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Flexural strength of Ferrocement panels using Self compacting Mortar and Low cost Steel Fibers

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ABSTRACT

Certain limitations in traditional ferrocement construction could be overcome with the help of stronger, durable and better quality Self-Compacting Mortar (SCM) and Low cost Steel Fibers. An attempt was made in this work to develop a satisfactory SCM, that auto-compacts by de-airing without any means of mechanical compaction, while it fills and flows throughout the form under its own weight and remains stable in fresh state. Static and dynamic stability of SCM i.e. compatibility of cement and chemical admixture as well as segregation-bleeding resistance throughout the casting process is vital. In addition to the inclusion of fibers in to mortar not only provides considerably more ductile structure but also improves the structural properties such as tensile strength, static flexural strength, impact strength, flexural toughness and the energy absorption capacity of the high strength concrete. the properties and proportions of mix ingredients, stability is highly sensitive to the powder-admixture compatibility, especially if fly ash is used. Therefore, production of stable and workable SCM is challenging. The present study was limited to laboratory tests and aimed to develop acceptable SCM using locally available materials, ensuring flowing ability, filling ability and control over segregation and bleeding. Compatibility issues were studied using various cements and admixtures by Visual Stability Index test, mini-Slump Flow, mini-V-Funnel, Mesh-Ring and Free-Fall tests were developed to ascertain the stability and workability of several SCM mixes. Demo ferrocement panels were cast using SCM and Steel Fibers.

KEYWORDS: *SCM, Ferrocement panel, Low cost steel fibers.*

I. INTRODUCTION

A. Ferrocement

Ferrocement is a type of thin walled reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layer of continuous and relatively small size wire mess. The mess may be made of metallic or other suitable material. Since these materials are widely available and are relatively low in cost, and since the building techniques are enough to be done by unskilled labor. It can be shaped to any form and can be formed into section less than inch thick, and assembled over a light form work. The main advantages of ferrocement is that it requires no formwork, which allows it be fabricated into very general shapes, some very complicated to build with standard masonry, reinforced concrete or steel. Ferrocement is attractive alternative to reinforced concrete and steel structures. The material has been used in several structure such as boats, school building, water tanks etc. the plastic potential, simple construction techniques and low cost justify its use, especially in developing countries.

B. Self-compacting mortar (SCM).

Due to high water cement ratio to increase workability and poor compaction mostly happened due to the need of speedy construction in mortar the defects were identified leading to the introduction of Self Compacting Mortar. Self-Compacting Mortar, as the name indicates, is a type of mortar that does not require external or internal compaction but it gets compacted under its self-weight. It is commonly abbreviated as SCM and defined as the mortar which can be placed and compacted into every corner of a form work, purely by means of its self-weight by eliminating the need of vibration or any type of compacting effort. Self-Compacting Mortar is also known as Self Consolidating Mortar. SCM is highly flow able, non-segregating mortar that can spread into place, fill formwork, and encapsulate reinforcement without any mechanical consolidation. Mortar serves as the basis for the workability properties these properties could be assessed by self-compacting mortars (SCM). In fact, assessing the properties of SCM is the objective of this study was to evaluate the effectiveness of various mineral additives and chemical admixtures in producing SCMs. For this purpose, mineral additives (fly ash), super plasticizers were used. Mixtures of SCM were prepared keeping the amount of mixing water and total powder content (Portland cement and mineral additives) constant. Workability of the fresh mortar was determined using mini V-funnel and mini slump flow tests.

C. Steel fiber

Steel fiber concrete is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers – each of which lend varying properties to the concrete. Fibers are usually used in concrete to control cracking due to plastic shrinkage and to drying shrinkage.

They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of fibers produce greater impact, abrasion, and shatter–resistance in concrete.

