An Experimental Investigation on Flexural Strength of Ferrocement Slab Made of Slag Sand Partially Replaced With Iron Ore Tailings

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Abstract: Effective use of slag sand and Iron Ore Tailings and other waste obtained from the manufacturing industry and mining industry like waste foundry sand, will reduce the negative impact on the environment and also will provide opportunities for effective use of natural resources and contribute to sustainability. The aim of this research project is to study the flexural strength of ferrocement slab made of slag sand partially replaced with iron ore tailings with sustainability point of view. Investigation of 48 slab panels of 700mm x 300 mm size with thickness 25 mm and 30 mm was conducted using 1 and 2 layers of weld mesh reinforcement casted with different percentage of iron ore tailings. Slabs were tested in Universal Testing Machine, which showed good results with 15% of iron ore tailings.

Keywords: Flexural Strength, Ferrocement, Slag Sand, Iron Ore Tailings.

1. INTRODUCTION

Inception and evolution of ferrocement technology is as old as cement concrete. Its advantages and applications are to be experimented and explored more in the rapidly growing construction world. Western countries are making use of ferrocement components in their building construction with the help of sophisticated technology. In spite of having a large number of labour forces, Asian countries are still far behind in adopting the ferrocement technique as a simple solution for low cost housing problems and other urgent needs. Nowadays, a great amount of research has been taken up by the governmental and technical agencies in East and West to promote the use of ferrocement in roof slabs, domes, water tanks, retrofitting etc. “Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable materials.”[5]. Ferrocement is a highly versatile form of reinforced cement concrete made up of wire mesh, sand, water and cement, which possesses unique qualities of strength and serviceability [6].

As the population is increasing and housing demand is growing, “reinforced concrete has been extensively recommended for the construction of houses, buildings, roads, bridges and dams” [7] Ever since the World summit of 2010 in Brazil and the latest one in France a few months back, ecology has been vehemently highlighted in the world politico-economic debates. The danger of Global warming and the alarming damage that is waiting to occur due to carbon emission is a concern for all nations. However, huge production of cement and its use in construction industry in different ways is made
inevitable nowadays. According to various studies the impacts of this superfluous use of cement concrete construction alone contribute in the Global warming approximately 5 to 10%. At this juncture, creative ideas about production and use of innovative and sustainable materials for future constructions is necessary, which may pave the way for reduced impact of Global warming. Appropriate use of ferrocement materials like ferrocement roof slabs, water tanks, wall panels and similar elements may reduce a huge amount of use of concrete. Effective use of slag sand and Iron Ore Tailings (IOT) and other waste obtained from the manufacturing industry and mining industry like waste foundry sand will reduce the negative impact on the environment and also will provide opportunities for effective use of natural resources and contribute to sustainability.

2. LITERATURE REVIEW

Thenmozhi. R. et al. [1], has investigated the flexural behavior of ferro-cement slabs made of Self Compacting Micro-concrete using different number of weld mesh layers and slab thicknesses. In this paper it is noticed that all panels with single layer of weld mesh had failed immediately without giving any prior warning and it showed brittle failure. All panels were failed in flexure without giving ample sign of cracks until 25% of ultimate load reached. It is observed that behavior is linear till tension cracks were formed for all the elements. These cracks were formed at the bottom of surface of the slabs and spread vertically upward. Cracks were appeared between the supports and close to loading points while reaching half the ultimate load. In the case of slabs with two or more number of weld mesh layers more number of flexural cracks were formed in the region of pure bending. From the appearance of multiple cracks it can be concluded that ferrocement elements are having high ductility.

There are three phases of failure, which can be seen while applying two point loads on the slab panels such as pre-cracking stage, multiple cracking stage and failure stage.

Amala M. et al. [2], have studied the behavior of ferrocement panels under flexural loading in which welded square mesh has been used as reinforcement and copper slag is also used replacing river sand. Based on the flexural test and impact test results, the results observed are as follows:

1. They observed that ultimate load for cracking of ratios 1:1, 1:2, and 1:3 are 5.4kN, 6.56kN and 7.36kN for Static Loading and 5.36kN, 5.2kN, 5.22kN for Cyclic Loading respectively.

2. They observed ultimate load for cracking of ratios 1:1.26, 1:2.52, 1:3.48 are 5.4kN, 6.56kN, and 7.36kN for Static Loading and 5.36kN, 5.2kN, 5.22kN for Cyclic Loading.

3. It was concluded that among the cement mortar Ferro-cement slabs of 2 layers of different mix proportions, 1:2.52 cement with copper slag mix has provided the best results.

