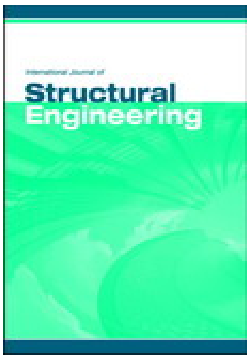

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A study on flexural behaviour of ferrocement slabs using foamed concrete

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A study on flexural behaviour of ferrocement slabs using foamed concrete

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Abstract: Ferrocement is a material used for construction consisting of wire meshes and a conventional cement mortar. The aim of this research is to evaluate experimentally the flexural behaviour of ferrocement slabs by considering different parameters such as types of sand, number of layers of wire mesh and percentage of foaming agent. Slabs were cast using river sand and manufactured sand (M-Sand) with single and double layers of welded wire mesh. Synthetic foaming agent was also added in the mortar mix in various percentages such as 0%, 0.2%, 0.4%, 0.6%, 0.8% and 1% by weight of cement. The effect of the above-mentioned parameters on the ultimate strength, deflection, energy absorption capacity and ductility of slabs was determined and discussed. From the test results, it is seen that behaviour of ferrocement slabs with M-Sand are almost similar to the behaviour of slabs with river sand in terms of ultimate load carrying capacity. The addition of foaming agent has significant influence on the self-weight reduction and improved ductility of ferrocement slabs.

Keywords: ferrocement; mortar; flexural; river sand; M sand; foaming agent.

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1 Introduction

Due to rapid growth of population and industrial development, developing countries are facing problems of housing shortages. In a housing construction, the roof constitutes the major expense and the most critical component is appropriate roofing. Ferrocement has several advantages as compared to other roofing materials and can play a major role in construction of houses in developing countries. Ferrocement is a light weight composite material with minimum thickness which usually consists of steel meshes in a layer of conventional cement mortar. Panels with fly ash for partial cement replacement and having bamboo in place of steel could be used as roofing panels predominantly for inaccessible roofing (Chithambaram and Kumar, 2017). Composite ferrocement-concrete beams are a practicable substitute for the conventional RC beams (Fahmy et al., 2014).

On the other hand, shortage of natural River Sand (RS) and its cost escalation in India especially in Tamil Nadu is a major cause of concern in the construction sectors and real estate business. Increase in demand for sand in the construction industry has led to an uncontrollable mining in river beds which in turn leads to ecological imbalance. Due to the extraordinary hike of cost of river sand, a gradual shift was noted towards the use of M-Sand as this material has several advantages in addition to being economic and ecological. Hence more efforts are required in order to find suitable modification for materials that are used in making ferrocement composites. M-Sand can be considered to be an effective alternative material for river sand in ferrocement elements. Considerable amount of literature is available on the behaviour of ferrocement slab panels using different constituent materials.

Another criterion needs to be considered for a roofing or wall element is their self-weight which contributes to better insulation properties and economy of foundations. One of the methods of reducing the self-weight is the introduction of stable voids by gas or by air within the hardened cement paste or mortar. Use of foaming agent introduces the air, which makes the material light. Foamed concrete consists of cement, water, fine aggregate and air voids. Recently there are few literatures on light weight foam concrete and they are briefly reviewed here. Application of foamed concrete structures with good mechanical and physical properties is increasing day by day (Sari and Sani, 2017). They discussed on the use of basic raw materials, their properties, process involved in the production of foamed concrete, and their application in foamed lightweight concrete with densities between 300 kg/m^3 and 1,800 kg/m^3. The factors that influence the strengths and weaknesses of foamed concrete were also discussed. Replacing natural sand in the foam concrete mixture will not only reuse industrial waste, but also reduce concrete costs as well as improve the technical properties of foam concrete. Use of appropriate amounts of blast furnace slag and fly ash as a replacement of natural sand could produce eco-friendly foam concrete which has many positive environmental impacts (Kim et al., 2020).