II. EXPERIMENTAL PROGRAM

A. Materials

a. Cement

Ordinary Portland cement, 53 grade shall be manufactured by intimately mixing together calcareous sand argillaceous and/or other silica, alumina or iron oxide bearing materials, burning them at a clinkering temperature and grinding the resultant clinker so as to produce a cement capable of complying with this standard. No material shall be added after burning, other than gypsum, water, performance improver(s), and not more than a total of 1.0 percent of air-entraining agents or other agents including coloring agents, which have proved not to be harmful. 53 Grade OPC Ultra tech cement confirming IS 12269-1987 was used for all the mixes.

b. Sand

Fine Aggregate plays an important role in concrete as it help in practical packing in high strength concrete. It bound together with cementing material. The strength of concrete depends on the bond between the cement and the aggregate. If the bond between aggregate and cementious material is poor then the concrete give poor strength. Also the fine aggregate greatly influence on the workability of the concrete. Hence natural aggregate of locally available are used for the present work. River sand is used as a fine aggregate, it confirms to zone II of IS 383- 1970.

c. Admixture

There is a variety of commercially available High Range Water Reducing Agents (HRWRs) that can be used to produce SCM. The most typical admixtures used are Poly carboxylate Ether (PCE) based. In general, HRWRs increase fluidity, reduces water requirement though maintaining stability of the mix. The admixtures, along with other proportioning techniques such as combined gradation of aggregates, powder content or both, are controlled to impart stability. The admixtures used in the work included PCE based admixtures to achieve required SCM properties. It included BASF Master Glenium Sky 8784 (HRWR1) and Kemsuplast 220 MPQC.

d. Fly ash

Fly ash particles are spherical with a smooth surface that can act as a ball bearing within the paste of the SCM mixture. Because of this, fly ash may enhance the workability and slump flow of SCM and can thus reduce thixotrophic effect.

Slump flow values are increased when the replacement rates are between 20% and 40% of portland cement. Optimum replacement values are dictated by Meshob specifications, material compatibility, and cost. Pozzocrete 60 is used as partial cement replacement product.

e. Steel fibers

Steel fibers used in concrete to Improve structural strength, reduce steel reinforcement requirements, reduce crack widths and control the crack widths tightly, thus improving durability and improve impact and abrasion resistance. We are used binding wire as low cost steel fiber.

FIGURE NO.1 - STEEL FIBER

f. Water

Water plays an important role in concrete as the addition of water in cement paste the hydration reaction start. The water used in the concrete should be portable. When water mix with cement paste forms and cement paste bound the other ingredients of concrete. The C-S-H gel binds the other ingredients of concrete. As per IS 456-2000 water used for the mixing and curing shall be clean and free from injuries amounts of oils, alkalis, salts, sugars, organic materials or other substances that may deleterious to concrete or steel. In this work, available tap water is used for concreting.

B. Tests

Slump cone test, V-funnel test, Free fall test and Mesh ring test are performed for testing properties of SCM such as Flowing ability, Filling ability, workability and Passing ability.

a. Slump flow test (ASTM C143/C143M)

This test method covers the determination of slump flow of self-consolidating mortar in the laboratory or field. This test method is used to monitor the consistency of fresh consolidated mortar. Test procedure is as follow

1. The mini slump flow test refers to the standard slump test (ASTM C143/C143M).
2. The mini slump cone is placed in the centre of the slump flow board, either in the normal orientation (large opening down) or inverted (small opening down).
3. It is filled in one lift (no rodding or other consolidation) with SCM, taking care to be sure the sample is well mixed and not segregated in the sampling process.
4. The cone is then raised in 3 ±1 seconds to a height of 230 ±75 mm (9 ±3 in.), allowing the fluid concrete to flow onto the slump flow board.
5. The slump flow is the diameter of the resulting concrete ―patty obtained from the average of measuring the greatest diameter and diameter perpendicular to this direction. Large differences between the two diameters indicate a non-level surface, which must be corrected.
6. SCM generally has slump flow of 250 to 300 mm.

Figure No. 2 – Mini slump cone

b. Free fall test

To predict the performance of SCM after falling from height say 2 – 3 m in a panel, we had developed a test called Mortar Free fall test. Due to free fall, dynamic stability after getting impacted could be analyzed. Procedure for the test is as followed.

The SCM mix is properly prepared and given sufficient time given for initializing the role of admixture i.e., Open Time. Then around 1.25 litre Fresh mortar is taken in a pan and lifted to a height of about 2.5m. The pan is so inclined that SCM falls freely by its own weight. The mix will fall like a splatter but will be slowly mixed by its own weight and after few seconds the splatter will turn in smooth slump flow like condition.