Phalke J. Randhir, et al [3], studied on the effect of using different number of wire mesh layers on the flexural strength of flat ferrocement panels. Also, the investigators related the effect of varying the number of wire mesh layers and the use of steel fibers on the ultimate strength and ductility of ferrocement slab panels. They report that the, flexural loads at its first crack and ultimate loads depend on the number of reinforcing mesh layers used in ferrocement panel. Increasing the number of layers of wire mesh from 2 to 4 layers increases the ductility and capability to absorb energy of the panels. Result shows that adoption of steel fibers by increasing the number of layers leads to 58% increase in load carrying capacity and 33% decrease in deflection.

Kumar B N et al [4], Iron Ore Tailings (IOT) used as partial replacement to fine aggregates at levels of 10, 20,30,40,50 percent. The results demonstrate that:

1. As the IOT percentage increases workability of mix reduces. Hence, for better workability needs use of super plasticizer is recommended.
2. Replacement of 40% IOT gives maximum compressive strength which is more than the reference mix and other replacement percentages.

3. Reference mix showed flexural strength more than the IOT replaced mixes.

4. The number of repetitions to failure obtained for Mix 4 is more than IRC (reference mix) up to 0.7 stress ratio. This showed that IOT replaced concrete can be used for pavements; in particular it is recommended for village roads with lower traffic loads.

3. TEST PROGRAM

The parameters considered for investigation in this study are the number of layers of weld mesh, one and two as well as the variation of IOT percentage 0, 10, 15, and 20% in the mix proportion in two different thickness of slabs 25mm and 30mm respectively, to check the compressive strength, flexural strength and the deflection.

4. MATERIALS

Material used in the present investigation was carefully selected and tested in the laboratory to assess the quality and suitability in making the specimen in a proper way. A mesh size of 18mmx18mm with galvanized iron of diameter 1.2mm was used. 3mm galvanized iron was used as spacer bars. A total of 48 number of slab panels were casted in four different mix proportions with two different thicknesses of 3 samples each for testing flexural strength. Ordinary Portland Cement (OPC), 53 Grade conforming to IS: 12269-1987 is used in the present study. The cement used is Chettinad brand. For the present test the fine aggregate used is slag sand. Iron Ore Tailings replaced portion of slag sand. The normally used coarse aggregates were adopted.

5. TEST PROCEDURE

A. Flexural strength

Formula for flexural strength is:

\[ F_s = \frac{PL}{bd^2} \]

Where,

- \( P \) = load in KN
- \( L \) = span length between the support in mm
- \( b \) = breadth of the slab specimen in mm
- \( d \) = depth of slab in mm

After the slab specimen are cured and dried for an hour, and the specimen is whitewashed in order to identify the minor cracks during loading. The method used in flexure testing is the two point loading method. The test specimen should be turned on its side with respect to its position as molded and centered on bearing blocks. The load applying blocks shall be brought in contact with the upper surface at the third points between the supports. Make some arrangement to ensure full contact between specimen and the load applying block and the supports. Arrange the loading range and loading interval according to the slab requirement. Deflection gauge meter was attached at the center of the slab in order to get the central deflection of yield and so on.
Table 1. Details of Slab Specimen

| Series | Slab ID | Dimensions [mm] | No. of layers of WM | IOT % |
|--------|---------|-----------------|---------------------|-------|
| A      | A11, A12, A13 | 700 | 300 | 25 | 1 | 0 |
|        | A21, A22, A23 | 700 | 300 | 30 | 2 | 2 |
| B      | B11, B12, B13 | 700 | 300 | 25 | 1 | 1 |
|        | B21, B22, B23 | 700 | 300 | 30 | 2 | 2 |
| C      | C11, C12, C13 | 700 | 300 | 25 | 1 | 10 |
|        | C21, C22, C23 | 700 | 300 | 30 | 2 | 2 |
| D      | D11, D12, D13 | 700 | 300 | 25 | 1 | 1 |
|        | D21, D22, D23 | 700 | 300 | 30 | 2 | 2 |
| E      | E11, E12, E13 | 700 | 300 | 25 | 1 | 15 |
|        | E21, E22, E23 | 700 | 300 | 30 | 2 | 2 |
| F      | F11, F12, F13 | 700 | 300 | 25 | 1 | 1 |
|        | F21, F22, F23 | 700 | 300 | 30 | 2 | 2 |
| G      | G11, G12, G13 | 700 | 300 | 25 | 1 | 20 |
|        | G21, G22, G23 | 700 | 300 | 30 | 2 | 2 |
| H      | H11, H12, H13 | 700 | 300 | 25 | 1 | 1 |
|        | H21, H22, H23 | 700 | 300 | 30 | 2 | 2 |

Applying the load at a uniform rate in order to avoid shocks. Minute cracks’ developed during loading(Figure 1) was carefully noted and the yield load, yield crack and deflection at the center due to yield load was recorded. Continue the loading till the specimen reaches ultimate load. The yield loads, crack formation, yield deflection and ultimate load etc. was noted of various slab specimens and the results was entered in a tabular form for easy comparison and for further study.