Because of having desirable strength, foam concrete could be an alternative construction material for industrial buildings. Foam concrete requires no vibration or compaction and it fills all cavities, voids and seams over a long distance. It offers fast and settlement free construction with good heat insulation and air content. It has good thermal insulation; good freeze/thawing properties and has excellent fire resistance properties (Jalal et al., 2017). It is possible to utilise light weight foamed concrete as a structural element for prefabrication concrete house, due to its lower density and its high strength properties (Risdanareni, 2016). Structural lightweight concrete could be developed successfully using normal coarse aggregates and foaming agent without the need of light weight aggregates (Lee et al., 2014). The possibility of using both natural and synthetic foaming agents and the use of silica fume as a partial substitution of binder were explored and the addition of silica fume has influence of the compressive strength of foamed concrete for both types of foaming agents (Varghese et al., 2017).

Foamed concrete shows excellent physical characteristics such as low self-weight, relatively high strength and outstanding acoustic and thermal insulation properties. It allows for minimal consumption of aggregate, and by replacement of a part of cement by fly ash, it contributes to the waste utilisation principles (Kozłowski and Kadela, 2018). Stability of foam concrete is dependent on several factors like mix design, type of foaming agent, foam preparation methods, type of additives used, etc. (Fu et al., 2020). Polyurethane foamed concrete has shown the potential for use in structural applications and the polyurethane concrete samples cured by moisture have the highest compressive strength at all ages (Harith, 2018).

Foamed concrete possesses low density and high strength-to-weight ratio. Use of foamed concrete reduces dead loads on the structure and foundation and thus contributes to energy conservation and hence lowers the labour cost during construction. Compared to normal concrete, it also reduces the cost of production and transportation of building components and therefore has the potential of being used as a structural material (Mugahed Amran et al., 2015). In place of conventional load bearing wall systems, precast foamed concrete sandwich panels have the potential to be considered an alternative (Mugahed Amran et al., 2016). When the polypropylene wire meshes are used in ferrocement panels, an enhancement in the resistance against bending and punching shear could be seen (Khurram et al., 2020). Ferrocement box with lightweight non-autoclaved aerated concrete as an encasement has high performance with good compressive and flexural strengths and enhanced ductility and could be used in earthquake prone areas (Memon et al., 2007). Foam concrete reinforced with glass fibres has better mechanical properties (Calis et al., 2021).

Even though considerable research has been done on ferrocement slab panels, limited works have been reported on the use of foamed concrete in ferrocement elements. The impact of various parameters on the application of foamed concrete in ferrocement panels are to be given more focus for its successful implementation in practical structures. Hence an attempt has been made through present investigation to study the flexural behaviour of ferrocement flat panels using foamed concrete.

2 Experimental program

2.1 Parameters of study

The following parameters are considered in this experimental investigation.

1 type of sand: river sand and M-Sand

2 number of layers of welded galvanised iron (GI) mesh: one and two layers

3 percentage of foaming agent: 0%, 0.2%, 0.4%, 0.6%, 0.8% and 1% by weight of cement.

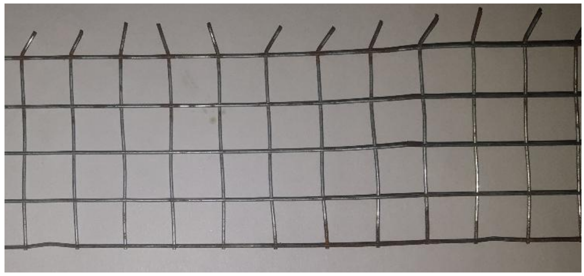
2.2 Materials used

River sand and M-Sand passing through 4.75 mm sieve were used for the casting of ferrocement flat panels. Both river sand and M-Sand confirms Zone II of IS 383 (2016) requirements. Cement used for preparing mortar is fly ash-based Portland pozzolana cement (PPC) which confirms the specifications of IS 1489 (Part 1) (1991). The setting time of cement was tested by Vicat Apparatus method described in IS 4031-5 (1988). Potable water which is clean and free from substances that are deleterious to concrete is used for making the mortar. GI welded mesh coated with zinc galvanising coating with square openings as shown in Figure 1 was used as reinforcement in ferrocement panels. Synthetic-based foaming agent Dewfoam –LW in liquid form is used in this study, which is an air entraining admixture articulated from selected polymers which has an ability to form microscopic air bubbles. It is used in various percentages like 0%, 0.2%, 0.4%, 0.6%, 0.8% and 1% by weight of cement. Dewfoam-LW complies with IS 9103 (1999), ASTM International ASTM C260/C260M–10a (2016), BS 5075 (part 2) and EN 934 (part 2). Table 1 summarises the properties of materials used in this experimental program.

