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# STRENGTH STUDIES ON UNCONVENTIONAL CONCRETE WHEN PARTIALLY REPLACED WITH CERAMIC TILE AGGREGATE

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## ABSTRACT

This research paper investigates the strength of unconventional concrete (UC) when coarse aggregate is partially replaced with ceramic tile aggregate (CTA). The research was carried out in two phases. In the first phase, the strength parameters of unconventional concrete with that of conventional concrete of M30 grade were analyzed. In the second phase, coarse aggregate in the unconventional concrete was partially replaced with ceramic tile aggregate by 10%, 20% and 30%. The results of the experimental study determine the effective use of ceramic tile aggregate as a partial replacement of coarse aggregate in unconventional concrete and also serves in solid waste management.

**Keywords:** *Unconventional concrete (UC), ceramic tile aggregate (CTA).*

## I. INTRODUCTION

Cement industries all around the world are responsible for the emission of about 5% of overall carbon-di-oxide by the process of manufacturing of cement. Production of 1 tonne of cement releases about 0.90 tonnes of carbon-di-oxide in the atmosphere. Additionally, production of 1 tonne of concrete releases about 180 kilograms of carbon-di-oxide.

According to a report from Portland Cement Association (PCA), the global annual consumption of cement was 9.2 million metric tonnes in 2014 and has been increasing at 3% to 4% annually. This volume of cement consumption in concrete world-wide liberates plentiful carbon-di-oxide into the atmosphere to cause severe global warming. By the use of alternatives for cement as a pozzolanic material, the amount of carbon footprint can be brought down hence reducing the global warming.

Conventional concrete is a mix of four basic components - namely, cement, fine aggregate, coarse aggregate and water. Research in the field of concrete technology indicated that materials with pozzolanic properties can be used in concrete as substitutes or additives to cement. By-products of power plants, electric arc furnaces and iron ore industries like Fly Ash, Silica Fume and Ground Granulated Blast Furnace Slag (GGBS) respectively, possess good pozzolanic properties and can be used as a replacement of cement in concrete effectually. This has led to a new expression by the name “unconventional concrete”.

Unconventional concrete can be prepared when one or more additions or replacements are done in a mix of concrete. Prior research in unconventional concrete used Fly Ash, Silica Fume and Ground Granulated Blast Furnace Slag (GGBS) as a replacement for cement discretely or a combination of two. In the first phase of the project, on the basis of references and results from various earlier researches, a trial mix of unconventional concrete of M30 grade with 30% replacement of cement with 10% each of Fly Ash, Silica Fume and Ground Granulated Blast Furnace Slag (GGBS) was prepared and tested. Test results for strength parameters indicated an increase in compressive strength for the unconventional concrete.

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## II. SCOPE

Thorough investigations through various researches performed for different mixes of concrete with different variations of replacements suggests that there has been very little work done by replacing cement in concrete with fly ash, ground granulated blast furnace slag (GGBS), silica fume concurrently. Also, conclusions from various investigations and researches earlier stated suggest that for a higher grade of concrete mix such as M30, maximum replacement of cement by other pozzolans by 30%-40% gives better results. Furthermore, the optimum content of pozzolans such as fly ash, GGBS and silica fume in concrete mix is around 10%-12%. Based on conclusions drawn, a research on the variation in strength parameters when cement was replaced by these pozzolans in equal amounts i.e. 10% of total cement content each was open for question. This lead to the formation of "unconventional concrete" for the current project.

Additionally, ceramic waste as a replacement of coarse aggregate has drawn less attention through time and there is a need for an increased study in the same matter. In the later half of the present research work, ceramic waste was used as a replacement for coarse aggregate at 0%, 10%, 20% and 30% variations for M30 grade concrete mix and the strength parameters such as compressive strength and split tensile strength were studied.

## III. MATERIALS

### A. Cement

Locally available 43 grade ordinary Portland cement (OPC) of Birla A1 brand has been used in the present research project. The cement used was fresh and without any lumps. The cement thus procured was tested for physical and chemical requirements in accordance with are 8112:1989.