![Figure 1. Four point loading in UTM](image)

Moment carrying capacity of the slab specimen can be calculated using bending equation. It is as follows:

\[ \frac{M}{I} = \frac{F}{y} \]

Where,
- \( M \) = moment
- \( I \) = moment of inertia of the slab specimen
- \( F \) = the bending stress
- \( y \) = half the depth of slab i.e.; \( d/2 \)

6. RESULTS AND DISCUSSIONS

A. Compressive strength

The compressive strength of cubes were tested in a Compression Testing Machine (CTM) after specified curing period for different percentage of IOT by replacing slag sand in the mix. The compressive strength of cube specimen of different curing period is tabulated(Table 2) with graph showing compressive strength Vs. IOT % with different curing period. Concrete has high compressive
strength. From the graph in figure 2 it can be observed that 28 day compressive strength of cubes having specimen with 15% IOT (34.78N/mm²) is found to be very close to the values corresponding to specimen with 0% IOT. From this it is inferred that the specimen with 15% IOT is the optimum percentage for replacing slag sand.

Table 2. Cube Compressive Strength

| Curing in Days | IOT % | Cube Compressive Strength [N/mm²] |
|---------------|------|----------------------------------|
| 7 days        | 0%   | 15.92                            |
| 28 days       | 0%   | 34.87                            |
| 7 days        | 10%  | 18.25                            |
| 28 days       | 10%  | 34.69                            |
| 7 days        | 15%  | 18.44                            |
| 28 days       | 15%  | 34.78                            |
| 7 days        | 20%  | 18.57                            |
| 28 days       | 20%  | 27                               |

B. Flexural strength

Flexural strength of beams (Table 3) and slab specimen were tested in flexural testing setup arranged in a UTM. The flexural strength was calculated depending on the failure plane position from the support of the beam specimen. But, in the case of slab panel flexural strength were obtained by observing the yield and ultimate load and using the particular formula. All the experimental values were tabulated and graphs of flexural strength vs. percentage variation of IOT and load vs. deflection of 25mm(Figure 4) and 30mm(Figure 5) thickness slabs were separately plotted. By observing the
results obtained for flexural strength of beam (Figure 3) 20% has the highest value, which has an increment of 38% from the reference mix.

Table 3. Flexural Strength of beam

| Curing in Days | IOT % | Flexure Strength of Beam [N/mm²] |
|---------------|------|----------------------------------|
| 28 days       | 0%   | 5                                |
| 28 days       | 10%  | 6.72                             |
| 28 days       | 15%  | 6.76                             |
| 28 days       | 20%  | 6.9                              |

Figure 3. Flexural Strength of Beam

Figure 4. Flexural strength vs. variation of IOT% for 25mm thick slab.
C. Flexural strength of slab

Observing the graph of flexural strength of slab of 25mm thick having single layered with 15% of IOT showed the highest value and from there onwards there was a sudden decrease in the strength where specimens with 20% had the least value. In the case of two layered slabs, the flexural strength values are found to be comparatively similar for specimens with 10, 15 and 20% and the values are greater by 9.4% than the reference mix. In the case of flexural strength of slab of 30mm thick having single layered with 10% of IOT showed highest strength. Its value is higher than reference mix by 41%. But, in the case of two layered 30mm slabs with 10% IOT are preferred.

D. Deflection

Comparing the load deflection graph of 25mm thick slab having one and two layers showed that specimens with 10% and 15% IOT had lesser values compared to reference mix. The values of deflection for the 20% mix were found to be 14% greater than mix with 10% and 15% IOT. In single layered 30mm thick slabs mix with 20% IOT showed least deflection than mix with 15% IOT.

The experimental results of flexural strength and moment have been tabulated below in table 4 and 5.