Table 1 Material properties

Material	*Property*	*Value*
River sand	Specific gravity	2.51
	Bulk density	1,715 kg/m^3
	Fineness modulus	2.56 (zone II)
M-Sand	Specific gravity	2.55
	Bulk density	1,761 kg/m^3
	Fineness modulus	2.87 (zone II)
PPC	Specific gravity	2.94
	Bulk density	1,400 kg/m^3
	Fineness-specific surface area	343 m^2/kg
	Normal consistency	31%
	Initial and final setting time	36 and 570 minutes
GI welded wire mesh	Average diameter	0.98 mm
	Size of aperture	12.7 mm × 12.7 mm
	Weight	1,220 g/m^2
	Yield strength in tension	409 N/mm^2
Foaming agent	Colour	Brown liquid
	Specific gravity	1.03
	Chloride content	Nil

Figure 1 GI welded mesh



2.3 Mix design and specimens testing procedure

Mix design of mortar was done by volume batching with cement: sand ratio of 1:3 and a water cement ratio of 0.45. In the mix design, volume shrinkage of 25% is assumed after the addition of water in the dry mix and hence 1 cubic metre of dry mix is considered to be equivalent to 0.75 cubic metre of wet volume. Hence, the volume of one cubic metre of the wet mortar is assumed to be equivalent to 1.33 cubic metre of dry mortar. Knowing the dry mortar volume, cement and sand proportion and bulk density of dry materials, quantity of each material was arrived at. From the water cement ratio, quantity of water needed for the mix was found and the quantities of materials are given in Table 2. For making the foamed concrete, the preformed foam is mixed with cement and sand. To produce foam in the form of bubbles, the calculated quantity of foaming agent as per the dosages considered for the study based on the weight of cement and the water are thoroughly mixed first using a mechanical stirrer uniformly and at a steady pace so as to achieve foam with good stability. The foam thus created was then poured into the dry mix of cement and sand followed by mixing.

Table 2 Material quantities

Type of sand	*Cement (kg/m³)*	*Fine aggregate (kg/m³)*	*Water (kg/m³)*
River sand	465.5	1,710.7	209.5
M-Sand	465.5	1,756.6	209.5

Flow table test which is in compliance with IS: 4031 (Part 5) – 1988 was done to measure the workability of the mortar mixes containing river sand and M-Sand. Compressive and flexural strength tests were performed as per IS: 1727 (1967) on cubes and prisms of size 70.6 mm × 70.6 mm × 70.6 mm and 160 mm × 40 mm × 40 mm respectively. Cube specimens were weighed before compression test, for the calculation of density.

Totally 24 slabs were cast in this study out of which twelve slabs were prepared using river sand and another twelve slabs were made using M-Sand. The size of the slab panel is 900 mm × 300 mm × 25 mm and it is cast using rectangular wooden planks. Two slabs are considered as control specimens without foaming agent. For each type of sand and for each percentage of foaming agent considered, slabs were cast with one layer of mesh as well as two layers of mesh. A thin layer of this mortar is then placed into the moulds over which a layer of welded mesh is placed followed by the second layer of mortar and surface finishing. The same procedure is repeated twice for slabs with two layers of mesh. After demoulding and subsequent water curing for 28 days, the slab specimens were painted using lime powder for better visibility of cracks during testing. Ferrocement slabs were tested in Universal Testing Machine of capacity 400 kN and during the test, they were simply supported over a span of 750 mm. The load was distributed as two-line loads kept 125 mm apart symmetrical to centreline of slab on the top face such that the distance between the two loading lines is 250 mm and the distance between the loading lines and the nearest support is also 250 mm. The load was applied gradually in small increments and the deflection was measured at the centre of the slab for every 0.5 kN increment of load up to failure using a dial gauge.

