Flexural strength evaluation of prestressed concrete beams with partial replacement of coarse aggregate by ceramic wastes
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ABSTRACT

The present study deals with the improved performance on compressive and flexural strength of prestressed concrete beams with the effect of ceramic wastes by partial replacement of coarse aggregates. Experimental work was carried out to investigate the effect of ceramic wastes by partially replacing aggregate and using same quantity of water. In this program cube samples of size 150mm x 150mm x 150mm for different percentage of ceramic wastes with partial replacement of aggregates were casted and tested. The concrete mixes had 5%, 10% of ceramic wastes replacing coarse aggregate partially, so as to determine the best proportion, which would give maximum compressive strength.

It reveals that with 5% ceramic wastes each partial replacement of coarse aggregate were found to be most favorable combinations for casting of prestressed concrete flexural members. There are two beam specimens of the same dimensions were casted and tested for their flexural strength. The dimensions of each beam were 125mm x 250mm x 3200mm. The beams were tested on universal testing machine (UTM) to verify their flexural strength after curing with two point load and. The results were compared with the beam of varying flexural strength.

Key words: Prestressed concrete, ceramic waste, flexural strength, partial replacement, compressive strength.

1. Introduction

1.1 General

It has been estimated that about 30% of the daily production in the ceramic industry goes to waste. This waste is not recycled in any form at present. However, the ceramic wastes are durable, hard and highly resistant to biological, chemical and physical degradation forces. Use of inorganic industrial residual products in making concrete will lead to sustainable concrete design and greener environment.

A review of earlier research shows that industrial as well as other wastes were used in concrete making to improve the properties of concrete and to reduce cost. The main objective of this investigation is to study the performance of prestressed concrete with ceramic waste as coarse aggregate.

1.2 Need for high strength steel and concrete
The normal loss of stress in steel is generally about 100 to 240 N/mm² and it is apparent that if this loss of stress is to be a small portion of the initial stress, the stress in the steel in the initial stages must be very high, about 1200 to 2000 N/mm². These high stress ranges are possible only with the use of high-strength steel.

1.3 Basic Concept of Prestressing

Prestressed concrete is basically concrete in which internal stresses of a suitable magnitude and distribution are introduced so that the stresses resulting from external loads are counteracted to a desired degree. The apparent tensile strength of that material, because the subsequent application of tensile stress must first nullify the compressive prestress.

1.4 Properties of ceramics

1.4.1 Physical properties

2 Optical properties: Transparency; Translucency.
3 Color: depends on visible light interaction with “ions” or “pigments”.
   (Color from ions [typically 0.2-0.4%] depends on the oxidation state)
4 Most ceramics are clear (i.e., transparent).
5 Scattering or diffusion of light.

1.4.2 Chemical properties

Chemical and electrochemical properties:
1. Chemical / Electrochemical corrosion properties: Very few under normal circumstances.
2. Solubility: Soluble in certain strong acids (HF) and strong bases. Usually non-crystalline (glassy) phases dissolve first. Capable of selective ion leaching and ion-exchange reactions.

1.4.3 Mechanical properties

Properties depend both on temperature and degree of crystallinity.
1. Mechanical properties versus melting temperature:
   a. Generally strength and modulus go up and down together.
   b. Modulus (E) at 25°C linearly related to melting temperature (Tm).
   c. (Ceramics = 30-350 GPa, Metals = 50-200 GPa, Polymers = <50 GPa)
2. Mechanical properties versus degree of crystallinity:
   a. Crystalline phases are stronger.
   b. At low T’s, crystalline and non-crystalline phases are brittle vice versa.