### Table 4. Experimental and calculated results of slab panels

| Slab-ID | depth (t/mm) | Load(KN) | Def. A (max) | Y-EYS (N/mm²) | Y-M (N/mm) | U-M | M-I (N/mm²) | M-I (N-mm) |
|---------|--------------|----------|--------------|----------------|-------------|-----|-------------|------------|
| A11     | 25           | 2.8      | 3.4          | 8.96           | 280         | 9.60| 309025      | 320        |
| A12     | 25           | 3.2      | 3.2          | 10.24          | 320         | 12.16| 309025      | 380        |
| A13     | 25           | 2.8      | 3.3          | 8.96           | 280         | 9.60| 309025      | 320        |
| A14     | 25           | 3.4      | 3.0          | 9.60           | 300         | 12.80| 309025      | 400        |
| A21     | 25           | 3.7      | 4.1          | 11.84          | 370         | 13.12| 309025      | 410        |
| A22     | 25           | 3.6      | 3.6          | 11.82          | 360         | 11.52| 309025      | 360        |
| B11     | 30           | 3.4      | 4.1          | 7.56           | 340         | 6.11 | 675000      | 400        |
| B12     | 30           | 3.4      | 4.2          | 6.67           | 300         | 6.33 | 675000      | 420        |
| B13     | 30           | 3.2      | 4.5          | 7.11           | 320         | 10.00| 675000      | 450        |
| B21     | 30           | 3.6      | 4.3          | 8.00           | 360         | 9.78 | 675000      | 400        |
| B22     | 30           | 3.4      | 4.6          | 7.56           | 340         | 10.22| 675000      | 460        |
| B23     | 30           | 3.6      | 4.5          | 8.00           | 360         | 10.00| 675000      | 450        |
| C11     | 25           | 2.5      | 3.5          | 7.68           | 284         | 11.20| 309025      | 350        |
| C12     | 25           | 2.8      | 3.6          | 8.96           | 280         | 11.52| 309025      | 360        |
| C13     | 25           | 2.6      | 3.7          | 8.32           | 260         | 11.84| 309025      | 370        |
| C21     | 25           | 3.8      | 4.4          | 12.16          | 289         | 14.08| 309025      | 440        |
| C22     | 25           | 3.4      | 4.3          | 9.60           | 300         | 13.76| 309025      | 430        |
| C31     | 25           | 3.5      | 4.6          | 7.78           | 350         | 10.22| 675000      | 460        |
| D11     | 30           | 3.2      | 4.8          | 7.11           | 320         | 10.67| 675000      | 480        |
| D12     | 30           | 3.4      | 4.2          | 6.67           | 300         | 9.33 | 675000      | 420        |
| D13     | 30           | 3.5      | 4.6          | 7.78           | 350         | 10.22| 675000      | 460        |
| D21     | 30           | 4.6      | 5.8          | 10.22          | 460         | 12.89| 675000      | 580        |
| D22     | 30           | 4.2      | 6.4          | 9.33           | 420         | 13.33| 675000      | 460        |
| D23     | 30           | 4.4      | 6.3          | 9.78           | 440         | 14.00| 675000      | 430        |
| E11     | 25           | 2.9      | 3.6          | 9.28           | 250         | 11.52| 309025      | 360        |
| E12     | 25           | 2.6      | 3.8          | 8.33           | 260         | 12.48| 309025      | 390        |
| E13     | 25           | 2.4      | 3.8          | 7.68           | 240         | 12.16| 309025      | 380        |
| E21     | 25           | 3.4      | 4.2          | 10.88          | 340         | 13.44| 309025      | 410        |
| E22     | 25           | 2.8      | 4.1          | 8.96           | 280         | 13.12| 309025      | 410        |
| E23     | 25           | 3.4      | 4.2          | 9.60           | 300         | 14.40| 309025      | 420        |
Table 5. Experimental and calculated results of slab panels.