3 Results and discussion

3.1 Properties of mortar

The fresh and hardened properties like density, compressive strength and flexural strength of foamed concrete were measured at 28 days and the average values are shown in Table 3. The flow percentage of the reference mixes is 68.25 for river sand and 78.37 for M-Sand. M-Sand samples have better workability which is attributed to the fact that, there is an increase in the volume of the paste due to increased fines content and hence there is a balance achieved in the reduction of workability as the particles of M-Sand having rough surface texture. The foaming agent reduces the flowability of the mortar by exhibiting a lower spread value. This is because of the reason that the increased air content in the mix leads to an increased cohesion and as a consequence of this increased adhesion between the solid particles and air bubbles, the mix became stiffer which has an impact on the workability reduction.

Table 3 Workability and strength properties

Percentage of foaming agent	*Flow percentage*		*Density (kg/m³)*		*Compressive strength (N/mm²)*		*Flexural strength (N/mm²)*	
	RS	*MS*	*RS*	*MS*	*RS*	*MS*	*RS*	*MS*
0	68.25	78.37	2,067	2,098	36.81	39.25	5.83	5.91
0.2	66.19	75.28	2,014	2,049	34.90	37.25	5.14	5.59
0.4	63.20	71.03	1,835	1,912	33.26	36.98	4.72	5.36
0.6	59.88	66.72	1,797	1,872	32.67	35.43	4.39	5.11
0.8	57.42	63.91	1,722	1,791	31.93	33.29	4.22	4.88
1.0	55.15	60.54	1,662	1,723	30.24	31.92	3.94	4.28

As the foaming agent content is increased, the hardened density of the specimens decreased and an exponential decrease is observed for river sand and M-Sand samples. This might be due to the presence of low content of cementitious material and greater air content due to voids in the sample. Comparatively, M-Sand samples have higher density than the samples with river sand for reference as well as for samples with foaming agent. The density reduces from 2,067 kg/m^3 to 1,662 kg/m^3 for river sand and from 2,098 kg/m^3 to 1,723 kg/m^3 for M-Sand mortar through 0% to 1% of foam content. From the experimentally obtained values, we could see a direct relationship existing between the compressive strength and the density. The compressive strength of samples reduces from 36.81 N/mm^2 to 30.24 N/mm^2 at 1% foam content for river sand mortar and from

39.25 N/mm^2 to 31.92 N/mm^2 for M-Sand mortar. Hence, addition of foaming agent drained the compressive strength of mortar which is mainly due to the presence of air voids created through the formation of bubbles in the foam. The flexural strength of the samples is in the range of 4.24 N/mm^2 to 5.91 N/mm^2 and the maximum strength is noted for reference M-Sand samples because of their higher density. The flexural strength also has a correlation with density and compressive strength with maximum values recorded for samples without foaming agent that have greater density and compressive strength. As the river sand specimens have relatively lower density and compressive strength, flexural strength is also noted to be on the lower side in comparison to M-Sand specimens. For the mixes tested, it has been noticed that the flexural strength is about 13% to 15% of the compressive strength of the same mix. Hence, there is a falling trend on the workability, density, compressive and flexural strengths of mortar mixes due to addition of foaming agent.