***Table 1. Physical properties of OPC 43 Grade used***

| S. No. | Properties | Test Result | IS Require -ments |
|---|---|---|---|
| 1. | Normal Consistency | 35% | -- |
| 2. | Specific Gravity | 3.15 | -- |
| 3. | Initial Setting Time | 48 min. | Not less than 30 min. |
| | Final Setting Time | 545 min. | Not more than 600 min. |
| 4. | Soundness by Le Chatelier | 3 mm | Not more than 10 mm |
| 5. | Fineness of Cement | 2% | Less than 10% |
| 6. | Compressive Strength | 45.3 MPa | 43 MPa |

### B. Fine Aggregate

River sand available in the local market was used as fine aggregate for the experimental work of the project. A property of fine aggregate such as fineness modulus, specific gravity, water absorption and gradation were subjected to tests in accordance with IS 2386:1963 and the following results were obtained.

*Table 2. Properties of Fine Aggregate*

| S. No. | Properties | Result |
|---|---|---|
| 1. | Fineness modulus | 2.7 |
| 2. | Specific gravity | 2.7 |
| 3. | Water absorption | 1.5% |

### C. Coarse Aggregate

The size of aggregates above the range of 4.75 mm are termed as coarse aggregate. In the present project, coarse aggregates passing through 20 mm and retaining on 12.5 mm were used. The aggregate was tested for its physical requirements such as gradation, fineness modulus, specific gravity and bulk density in accordance with IS 2386:1963 and IS 383:1970.

*Table 3. Physical properties of coarse aggregate*

| S. No. | Properties | Result |
|---|---|---|
| 1. | Fineness modulus | 7.228 |
| 2. | Specific gravity | 2.7 |
| 3. | Water absorption | 1% |

### D. Water

Water available from the local sources conforming to the requirements of water for concreting and curing as per IS: 456-2000 was used. Fresh portable water free from organic matter and oil was used in mixing the concrete. Water in required quantities was measured by graduated jar and added to the concrete. The pH of the water used should not be less than 6.

### E. Fly Ash

For this study, fly ash is incurred from National Thermal Power Corporation Limited (NTPC), Ramagundam. NTPC have installed facilities for segregation and collection of fly ash into 6 different fields. As the field number increases the fineness of fly ash increases but the quantity decreases. Field-1 fly ash has coarse particles and is not suitable for concrete applications. Fly ash from Field-2 onwards is segregated, packed and used for concrete applications. Since maximum availability of fly ash is from Field-2, same was used for our study. This fly ash conforms to the requirements of IS: 3812 Part 1 and also ASTM C-618 type F.

### F. Ground Granulated Blast Furnace Slag (GGBS)

The GGBS used in research was obtained from a Steel Plant in Chennai. Ground granulated blast-furnace slag is the granular material formed when molten iron blast furnace slag is rapidly chilled by immersion in water. It is a granular product with very limited crystal formation, is highly cementations in nature and, ground to cement fineness, and hydrates like port land cement. The specific gravity of GGBS is 2.85.

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*Table 4. Typical properties of GGBS*

| Physical Properties | |
|---|---|
| Calcium Oxide | 40% |
| Silica | 35% |
| Alumina | 13% |
| Magnesia | 8% |
| Chemical Properties | |
| Colour | Off white |
| Specific gravity | 2.85 |
| Bulk density | 1200 kg/m$^3$ |
| Fineness | 350 m$^2$/kg |

**G. Silica Fume (SF)**

The Silica fume used in present research was obtained from Chennai. Silica fume, also referred to as microsilica or condensed silica fume, is another material that is used as an artificial pozzolanic admixture. It is a product resulting from reduction of high purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume rises as an oxidised vapour. It cools, condenses and is collected in cloth bags. It is further processed to remove impurities and to control particle size. Condensed silica fume is essentially silicon dioxide (more than 90%) in non-crystalline form. Since it is an air-borne material like fly ash, it has spherical shape. It is extremely fine with particle size less than 1 micron and with an average diameter of about 0.1 micron, about 100 times smaller than average cement particles. Silica fume has specific surface area of about 20,000 m$^2$/kg, as against 230 to 300 m$^2$/kg.