2. Properties of materials

2.1 Cement

OPC 53 grade cement
   a. Fineness modulus of cement = \((W2/W1) \times 100 = (38/400) \times 100 = 9.5\% < 10\% \text{ (IS: 269 – 1976)}
   b. Specific gravity of cement = 3.15
2.2 Fine aggregate

Specific gravity of fine aggregate,
Specific gravity of sand, \( G \) = \( \frac{(W2-W1)}{[(W4-W1)-(W3-W2)]} \) = 2.61
Permissible limit is in between 2.4 and 2.9(IS 2386 – part I -1963)

2.3 Coarse Aggregate

a. Specific gravity
Specific gravity \( G \) = \( \frac{(W2-W1)}{[(W4-W1)-(W3-W2)]} \) = 2.76
Permissible limit is in between 2.5 to 3

b. Water absorption test
Percentage of water absorption = \( \frac{(W2 – W1)}{W1} \times 100 \) = 0.15%

c. Impact test
12.5mm passing 10mm retained 25 stokes
Aggregate impact strength = \( \frac{(2.36mm\, sieve\, pass/Weight\, of\, aggregate\, taken)}{100} \) = 17%

2.4 Properties of Ceramic Wastes

![Figure 1: Ceramic waste](image)

a. Specific gravity
Specific gravity = \( \frac{(W2 – W1)}{[(W4 – W1)-(W3 – W2)]} \) = 2.25
b. Water absorption test

Weight of dry specimen = 2000gm
Weight of saturated specimen = 2004.4gm
% of water absorption = (2004.4-2000)/2000 x 100 =0.22%

c. Impact test

12.5mm passing 10mm retained 25 stokes
Ceramics impact strength = (2.36mm sieve pass/Weight of Ceramic taken)x 100
= 15.6%

2.5 Prestressing Strand

![Prestressing strand image]

Figure 2: Prestressing strand

Ultimate tensile strength = Load / Area
= (3.3 x 10^3) / (π/4 x 5^2)
= 1680 N / mm^2

3. Design methodology

3.1 Concrete mix design

3.1.1 General

1. Mix design is known as selection of mix ingredients and their proportions required in a concrete mix.
2. In India the most commonly used method for mix design is the Indian standard method.
3. The mix design involves calculations of the amount of cement, FA and CA in addition to other related parameters.
3.1.2 Design stipulations: M35

For M35 grade of concrete characteristic strength at 28th days:
- Maximum nominal size of aggregate: 20mm
- Degree of quality control: good
- Type of exposure: moderate

Materials used

- Type of cement = OPC53 grade
- Specific gravity of cement = 3.15
- Specific gravity of fine aggregate = 2.61
- Specific gravity of coarse aggregate = 2.7

Mix Proportioning

Target mean strength of concrete:
- $f_{ck''} = f_{ck} + 1.65s = 35 + 1.65 \times 5 = 43.25 \text{N/mm}^2$
- Water-cement ratio: $W/C$ for $f_{ck''} = 43.25 \text{ Mpa}$ is $0.4$
  - $0.4 < 0.6$ hence prescribed for moderate.

Selection of water and sand content

- For aggregate size = 20mm
- Water content/m$^3$ = 186 kg
  - Estimate of water content for 75mm slump = $(186 + 6) / (100 \times 186)$
  - The required water content = 197lit

Determination of cement content

- Water – cement ratio = 0.4
- Cement = $197 / 0.4 = 492.5 \text{Kg/m}^3$
  - This cement is adequate for moderate.

Volume of coarse and fine aggregate

Mix calculations per unit volume of concrete as follows:
- a) Volume of concrete = 1m$^3$
- b) Volume of cement = $(\text{Mass/Specific gravity}) \times 1/1000$
  - = $(492.5 / 3.15) \times 1/1000$
- c) Volume of water = $(\text{Mass/Specific gravity}) \times 1/1000$
  - = $(197 / 1) \times 1/1000 = 0.197 \text{m}^3$
- d) Volume of all in aggregate = $(a) - (b + c)$
  - = $1 - (0.156 + 0.197) = 0.647 \text{m}^3$
- e) Mass of Coarse aggregate = $(d) \times \text{Volume of CA x Sp.gravity x1000}$
  - = $0.647 \times 0.62 \times 2.76 \times 1000 = 1107.146 \text{Kg}$
- f) Mass of FA = $(d) \times \text{Volume of FA x Sp.gravity x1000}$
  - = $0.647 \times 0.38 \times 2.61 \times 1000 = 641.069 \text{Kg}$

