Experimental investigation on Ferrocement slab using partial replacement of cement by ceramic powder

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Abstract: In this study, flexural behaviour of the Ferrocement panels of size 500 mm x 500 mm x 50 mm with partial replacement of ceramic powder under monotonic loading is observed. All the Ferrocement panels were casted with cement mortar of mix proportion 1:4 with w/c ratio of 0.45 and all the specimens were casted with single layer of galvanized welded wire mesh of 2mm diameter with mesh opening of 12.5 mm x 12.5 mm. The ceramic powder is administered at various percentage replacement of cement by weight and the adopted variations are 0%, 5%, 10% and 15%. Compressive strength of the mortar mix for all the different ratios of ceramic powder was carried out and the results were discussed. It can be concluded that the Panel with 10% replacement of ceramic powder offers appreciable results than the other panels.

1. Introduction
Ferrocement panel construction avoids the complicated formwork as in Reinforced cement concrete (RCC), as its thickness range in between 15 mm to 50 mm. Instead of large diameter rebars, it requires only smaller diameter of wire mesh of 0.6 mm to 2mm which may be square, rectangle or hexagonal with the mesh openings of 10mm, 12.5 mm and 15 mm. Galvanized welded wire mesh are the best as compared with the other wire meshes. From the research, it could understand the daily waste would be 30 percent from the ceramic industry, which is hard, durable. Hence, the disposal rate of ceramic waste is increased due to bulk production and requirement, so now-a-days, this ceramic powder is used as a partial replacement of cement in mortar mix and concrete. ACI-549R\textsuperscript{[1]} stats that normally, 15 percent is the acceptable limit for the replacement of cement in the Ferrocement construction. Also, three-point loading is preferred for the investigation of flexural behaviour in the Ferrocement construction. Hemalatha\textsuperscript{[2]} deals with the investigation of ferrocement slabs subjected to impact test. A total of 4 slabs were cast and tested, the size of these slabs is of 300 mm x 300 mm x 25 mm. These slabs were cast by varying the number and size of reinforcing mesh layers. Cement mortar matrix mix for ferrocement slabs was finalized by developing 5 mixes of high strength mortar. A mix of ratio 1:1 mortar with 90% cement, 10% silica fume and M-sand gives the compressive strength of 80-90MPa, therefore it is adopted as a best mix for ferrocement slab. Further welded mesh of 2 and 4 layers of 60mm and 30mm openings were used as a reinforcement content of 0.63%, 1.25%, 1.69% and 2.32% to cross sectional area of the slab. From the results of this study, it is observed that impact strength and energy increase with increase in mesh layers and mesh size. Saranya S\textsuperscript{[3]} has investigated in the strength and durability aspects of Ferrocement by conducting various experiments: Compressive strength of cement mortar, Flexural behaviour of panel size 900 mm x 300 mm x 25 mm - 12 nos. with single layer crimped wire mesh and single layer galvanized wire mesh were used to study the strength factor and water absorption with 9 mortar cubes, rapid chloride penetration with 9 mortar cylinder of size 100 mm x 200 mm and half-cell potential with 12 Ferrocement panel of size 900 mm x 300 mm x 25 mm for durability studies. Sodium nitrate with density 1.152 kg/m\textsuperscript{3} of 1% and 2% has been incorporated as inhibitors. Also, the crack pattern for the
all the panels were recorded. After conducting these experiments with 24 Ferrocement panels, it is seen concluded that crimped wire mesh with sodium nitrate inhibitor of 2% shows greater difference than the specimens with galvanized wire mesh in all the experiments.

B. Santhosh [4] has investigated experimentally on flexural behaviour of Ferro cement composite beam using self-compacted concrete. The Ferro cement largely depends on its durability aspects and corrosion problems of thin reinforcing wire or welded mesh. In composite beam the slab consists of concrete which is Self-Compacting Concrete or Self-consolidating concrete has low yield stress necessary to ensure uniform suspension of solid particles. In particular, the method of shear transfer between composite layers is going to be examined. In this phase the literatures are collected and they are studied in order to get an idea of Ferro cement composite beams and materials required for the project are collected and basic materials testing was done for designing the mix. Various types of composite beam specimens are going to test under a two-point loading system up to failure in next phase. Generally composite beam has good ductility, cracking strength and ultimate capacity. From experimental data the flexural Behaviour and load - deflection of composite beam is to be studied.

S. Jeeva Chithambaram and Sanjay Kumar [5] investigated the flexural behaviour of ferrocement slabs with the replacement of cement with fly-ash and bamboo strips was placed in the two layers along with the chicken mesh. Six Ferrocement panels of size 940 mm x 470 mm with the thickness of 40 mm and 50 mm each with the CM 1:3 and another six panels with 15% replacement of cement with fly-ash and with the bamboo strips. All the specimens were tested under monotonically increasing uniformly distributed load. Obtained experimental results were compared with the theoretical results and both the values are almost same.