| Slab ID | depth (mm) | \\(
|--------|------------|----------|
| L (mm) | E (N/mm²) | \(Y_e (N/mm²)\) | \(Y_m (N/mm²)\) | \(U_{L} (N/mm²)\) | \(M_{L} (N/mm²)\) | \(\mu_{L} (N/mm²)\) |
|---------|------------|------------|
| F1     | 30         | 4.6        | 9.6          | 300            | 10.22        | 675000        | 400 |
| F2     | 30         | 2.8        | 1.5          | 5.2            | 28          | 8.67          | 675000        | 390 |
| F3     | 30         | 3.7        | 2.5          | 8.2            | 370          | 9.11          | 675000        | 410 |
| F4     | 30         | 3.6        | 2.4          | 3.8            | 300          | 10.00         | 675000        | 450 |
| F5     | 30         | 3.8        | 2.5          | 8.4            | 380          | 10.44         | 675000        | 470 |
| F6     | 30         | 3.9        | 2.8          | 8.6            | 390          | 11.11         | 675000        | 500 |
| F7     | 25         | 2.3        | 3.0          | 7.3            | 230          | 10.24         | 390250        | 320 |
| F8     | 25         | 2.8        | 1.5          | 8.9            | 310          | 9.60          | 500250        | 300 |
| F9     | 25         | 2.6        | 0.55         | 8.2            | 260          | 10.08         | 390250        | 340 |
| C1     | 25         | 3          | 3.5          | 9.6            | 300          | 12.80         | 390250        | 400 |
| C2     | 25         | 4          | 4.4          | 12.8           | 400          | 14.08         | 390250        | 440 |
| C3     | 25         | 3.5        | 2.4          | 11.2           | 350          | 13.44         | 390250        | 420 |
| H1     | 30         | 3.6        | 2.5          | 8.0            | 340          | 9.11          | 675000        | 410 |
| H2     | 30         | 2.8        | 0.5          | 6.2            | 280          | 9.33          | 675000        | 420 |
| H3     | 30         | 3.6        | 2.6          | 8.0            | 360          | 9.56          | 675000        | 430 |
| H4     | 30         | 3.8        | 1.9          | 8.4            | 380          | 9.78          | 675000        | 410 |
| H5     | 30         | 3.6        | 2.0          | 8.0            | 360          | 10.22         | 675000        | 440 |

7. CONCLUSIONS

From the tests performed on materials for assessing properties and tests on hardened ferrocement slabs to obtain mechanical properties such as compressive and flexural strengths the following conclusions are drawn:

1. Replacement of 15% IOT mix showed the better result of flexural strength than original reference mix by 9% increase for 2 layered weld mesh and 15% increase in single layered with 25mm thick slab specimen.
2. Replacement of 10% of IOT mix gives the highest flexural strength value that is 34% increase than the reference IOT mix for double layered weld mesh but only a 6% increase for single layered mesh with 30mm thick slab specimen.
3. Addition of 15% IOT mix showed the highest compressive strength which is approximately close to the reference mix that is 0% IOT.
4. Increasing the thickness of the slab made of 10% IOT added mix enhances the load carrying capacity by 24% than the 0% IOT mix. Increasing the number of layers of mesh increases the yield load by 36% than the one-layered slab and reduces the sudden appearance of cracks.
5. For single layered slabs, cracks and failure were sudden and brittle in nature.
6. In most of the cases after loading, cracks gradually appear at the center of slabs and deflection also will be more at the center. As the load increases, width of crack also grows and finally failure occurs.
7. As the IOT percentage increases, workabiliy of mix reduces. Hence, for a better workability use of appropriate super plasticizer is recommended.
8. Use of IOT in ferrocement slabs as a partial replacement of fine aggregate paves the way for efficient and economical utilization of the iron ore tailings and mineral wastes and which helps to reduce the impact of global warming to certain extent.

ACKNOWLEDGEMENT

The authors acknowledges the support provided by CHRIST (Deemed to be University), School of Engineering and Technology, Bangalore, India and Carmel Polytechnic College, Kerala, India
REFERENCES

[1] Thenmozhi R and Depashri S, “Experimental Studies on Flexural Strength of Ferrocement Slabs Using Self Compacting Micro-concrete”, International Journal of Advances on Civil Engineering (IJACE) vol. 4 pg. (1-2), 2014.

[2] Amala M and Neelamegam M, “Experimental Study of Flexure and Impact on Ferrocement Slabs”, Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X. PP 62-66, 2014.

[3] Phalke R J and Gaidhankar D G, ”Flexural behaviour of ferrocement slab panels using welded square mesh by incorporating steel fibres”, International Journal of Research in Engineering and Technology eISSN: 2319-1163 — pISSN: 2321-7308, 2014.

[4] Kumar B N, Suhas R, Suhas R, Santosh U S and Srishaila J M, Utilization of iron ore tailings as replacement to fine aggregates in cement concrete pavements, International Journal of Research in Engineering and Technology eISSN: 2319-1163 — pISSN: 2321-7308, 2014.

[5] ACI 549R-97, “State of the Art Report on Ferrocement (ACI 549 R-97).

[6] Nagesh M. Kulkarni and D.G.Gaidhankar, Analysis and Design of Ferrocement Panels an Experimental Study, International Journal of Inventive Engineering and Sciences, Vol. 1, No.52013.

[7] Shanthakumar.A.R, Concrete Technology, Oxford University Press, March 2012.