Mix proportion
3.2 Design of pretensioned beam

Size of beam:
Cross section = 125mm x 250mm
Length = 3.2m
Live load = 10KN
Loss of stress at transfer = 1.4N/mm²
Diameter of prestressing strand = 5mm
Density of concrete = 24KN/m³
Self-weight of beam, Wg = 0.125 x 0.25 x 24 = 0.75KN/m
Section modulus, Z = (125 x 250²)/6 = 1302.08 x 10³ mm³
Self-weight moment, Mg = 0.125 x 0.25 x 24 = 0.96KNm
Live load moment, Mq = 10 x 1 = 10KNm
Permissible stresses, Ftt = 0N/mm²
Ftw = -1.4N/mm²
Required prestress at top and bottom
At bottom = [ftw / η + (Mq+Mg) / (η x Z b)]
= [-1.4/0.8+10.96 x 10⁶ / (0.8 x 1302.08 x 10³)] = 8.77N/mm²
At top = [ftt - (Mg/Zt)] = [0-0.96x10⁶ / (1302.08 x 10³)]
= -0.737N/mm²
Prestressing force = [A (finf Z b + fsup Z t) / (Z b+Z t)]
= [31250(8.77-0.737)1302.08 x 10³ / [(2 x 1302.08 x 10³)]
P = 125.51KN
Eccentricity, e = Zt Zb (finf-fsup) / [(A (finf Z t+finf Z b)) IfvZt = Zb,
e = Z/A x (finf-fsup)/ (finf+fsup)
= [(1302.08 x 10³) / (31250)] x [9.507/8.033]
= 49.31mm. Say 50 mm.
Area of 5mm wire = (π/4) x 5² = 19.63mm²
Force in each wire = 19.63 x 1570 = 30826.87N
Number of wires = 125.51/30.826 = 4.07 Nos. (Say 5 Nos.)
Elongation length = P l / (AE)
= (30.826 x 10³ x 3200) / (19.63 x 210 x 10³)
δl = 23.9 mm (Say 24 mm)

3.3 Ultimate moment capacity

Moment of resistance (or) flexural strength, \( M_u = f_{pu} A_d (d - 0.42 x_u) \)
Effective reinforcement ratio: \( (A_p f_p) / (b d f_{ck}) \)
= (π/4) x 5² x 1600 / (35 x 125 x 250)
= 0.143
From IS 1343 , fpu = 1392 N / mm² \( x_u = 77.68mm \)
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$$Mu= 1392 \times 98.17 \times (250 – 0.42 \times 77.68)= 29.70 \text{ KNm}$$

Therefore, Ultimate moment capacity of beam = 29.70 KNm.

Ultimate Load
$$Mu= \frac{(Wu \ l)}{6} = \frac{(Mu \ 6)}{l}= \frac{(29.70 \times 6)}{6}= 59.4 \text{ KN}= 5.94 \text{ Tons}$$

4. Experimental Methods

4.1 Pretensioning

There are two ways in which prestressing of concrete by steel element can be accomplished, namely, pretensioning and post tensioning. In pretensioning, the tendons are tensioned before casting of concrete and in post tensioning tendons are tensioned after the concrete hardens enough to support the stress. In our work, the members were cast by using pretensioning.

![Figure 3: Mono Strand hydraulic jack](image)

4.2 Mould preparation and specimen casting

Cube samples of size 150mm x 150mm x 150mm for different percentage of ceramic wastes in partial replacement of aggregates were casted. The concrete mixes had 5%, 10% of ceramic wastes with partial replacement of aggregates. After final setting of cubes, the cube moulds were removed and cubes were kept curing for 28 days. All specimen beam 125mm x 250mm x 3200mm were casted with optimum compressive strength for the specific mix and consolidated using needle vibrator. After setting the beams are kept in curing tank for 28 days.