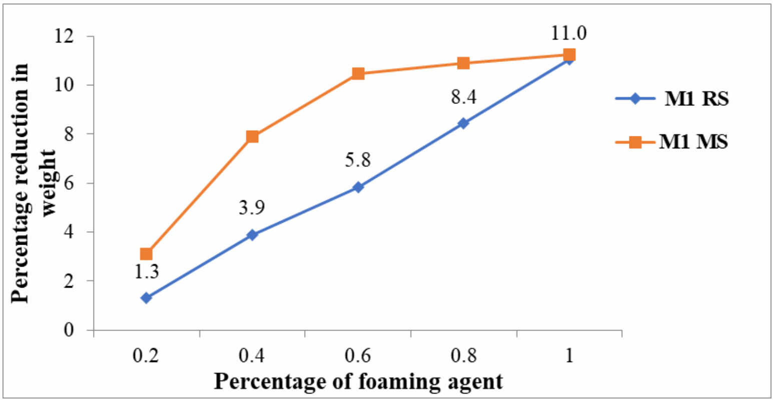
3.2 Self-weight of slabs

All the slab panels were weighed before testing to study the effect of addition of foaming agent. The weight of the slab panels is given in Table 4. From the test results it can be seen that, there is a considerable reduction in weight of slabs due to the addition of foaming agent. Self-weight decreases with an increase in the percentage of foaming agent which might be due to the presence of air voids created due to the addition of foaming agent and the resultant pore structure of concrete. This is applicable for slabs cast using river sand as well as M-Sand. This is also applicable for both single layer and double layers of mesh. In case of ferrocement slabs with single layer of mesh, more reduction in weight is achieved in slabs prepared using M-Sand as compared with slabs made using river sand as revealed in Figure 2. In case of ferrocement slabs with two layers of mesh, percentage reduction in weight is almost same for both M-Sand and river sand in few cases and in some cases percentage reduction in weight is higher for slabs prepared using river sand. In most of the cases, it is noticed that percentage reduction in weight is higher for slabs containing two layers of mesh in comparison with slabs with one layer of GI welded mesh. Hence addition of foaming agent has superficial benefit in reducing the self-weight which may lead to savings in the cost of foundation involved.

Table 4 Self-weight of slabs

Percentage of foaming agent	*Weight of slabs in kg*			
	River sand		*M-Sand*	
	One layer	*Two layers*	*One layer*	*Two layers*
0	15.4	16.2	17.96	18.38
0.2	15.2	15.4	17.4	17.79
0.4	14.8	15.1	16.54	17.22
0.6	14.5	14.8	16.08	16.76
0.8	14.1	14.3	16.0	16.23
1.0	13.7	13.9	15.94	16.1

Figure 2 Effect of foaming agent on self-weight (see online version for colours)



3.3 Ultimate load and deflection

The values of load carrying capacity of slabs along with the maximum deflection for all the slabs tested are given in Table 5. From the results it can be seen that, the type of sand has no significant effect in terms of load carrying capacity of slabs. The ultimate load is almost similar for ferrocement slabs made of river sand and M-Sand. Similarly, percentage of foaming agent has no effect on the ultimate load of slab panels. This is valid for both the parameters namely type of sand and number of layers of mesh. The load versus deflection graphs for slabs without foaming agent is shown in Figure 3. Similarly load vs deflection graphs for ferrocement panels with 0.2 %, 0.4%, 0.6%, 0.8% and 1% foaming agent are shown in Figure 4, Figure 5, Figure 6, Figure 7 and Figure 8, respectively. From Figures 4–8, it is noticed that at the same magnitude of load, slabs with two layers of mesh deflects less as compared with slabs consisting of single layer of welded mesh.

Table 5 Ultimate load and deflection

Percentage of foaming agent	*River sand*				*M-Sand*			
	One layer		*Two layers*		*One layer*		*Two layers*	
	Ultimate load (kN)	*Maximum deflection (mm)*	*Ultimate load (kN)*	*Maximum deflection (mm)*	*Ultimate load (kN)*	*Maximum deflection (mm)*	*Ultimate load (kN)*	*Maximum deflection (mm)*
0	5.5	15.3	6.5	13.5	5.88	15.5	6.3	14.1
0.2	5.4	10.7	6.2	16.3	5.72	18.8	6.8	20.1
0.4	6.06	18.4	6.8	19.5	5.68	21.7	6.6	25.1
0.6	5.94	20.0	6.04	21.5	5.8	15.3	6.4	24.4
0.8	5.84	25.9	7.1	26.5	5.34	13.4	6.52	26.8
1.0	5.68	16.5	5.8	25.4	5.72	13.5	6.54	23.5

Figure 3 Load vs. deflection: 0% foaming agent (see online version for colours)