The slump like condition of free fall test leads to judging and predicting the stability of SCM on the basis of splatter. Thus Visual Stability Index for Free Fall called as Free Fall VSI is introduced.

The test gives the constructability of SCM which will be readily used on site. The Free Fall test can directly predict the stability on site accurately. The FFVSI will prove to be check for assurance.

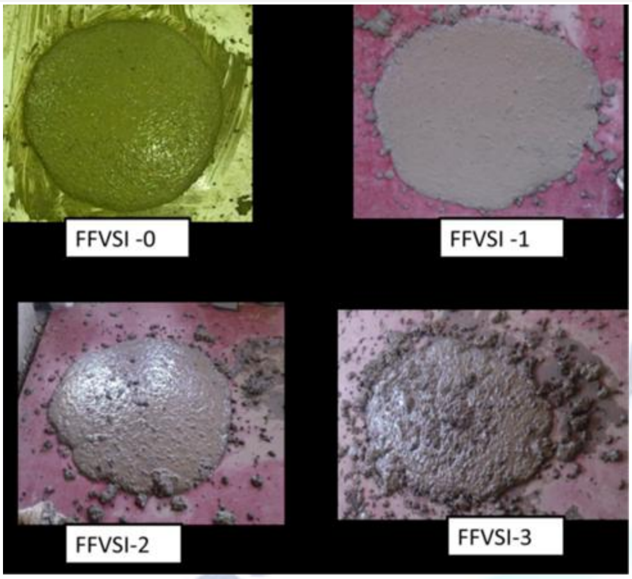

Figure No. 3 – Free fall Visual stability index

c. Mesh ring test (ASTM C1621/C1621M)

On the grounds of J-Ring Test for SCC, Mesh Ring Test for SCM is proposed for its application for ferrocement. The test must be carried out to check the passing ability of SCM through dense reinforcement of ferrocement.

The Mesh ring consists of circular ring of 6mm MS bars and skeletal bars which will support the mesh. The diameter and height of Mesh Ring is 300mm. Spacing between vertical skeletal bars is 160mm. Height of Mesh Ring is divided in two parts each of 150mm. The skeletal structure is winded with two layers of 26 gauge ½ inch chicken mesh.

d. V funnel test

V funnel test consist of v shaped funnel. This test is used to measured flow ability. Procedure of test as shown below

V funnel is set on firm ground. Apply oil inside the surface of funnel. Keep the trapdoor to allow any surplus water to drain. Close the trap door and place a bucket underneath. Fill the apparatus completely with the mortar without compacting or tamping. Simply strike off the concrete level with the top with trowel. Open trap door with in the 10 sec after filling and allow mortar to flow out under gravity. Start the stop watch when the trap door is opened, and record the time for the complete discharge. The whole test has to be performed within 5 minutes.

e. Flexural strength test on ferrrocement panels(ASTM C293).

In order to perform the flexural strength test on the ferrocement panels, the procedure of ASTM C293 for center point loading test was adopted. The flexural strengths of ferrocement panels produced were determined by a center point flexural test using a universal testing machine. The effective span of ferrocement panel was designed to be 450 mm. The flexural strength test was initiated by gradually increasing center point load and simultaneously corresponding Mid span deflection was measured. In each flexural strength test the number of cracks was recorded. Ultimate flexural strength was obtain using equation on theory of simple bending.

$$Fcu = wl/bd2$$

Where Fcu = Ultimate flexural strength N/mm2

w = load at failure

l = effective span

b = width of the specimen

d = effective depth

C. Mix proportion

Conventional Plain Mortar (PM) mixes were first proportioned based on nominal mix of 1:3.5, typically used in ferrocement applications. The w/c-ratios were varied from 0.3 to 0.45 by conducting several trials to achieve workable and stable mix.

Table No.1 – Mix Proportion for plain Mortar

Label	W/C Ratio	Cement (Kg)	Sand (Kg)	Water (Kg)
PM1	0.3	500	1750	150
PM2	0.35	495	1732	174
PM3	0.4	490	1735	196
PM4	0.45	485	1698	220

Start with lowest water cement ratio where acceptable mortar is formed. Start increasing water cement ratio by 0.5 also add 1% admixture simultaneously. Correspondingly other ingredients will also change. Based on the trials of conventional mortars, SCM mixes were formulated and trials were conducted. The SCM mixes were finalized as 1:2.5, 1:3 and 1:3.5 with w/c-ratio of 0.3 to 0.45.