*Table 5. Physical & Chemical Properties of Silica Fume*

| S. No. | Physical Properties | Result/Range |
|---|---|---|
| 1. | Bulk density | 750-850 Kg/m3 |
| 2. | Surface Area | 20000 m2/kg |
| 3. | Particle Shape | Irregular |
| | Particle size | N/A |
| | D50 | <7 micron |
| 4. | D95 | <20 micron |
| 5. | Specific gravity | 2.90 |
| 6. | Chemical Properties | Range/Result |
| 7. | $SiO_2$ | 30-36% |
| 8. | $Al_2O_3$ | 18 - 25% |
| 9. | $Fe_2O_3$ | .08-3% |
| 10. | CaO | 30-34 % |
| 11. | $SO_3$ | 0.1 -0.4 % |

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### H. Ceramic Waste

Ceramic tile aggregates (CTA) are crushed uniformly to about 20mm size manually using hammer and sieved through 20mm such that the aggregates collected are retaining on 12.5mm IS sieve. The various tests that were conducted on the ceramic tiles are specific gravity, water absorption and impact test.

*Table 6. Properties of Ceramic Tile Aggregate*

| S. No. | Particulars | Obtained Values |
|---|---|---|
| 1. | Specific gravity | 2.22 |
| 2. | Impact value | 24% |
| 3. | Water absorption | 14.4% |

*Table 7. Comparison of properties of ceramic tile aggregates (CTA) and normal aggregates*

| S. No. | Particulars | Normal Aggregate | CTA |
|---|---|---|---|
| 1. | Shape | Angular | Flaky |
| 2. | Texture | Rough | All sides rough except top face |
| 3. | Specific gravity | 2.7 | 2.22 |
| 4. | Impact value | 15% | 24% |
| 5. | Water absorption | 1% | 14.4% |

## IV. METHODOLOGY

Mix proportion for M30 grade concrete was arrived at by preparing appropriate trial mixes. The test for workability has been performed using slump cone test. Using the mix proportions so obtained for M30 grade, samples of cubes and cylinders were prepared. Later these specimens were subjected to tests to determine the compressive strength and split tensile strength at 7, 14 and 28 days.

### A. Mix Design

The material quantities obtained as per mix design method, (i.e. IS 10262:2009) arrived in trial mix are given in Table 10. The quantities of materials required are per one cubic meter of concrete. The detailed mix design procedure of M30 grade of concrete.

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*Table 8. Concrete proportion quantities per 1m3 for conventional concrete*

| S. No. | Grade | Materials(Kg/m3) | | | w/c |
|---|---|---|---|---|---|
| | | Cement | FA | CA | |
| 1. | M30 | 450 | 607 | 1178 | 0.40 |

*Table 9. Concrete proportion quantities per 1m$^3$ for unconventional concrete*

| S. No. | Grade | Materials(Kg/m$^3$) | | | w/c |
|---|---|---|---|---|---|
| | | Cement(70%) + Fly Ash+GGBS+ SF (10% each) | FA | CA | |
| 1 | M30 | 450 | 607 | 1178 | 0.40 |

*Table 10 Concrete propotion quantities per 1m$^3$ for unconventional concrete of M30 grade with replacement of course aggregate*

| S. No. | % replacement | Materials(Kg/m$^3$) | | | | w/c |
|---|---|---|---|---|---|---|
| | | Cement(70%) + Fly Ash+GGBS+ SF (10% each) | FA | CTA | CA | |
| 1 | 10 | 450 | 607 | 118 | 1060 | 0.4 |
| 2 | 20 | 450 | 607 | 236 | 942 | 0.4 |
| 3 | 30 | 450 | 607 | 353 | 825 | 0.4 |

### B. Experimental Procedure

The pozzolanic materials such as fly ash, GGBS and silica fume, which are used as replacement in unconventional concrete are procured. Ceramic waste is collected and transformed into ceramic tile aggregate such that it passes the 20 millimeter sieve and retains on 12.5 millimeter sieve. Test specimens are then prepared for M30 grade concrete based on the mix proportions and cured. Compressive test and split tensile tests are performed on these specimens.

### C. Tests conducte

Tests are conducted to find the compressive strength and split tensile strength of these specimens with the help of Universal Testing Machine (UTM) and results are tabulated. According to BIS 1881: part 116: 1983, the rate of load application is equal to 5 KN/sec or 0.22 N/mm$^2$/sec.