The main objective of this study was to investigate the suitability of the industrial waste material - ceramic powder in as the partial replacement of cement. The variations adopted are 0%, 5%, 10% and 15%. Mortar mix CM 1:4 with the water-cement ratio of 0.45 were used for all the specimens. Initially, cubes were casted to evaluate the compressive strength of the different mix. Then, Ferrocement panels of size 500 mm x 500 mm x 50 mm were casted for all the ratios and subjected to three-point loading to study the flexural behaviour of the panel. Also, the crack pattern of these specimens was carefully noted during the loading process. industrial plants, agricultural areas and at the same time achieving the required strength of concrete.

2. Experimental Procedure

2.1 Materials used

The materials required for the casting are cement, ceramic powder, fine aggregate, water and wire meshes, which are discussed below.

2.1.1 Cement and Ceramic Powder

OPC 43 Grade Cement conforming to IS 8112-2013[6] with the specific gravity – 3.06, consistency – 27.5% and fineness – 3.20 on IS 90-micron sieve was used. White colour ceramic powder was obtained from the industry near Ambattur which has the specific gravity – 2.90 and consistency – 32.5%. The chemical properties of the cement and ceramic powder are tabulated in Table 1.

| Oxides Composition | Oxide content in % |
|-------------------|-------------------|
|                   | Cement | Ceramic Powder |
| SiO₂              | 21.04  | 66.39          |
| CaO               | 64.36  | 3.65           |
| Al₂O₃             | 6.12   | 18.14          |
| Fe₂O₃             | 2.54   | 2.39           |
| MgO               | 2.31   | 3.58           |
| K₂O               | 0.64   | 3.28           |
| TiO₂              | 0.08   | 0.46           |
2.1.2 Sand, water and wire mesh

Local river sand passing through 4.75 mm sieve with a specific gravity of 2.63 and a fineness modulus of 2.70 conforming to grading zone III of IS-383-1970[7] was used as fine aggregates. Potable water with pH value less than 7 was used for casting. Table 2. Reveals the mechanical properties of wire mesh which has been used in this study.

| Wire mesh type       | Properties                        | Values          |
|----------------------|-----------------------------------|-----------------|
| Galvanized welded    | Diameter                          | 2 mm            |
| wire mesh            | Mesh openings                     | 12.5 mm         |
|                      | Yield strength in tension         | 390.12 N/mm²    |
|                      | Modulus of elasticity             | 98.68 x 10⁴ N/mm² |

2.2 Mortar mix

Mortar mix CM 1:4 with the water-cement ratio of 0.45 were used for all the variations of ceramic powder - 0%, 3%, 5% and 10%. All the required materials were weighed carefully and mixed in a Pan mixer. First, Cement, ceramic powder and sand were mixed for 2 minutes, the required water was poured and mixed for 3 minutes. Then, with the trowels, the mortar was applied into the mould. Table 3 shows the different mortar mix proportions used in this study.

Required proportion of material for a single panel was carefully measured for all the mortar mixes and it is labelled as below.

- CP 0 – Mix with 0% replacement of Ceramic powder.
- CP 5 – Mix with 5% replacement of Ceramic powder.
- CP 10 – Mix with 10% replacement of Ceramic powder.
- CP 15 – Mix with 15% replacement of Ceramic powder.

Table 3. Mix Proportions of Mortar

| Mortar Mix | Materials (kg/m³) | OPC | Ceramic Powder | Sand |
|------------|-------------------|-----|----------------|------|
| CP 0       | 385               | -   | -              | 1540 |
| CP 5       | 365               | 20  | 1540           |
| CP 10      | 346               | 39  | 1540           |
| CP 15      | 327               | 58  | 1540           |

2.3 Compressive Strength Test

Compressive Strength test was carried out as per IS 516 1978, to find the effect of ceramic powder in the mortar mix on the compressive strength. 100 mm cube specimen was used, after 24 hours, the cubes were demoulded and it was immersed in the water tank. All the specimens were tested in the Compression Testing machine of 3000 KN and noted the maximum load at which the specimen failed and it’s tabulated in Table 4.

Table 4. Compressive Strength Test Results

| Mortar Mix | Compressive Strength (N/mm²) |
|------------|-----------------------------|
|            | 7th Day | 28th Day |
| CP 0       | 23      | 35       |
| CP 5       | 26      | 37       |
| CP 10      | 33      | 41       |
| CP 15      | 31      | 39       |

Figure 1. shows the compressive strength results of 7th and 28th for all the mortar mix. It can be observed that compressive strength increases with the increase in percentage variations of ceramic powder as compared with the control or zero percent replacement in both 7th and 28th day compressive strength results.
Figure 1. Compressive Strength Results on 7th and 28th day.