Table No. 2 – Mix Proportion For SCM with Admix.

Label	W/C ratio	Cement Kg	Sand kg	Water Kg
SCM1	0.45	545	1905	245.25
SCM2	0.3	584	1756	176
SCM3	0.35	584	1756	205
SCM4	0.4	584	1756	233.6
SCM5	0.35	668	1668	233.6
SCM6	0.4	668	1668	267.2
SCM7	0.36	668	1668	240.5
SCM8	0.37	668	1668	247.16

Add 10%, 20% and 30% fly ash in SCM7 and SCM8 to find out optimum percentage of fly ash which gives required results. We observe that 20% fly ash is give better result than 10 and 30 percent. So we used 20% fly ash in SCM6 and SCM7.

Table No. 3 – Mix Proportion For SCM with Fly ash

Label	W/C Ratio	Cement (Kg)	Flyash (Kg)	Sand (Kg)	Water (Kg)
SCMF1	0.36	534.4	133.6	1668	240.5
SCMF2	0.37	534.4	133.6	1668	247.16

"SCM8" Proportion gives satisfactory results of all the tests i.e. Slump flow test, V-funnel test, Free fall test and Mesh ring test. By using Optimum SCM and Low cost Steel fibers Ferrocement panels are casted. The size of panels is 500X 300X 60 mm. The ferrocement panels varying in 3 types i.e. 1 wire mesh, 2 wire mesh and 3 wire mesh. For each type of ferrocement panel 3 samples are casted by using different percentage of steel fibers which is 0,2,4 and 6%. The flexural strength of panels is tested for 28 days through Center point flexural strength test.

III. RESULT AND DISCUSSION

A. Fresh Properties of SCM

Fresh properties of SCM are judged on results of Slump Flow Test, V funnel, Free fall test and FFVSI.For mortar to be stable and acceptable slump flow according to ACI should be 240-260 mm, FFVSI should be 0 and Time must range between 7 to 11 seconds.

Table no. 4 – Slump flow, FFVSI and Time

Mix	Slump Flow (mm)	FFVSI	Time (Sec)
SCM1	150	3	9.23
SCM4	200	3	15.17
SCM5	200	2	18.20

Discussions carried from table 4

1. Though Slump flow can be suitably improved but harden properties were not acceptable-False setting.
2. Above admixtures require high dosage of admixture to have standard Slump flow.
3. For SCM to be acceptable minimum slump flow should be 240mm as recommended by ACI which is not surpassed by the above mixes.
4. Increase in dosage results in increasing setting time. Thus Jump to another admixture for compatibility. 5. Hence though will studying fresh properties of SCM, we need to simultaneously check hardened properties so that compatibility issue is controlled.
6. Instability, poor workability, erratic setting, loss in strength are the signs of incompatibility in SCM
7. Hence, fresh and hardened performance of SCM can be seriously affected by the incompatibility of powder and HRWR.

Table No. 5 – Fresh Properties With Compatible Admixture

Mix	Slump flow (mm)	FFVSI	Time (Sec)
SCM6	210	2	14.59
SCM7	220	1	12.23
SCM8	205	1	11.30

Discussions from table 5

1. The mix has nofalse setting. Thus solving compatibility issue between admixture and powder.
2. Flow results required can be found out by proper tuning of W/C ratio and admixture dosage
3. Thixotropic effect results in restricting the flow
4. Aggregate pilling is observed for almost all slump flow tests.
5. Hence Fly Ash can be introduced to increase slump Flow and reduce aggregate pilling.

Table No. 6 – Properties after replacing Fly ash

Mix	Slump flow (mm)	FFVSI	Time (Sec)
SCMF1	245	0	10.07
SCMF2	254	0	9.20

Discussions on table no. 6

1.Targeted Slump flow is achieved with required stability
2.Thixotropic effect though reduced, but will remain to minimize pressure on formwork.
3. Flow is improved by addition of Fly Ash.
4. FFVSI also improved with fine tuning of addition of admixture.
5. From visual observations the mix can be clearly construed as a satisfactory mix.