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## V. RESULTS AND DISCUSSIONS

The research investigates the influence of admixtures such as fly ash, silica fume and GGBS when used simultaneously, on the compressive strength and tensile strength of concrete of M30 grade. It also investigates the variation in strength parameters like compressive strength and tensile strength when Ceramic Tile Aggregate (CTA) is used in unconventional concrete as a partial replacement to coarse aggregate.

**Results**

***A. Conventional Concrete Vs Unconventional Concrete***

**1) Compressive Strength Test**

***a) Variation of load values of compressive strength***

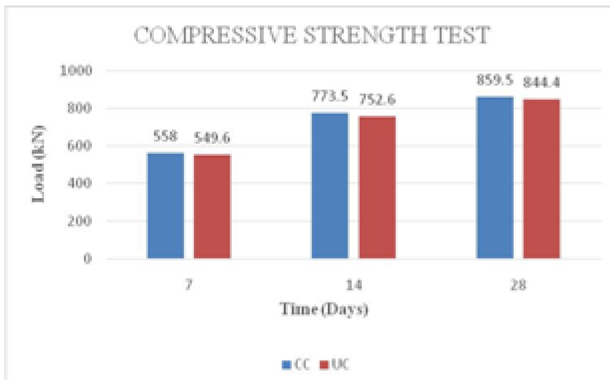


*Fig. 1. Load values of Compressive Strength test in kN*

***b) Variation of stress values of compressive strength***

*Table 12. Stress values of Compressive Strength test in N/mm²*

| MIX/DAYS | **7** | **14** | **28** |
|---|---|---|---|
| CC | 24.8 | 34.38 | 38.2 |
| UC | 24.4 | 33.44 | 37.53 |

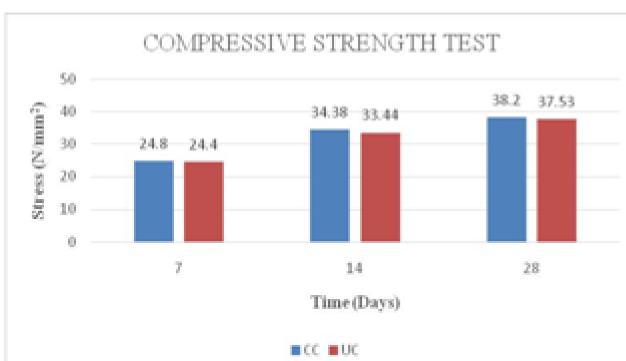


*Fig. 2. Stress values of Compressive Strength test in N/mm²*

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*2) Split Tensile Test*

**a) Variation of load values of split tensile strength**

*Table 11. Load values of Compressive Strength test in kN*

| MIX/DAYS | **7** | **14** | **28** |
|---|---|---|---|
| CC | 558 | 773.5 | 859.5 |
| UC | 549.6 | 752.6 | 844.4 |

*Table 13. Load values of Split Tensile test in kN*

| MIX/DAYS | **7** | **14** | **28** |
|---|---|---|---|
| CC | 151 | 170.3 | 222.6 |
| UC | 152.1 | 169.6 | 221.2 |

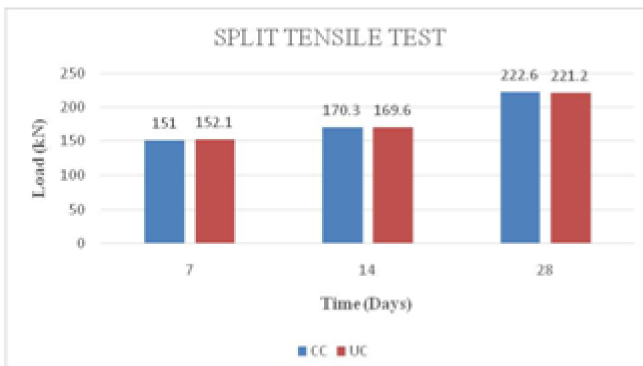


*Fig. 3. Load values of Split Tensile test in kN*