4.3 Steam curing

The casted beams are kept in,

- a. 4 hours for free atmosphere , 2.5 hours for inside the steam curing chamber (In first 1 hour temperature was gradually increased up to 30°C, another 1.5 hour the temperature gradually increased from 30°C to 60°C).
- b. Next the steam curing is maintaining the temperature at 60°C for 12 hours.
- c. After completion of 12 hours, the temperature was gradually reduced to 30°C
- d. duration of next 2 hours.
e. Then the steam curing chamber is turned off and next 5 hours the beams are maintained at off condition of the curing chamber.

Figure 4: Mould setup

Figure 5: Steam curing

4.4 Test Setup and procedure

The beam specimen was simply supported with a two point load applied at two – third of the span, as shown in figure – 2. Load was applied by using UTM (25 tons capacity) in 0.25 ton increments up to failure load. At the each load increment, cracks were inspected and marked, and the beam was photographed. Continuous monitoring was carried out all through the testing.

Figure 6 – Two point Loading
4.5 Test performed

4.5.1 Compressive strength

Table 2: Compressive strength

<table>
<thead>
<tr>
<th>S.No</th>
<th>Replacement % of Ceramics</th>
<th>Load (kN)</th>
<th>Area (mm²)</th>
<th>Compressive Strength At 28th day (kN/mm²)</th>
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<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>922.5</td>
<td>22500</td>
<td>41</td>
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<td>900</td>
<td>22500</td>
<td>40</td>
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</table>

Figure 7: Comparison of Compressive strength at 28 days

5.2 Flexural strength

The following diagram shows the comparison of Flexural Strength replacement of Coarse Aggregate with 5% and 10% of Ceramic wastes. The values of Deflection is provide on table 2 and table 3, on next to the diagram.

Figure 8: Comparison of Deflection
**Table 2: 5% Replacement of Coarse Aggregate by ceramics**

<table>
<thead>
<tr>
<th>S.no</th>
<th>Load in $10^4$ N</th>
<th>Deflections (Metal Gauge Readings) DIV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.00</td>
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<td>0.25</td>
<td>0.10</td>
</tr>
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<td>4</td>
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<td>2.25</td>
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<td>15</td>
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<td>27.0</td>
</tr>
<tr>
<td>21</td>
<td>5.00</td>
<td>Ultimate Load</td>
</tr>
</tbody>
</table>

1 Tonne=8 Division

**Table 3: 5% Replacement of Coarse Aggregate by ceramics**

<table>
<thead>
<tr>
<th>S.no</th>
<th>Load in $10^4$ N</th>
<th>Deflections (Metal Gauge Readings) DIV</th>
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<tbody>
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<tr>
<td>23</td>
<td>5.50</td>
<td>Ultimate load</td>
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</tbody>
</table>

1 Tonne=12 Division
5. Results

5.1 Test results

As above discussed, flexural strength of prestressed concrete beam specimens were found to be less by using analytical methods than experimental results. Further it was found that OPC + CERAMICS based on experimental results were less than that of OPC.

5.2 Discussion with results

By comparing the specimens tested it is evident that the compressive strength was reduced for the cubes and beam specimens using ceramics partially replacing to coarse aggregate. When quantity of water is kept same for all mixes. After reviewing and analyzing the results following points are predominantly revealed which are mentioned / discussed as given below:-

5.3 Conclusions

1. The flexural strength of OPC concrete prestressed beam has more flexural strength when coarse aggregate partially replaced with 5% and 10% of ceramics
2. Ceramics having maximum benefit than aggregate in terms of cost and strength comparison.
3. Deflection of prestressed concrete having less deflection in 10% of partial replacement when compared to 5% of ceramics replacement.
4. Load carrying capacity of partially replaced ceramic prestressed beam is high, when compared to ordinary prestressed beam.
5. Micro – Cracking character is essentially changed.

Acknowledgements

The authors would like to thank the management of Dhanalakshmi Srinivasan Engineering College for providing the facilities to carry out this work

6. References

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