### 2.4 Flexural Strength Test

The flexural behavior of the ferrocement panels of size 500 mm x 500 mm x 50 mm with galvanized wire mesh of single layer were tested under three – point loading as shown in Figure 2. All the Ferrocement panels were casted in timber formwork; corresponding mortar mix is poured up-to the mid-height (i.e.) 24 mm and Galvanized welded wire mesh of 2 mm diameter is placed over it, then the mortar is applied over the wire mesh for the height of 24 mm. Then, all the specimens were air dried for one day and it was demoulded and was immersed in the water tank for the period of 28 days at the room temperature of about 270°C. Finally, all the specimens were taken out and kept at the room temperature before testing. Also, the Ferrocement panels were labelled as same for the compressive strength testing. (CP 0, CP 5, CP 10 and CP 15).

![Three-point loading](image)

Figure 2. Three-point loading

Finally, all the specimens were tested for the flexural strength in Universal Testing machine (UTM) of capacity 40T. Specimens were placed at the UTM in such a way that the edges are simply supported over the roller and the single line load is applied at the center of the panel. The deflection at midspan is measured by a dial gauge having accuracy equal to 0.01mm. Cracking was carefully checked throughout the loading process and the corresponding cracking load is also noted. The central dial gauge was fixed and the initial reading of dial gauge was recorded at the beginning of the test. The load was applied in increment of 5 N and central slab deflections were measured. The applying load was continued until failure occurred.
3. Results and Discussion

3.1 Compressive Strength Test

From the Figure 1, we could see that the compressive strength of 7th day results shows a gradual increase of 13.04 % with respect to the replacement of cement by 5% as compared with the control specimen. Similarly, 43.47 % and 34.78 % for the 10% and 15 % replacement respectively. From the 28th day results, there is a small increment in the strength of 5.71%, 17.14 % and 11.43% w.r.t the replacement of cement by 5%, 10% and 15% respectively as compared with the 0% replacement.

It could be clearly understood that the 10% replacement of ceramic powder gives the optimum strength than all other variations. From this, we could understand that the ceramic powder with high amount of silicon dioxide which react with calcium hydroxide from the hydration process of cement results in higher compressive strength than the control specimen. Also, the high content of aluminium oxide in ceramic powder causes the early strength than the control specimen. The strength obtained for the 15% replacement of ceramic powder shows lesser value than the 10% replacement – in this, we could understand that even aluminium oxide content is higher but the amount of calcium hydroxide is not enough to react and give calcium aluminate hydrates.

3.2 Flexural Strength Test

The results of loads and deflections at first crack point and ultimate value of all the Ferrocement panels were tabulated in Table 5. From the Fig 3, we could understand that the ultimate capacity of slab with 0%, 5%,10%,15% replacement is 37kN, 42 kN, 52 kN and 48 kN respectively. From this, we could understand that the 10 % replacement is the optimum mix with higher load carrying capacity. The addition of ceramic powder increases the matrix density in concrete which ultimately leads to higher load carrying capacity of the element. Table 5 shows that there is a gradual increase of 13.51 % with respect to the replacement of cement by 5% as compared with the control specimen. Similarly, 40.54 % and 29.73 % for the 10% and 15 % replacement respectively.

| Sl. No | Specimen ID | First Crack Load (kN) | Deflection at First Crack Load (mm) | Ultimate Load (kN) | Deflection at Ultimate Load (mm) |
|--------|-------------|-----------------------|-----------------------------------|--------------------|----------------------------------|
| 1.     | CP 0        | 26.5                  | 3.6                               | 35                 | 8                                |
| 2.     | CP 5        | 29.6                  | 3.1                               | 40.5               | 8.9                              |
| 3.     | CP 10       | 37.3                  | 4.2                               | 51                 | 9.5                              |
| 4.     | CP 15       | 34.5                  | 3.5                               | 47                 | 9.1                              |

Table 5. Comparison of loads and deflection of ferrocement panels.

15 % percent replacement of cement with ceramic powder shows lesser value than 10% replacement, this leads to scarcity of cement content in the matrix to bond well. Thus, it ultimately reduces the strength on higher replacement of ceramic powder.

**Figure 3. Load vs Deflection of Ferrocement Panels**
4. Conclusions
The following observations were based on the experimental investigation on the partial replacement of cement with ceramic powder with different variations are discussed here,

- In the compressive Strength test, 10% replacement of ceramic powder gives the optimum strength than all other variations. Form this, we could understand that the ceramic powder with high amount of silicon dioxide which react with calcium hydroxide from the hydration process of cement results in higher compressive strength than the control specimen.

- In the Flexural behaviour, the ultimate capacity of slab with 0%, 5%, 10%, 15% replacement is 37kN, 42 kN, 52 kN and 48 kN respectively. 15% percent replacement of cement with ceramic powder shows lesser value than 10% replacement, this leads to scarcity of cement content in the matrix to bond well. Thus, it ultimately reduces the strength on higher replacement of ceramic powder.

5. References
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