**2) Variation of stress values of split tensile strength**

*Table 14. Stress values of Split Tensile test in N/mm$^2$*

| MIX/DAYS | **7** | **14** | **28** |
|---|---|---|---|
| CC | 8.5 | 9.62 | 12.6 |
| UC | 8.6 | 9.59 | 12.5 |

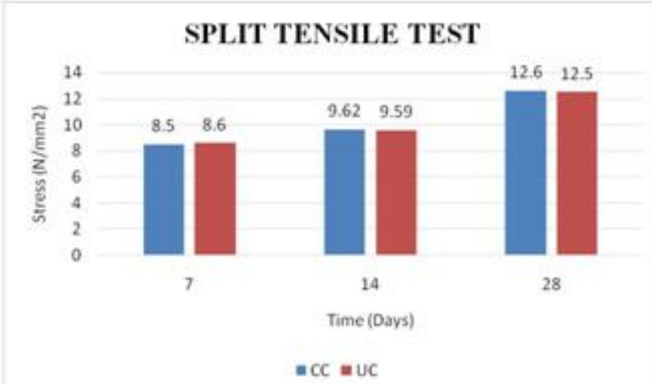


*Fig. 4. Stress values of Split Tensile test in N/mm$^2$*

### *B. Effect Of Ceramic Tile Aggregate (Cta) On Unconventional Concrete*

#### 1) Compressive Strength Test

##### *a) Variation of Load values of compressive strength*

*Table 15. Load values of Compressive Strength test in kN*

| MIX/DAYS | **7** | **14** | **28** |
|---|---|---|---|
| UC | 549.6 | 752.6 | 844.4 |
| UC- 10% | 610.8 | 704 | 865.1 |
| UC- 20% | 548.5 | 774 | 852.7 |
| UC- 30% | 538.8 | 779.9 | 897.7 |

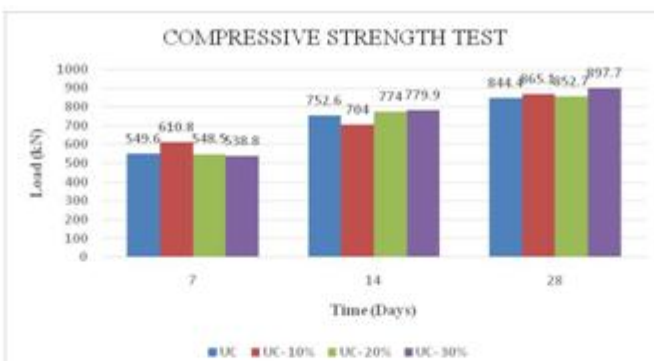


*Fig. 5. Load values of Compressive Strength test in kN*

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*b) Variation of stress values of split tensile strength*

*Table 16. Stress values of Compressive Strength test in N/mm²*

| MIX/DAYS | **7** | **14** | **28** |
|---|---|---|---|
| UC | 24.4 | 33.44 | 37.53 |
| UC- 10% | 26.15 | 31.28 | 38.45 |
| UC- 20% | 24.38 | 34.4 | 37.9 |
| UC- 30% | 23.95 | 35.55 | 39.9 |

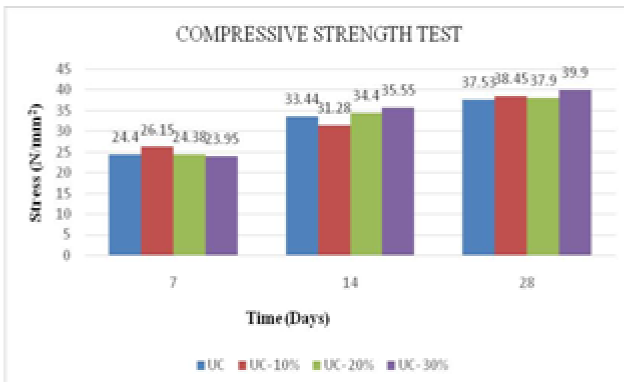


*Fig. 6. Stress values of Compressive Strength test in N/mm²*

### 2) Split Tensile Test

*a) Variation of Load values of split tensile strength*

*Table 17. Load values of Split Tensile test in kN*

| MIX/DAYS | **7** | **14** | **28** |
|---|---|---|---|
| UC | 152.1 | 169.6 | 221.2 |
| UC- 10% | 180.5 | 205 | 261.9 |
| UC- 20% | 138.1 | 158.4 | 210.6 |
| UC- 30% | 173.5 | 201.2 | 258.4 |

