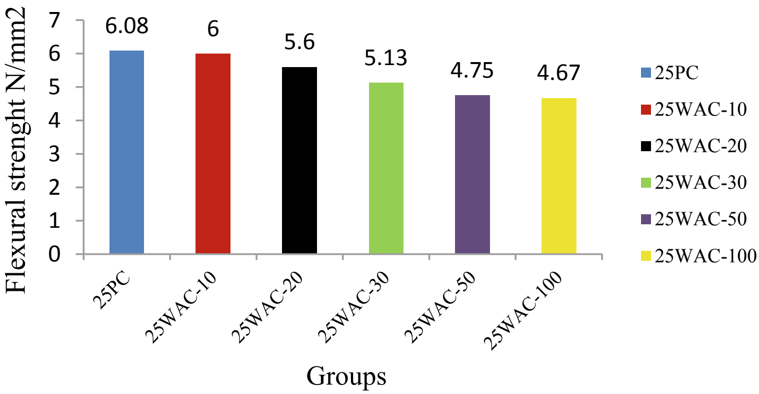

Fig. 9 Flexural strength result

5.4 Combined Flexural and Tensional Strength

This test involves the assessment of the combined effect of flexural and torsion (Fig. 10). Three samples for each group were tested. The load was applied and increased gradually till the failure occurred as shown in Fig. 11a–c. The final results in Fig. 11 noted increase in ultimate bending stress up to 20% replacement. Beyond 20% replacement WCA, ultimate bending stress is decreased as compared to reference concrete, where percentage of error for 20% replacement under torsion 243, 254 and 265 N m is equal to 0.0% and for 100% replacement under torsion 243,

Fig. 10 Experimental set-up for combined test flexural and torsion

254 and 265 N m is equal to 38, 41.66 and 45.45%, respectively. Final results are shown in Table 2. This result increase still may be because of flakiness and Pozzolanic property of ceramic tiles, and it may fill the gap completely, therefore, under torsion it may behave strongly.

6 Results and Discussions

Based on experimental investigations, following results have been found:

1. Compressive strength decreased 20% for 20% replacement where for 100%, it decreased to 30.73%.
2. Splitting tensile strength decreased 12% for 20% replacement where for 100%, it decreased to 20.05%.
3. Flexural strength decreased 7.89% for 20% replacement where for 100%, it decreased to 23.19%.
4. For combined flexural and torsion, ultimate bending stress increasing up to 20% replacement under torsion 243, 254 and 265 N m. For 10% replacement, increment is 30.7%, 30.7%, 30.7%, respectively, whereas for 20% replacement it is 0.0% for all and for 100% replacement under torsion 243, 254 and 265 N m it decreases to 38, 41.66 and 45.45%, respectively.

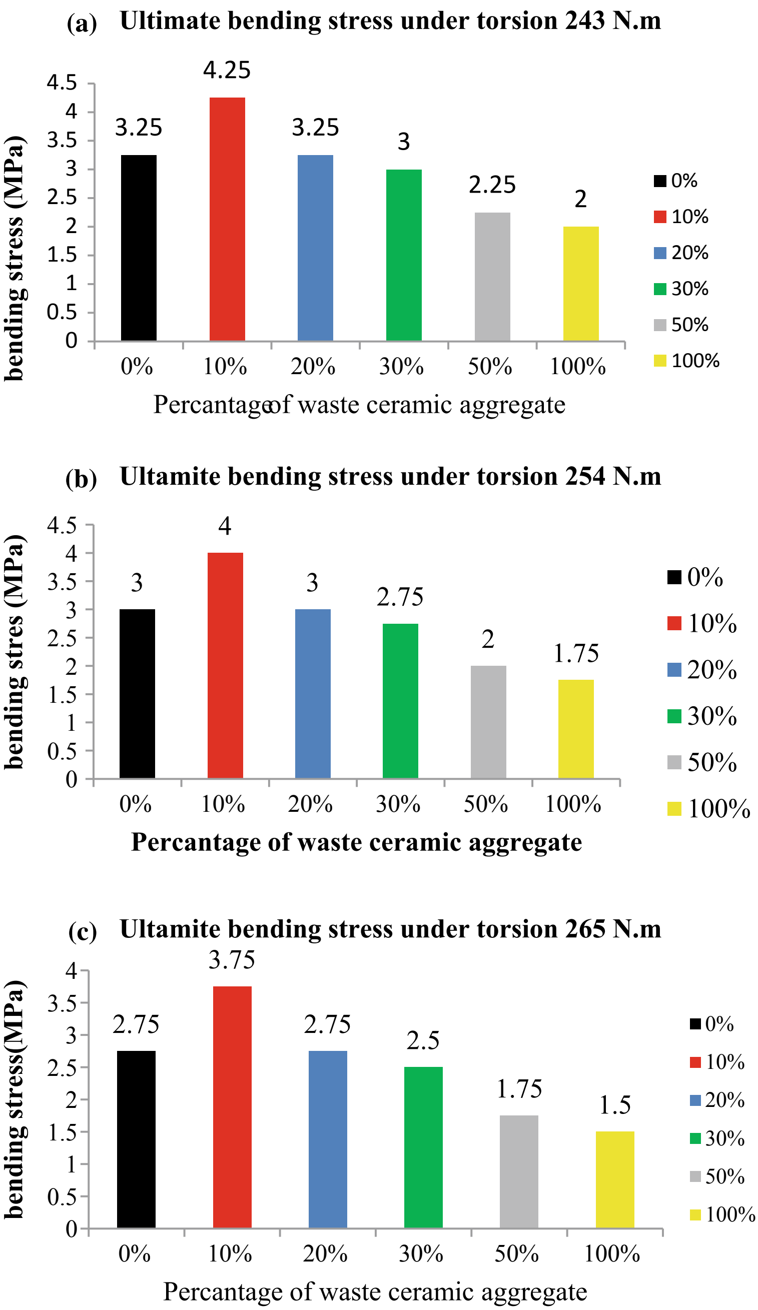

Fig. 11 **a** Combined test result under torsion 243 N m. **b** Combined test result under torsion 254 N m. **c** Combined test result under torsion 265 MPa

7 Conclusion

On the basis of the experimental study, it is found that less than 12% strength reduction up to 20% replacement is observed in tensile and flexural strength except compression, whereas for combined state, it is increasing up to 20% replacement. Therefore, it is concluded that the replacement up to 20% is highly appreciable.

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