B. Mesh Ring Results

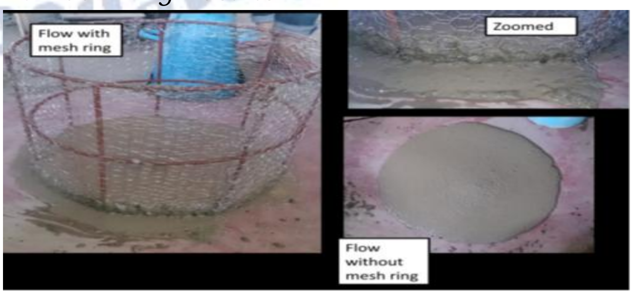

Figure No. 4 – Mesh ring test

Discussions on Mesh Ring Test:
1. The test was conducted for half-filled slump cone thus resulting in less pressure laterally.
2. The SCM is easily pass through a mesh.
3. Results obtained were reliable.

C. Compressive strength

For the applicability of SCM in construction industry, its hardened properties need to be checked. The test was carried after 28days of casting.

Figure No. 5 – Failure pattern of cube

Compressive Strength after 28 days = 54.78 Mpa

Perfect cup and cone failure. Failure pattern of breaking aggregates shows SCM is high performance mortar.

D. Flexural strength

Table No. 7: Average of load at failutre

Percentage steel fibers (%)	Load (KN)		
	1 Layer mesh	2 Layer mesh	3 Layer mesh
0	18.47	27.03	35.4
2	18.76	29.64	40.09
4	19.14	34.35	41.42
6	18.47	27.26	32.13

Table No. 8: Average deflection at failure

Percentage steel fibers (%)	Deflection (KN)		
	1 Layer mesh	2 Layer mesh	3 Layer mesh
0	2.77	4.68	6.69
2	3.11	5.64	7.21
4	3.34	6.47	7.88
6	2.91	4.09	6.83

Table No. 9: Average flexural strength

Percentage steel fibers (%)	Flexural Strength (Mpa)		
	1 Layer mesh	2 Layer mesh	3 Layer mesh
0	11.08	16.21	21.24
2	11.27	17.78	24.05
4	11.48	20.61	24.85
6	11.08	16.35	19.27

Inclusion of 4% steel fibers in a mortar of fabricated ferrocement panel improved the crack resistance and flexural strength. Flexural strength of panels is increased with increase in mesh. Addition of 6% steel fiber in mortar gives less strength compare to 4% and 2% fibers.

Figure No. 6 – Cracking of panels

VI. Conclusion

The results of this study have led to the following conclusions:

1. Use of 3rd generation PCE based HRWR is recommended for producing stable and workable SCM.
2. Optimum dosage of admixture is 1% which gives relative viscosity.
3. Fly ash replacement provided significant improvement in slump flow, stability and strength of SCM.
4. Fly ash produced thixotropic effect that can reduce formwork pressure of SCM.
5. The study proposed a new VSI rating for SCM that rationally evaluates the static stability of SCM.
6. The optimal water cement ratio is 0.37 with 1:2.5 Proportion which gives satisfactory result of all the test i.e. Slump flow, V funnel, Mesh ring, Free fall ect.
7. Though, relevant experience, strict quality control and trials are essential to produce satisfactory SCM, its potential use to efficiently produce good quality Ferrocement product.
8. Load carrying capacity and flexural strength of ferrocement panels increased with No. of welded wire mesh.
9. Flexural strength of panels increased with increased in Percentage of steel fibers at certain limit which is 4%. Steel fibers have ability to arrest the cracks, fibers composites possess increased extensibility and tensile strength, both at first crack and at ultimate, particular under flexural loading.
10. Steel fibers more than 4 percentages was reduce the load carrying capacity and flexural strength. It is because bond between fibers and mortar are reduced and the fibers are unable to hold the matrix together after loading.

11. Inclusion of 4% steel fiber in a mortar of fabricated ferrocement panel improved the crack resistance and flexural strength.

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