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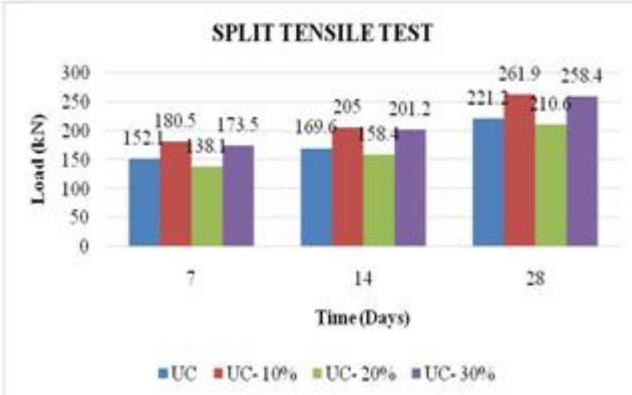


*Fig. 7. Load values of Split Tensile test in kN*

***b) Variation of stress values of split tensile strength***

*Table 18. Stress values of Split Tensile test in N/mm$^2$*

| MIX/DAYS | **7** | **14** | **28** |
|---|---|---|---|
| UC | 8.6 | 9.59 | 12.5 |
| UC- 10% | 10.2 | 11.58 | 14.8 |
| UC- 20% | 7.8 | 8.95 | 11.9 |
| UC- 30% | 9.8 | 11.37 | 14.6 |

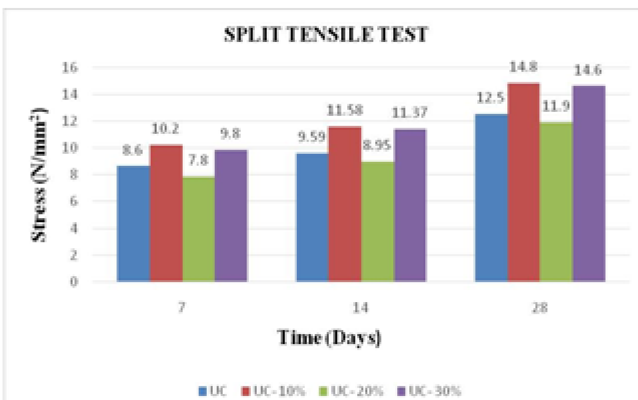


*Fig. 8. Stress values of Split Tensile test in N/mm$^2$*

**Discussions**

The results from the investigations carried out on concrete specimens of cubes and cylinders draw us to the following discussion

***Unconventional Concrete***

Compressive strength test results on unconventional concrete suggests that there is a marginal decrease in compressive stress by 1.75% when compared to conventional concrete of the same grade of concrete mix at the end of 28 days.

Even if there is a decrease in stress, it falls under the permissible limit and can be used as a replacement for conventional concrete. This would lead to a greener way of approach to concreting.

The split tensile test results on the other hand are more-or-less identical.

***Unconventional Concrete With Partial Replacement Of Coarse Aggregate***

When coarse aggregate was replaced by 10% with Ceramic Tile Aggregate (CTA) in unconventional concrete, an increase in compressive stress by 2.45% and tensile stress by 18.4% was observed when compared to unconventional concrete without replacement.

An increase in compressive stress by 1% and a simultaneous decrease in tensile stress by 4.8% was noted when coarse aggregate was replaced by 20% with Ceramic Tile Aggregate (CTA) in unconventional concrete.

The maximum increase in compressive stress was noticed when coarse aggregate was replaced by Ceramic Tile Aggregate (CTA) at a rate of 30%. The compressive stress increased by 6.3% and tensile stress by 16.8% when compared to unconventional concrete without replacement.

## VI. CONCLUSION

It can therefore be concluded that when unconventional concrete with 30% replacement of coarse aggregate with Ceramic Tile Aggregate (CTA) is used, the overall cost of the project can be reduced by 10%-15% and the carbon footprint due to the construction industry can be reduced making it an economical and greener approach towards construction.

## VII. ACKNOWLEDGMENT

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