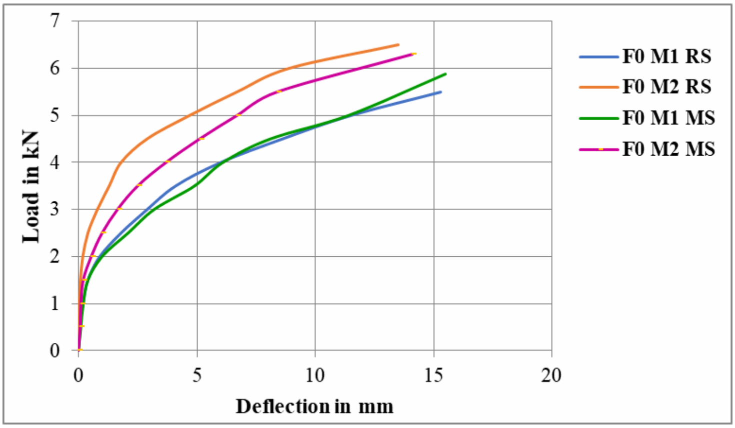


Figure 4 Load vs. deflection: 0.2% foaming agent (see online version for colours)

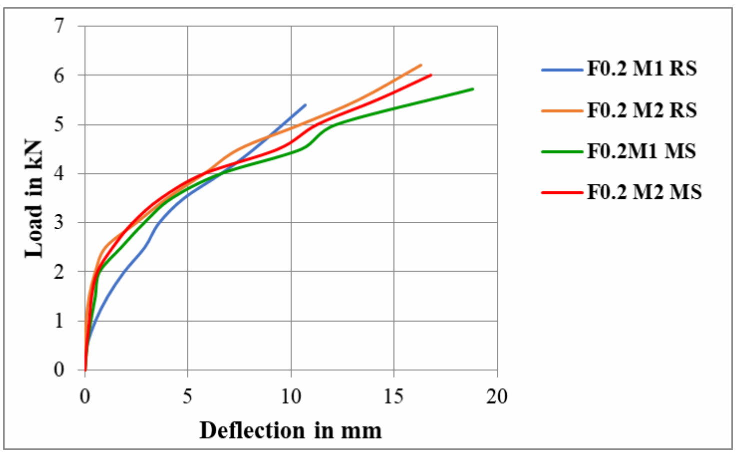


Figure 5 Load vs. deflection: 0.4% foaming agent (see online version for colours)

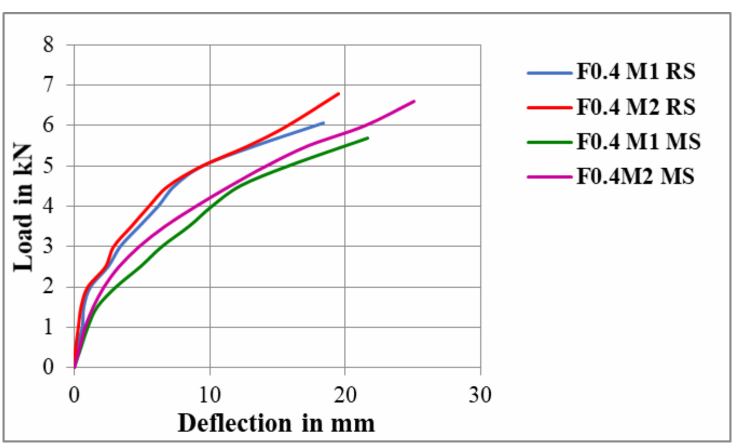


Figure 6 Load vs. deflection: 0.6% foaming agent (see online version for colours)

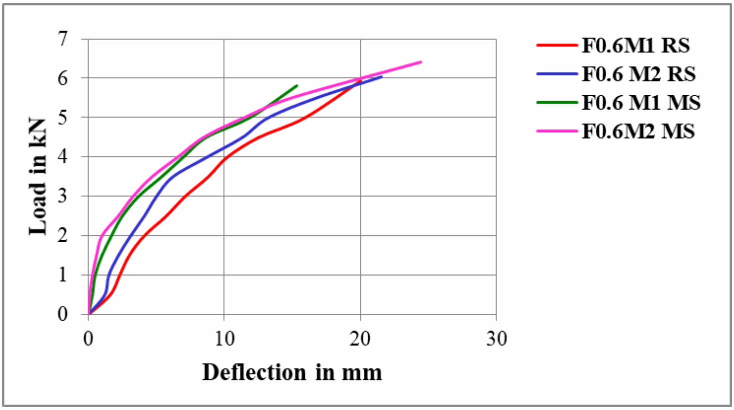


Figure 7 Load vs. deflection: 0.8% foaming agent (see online version for colours)

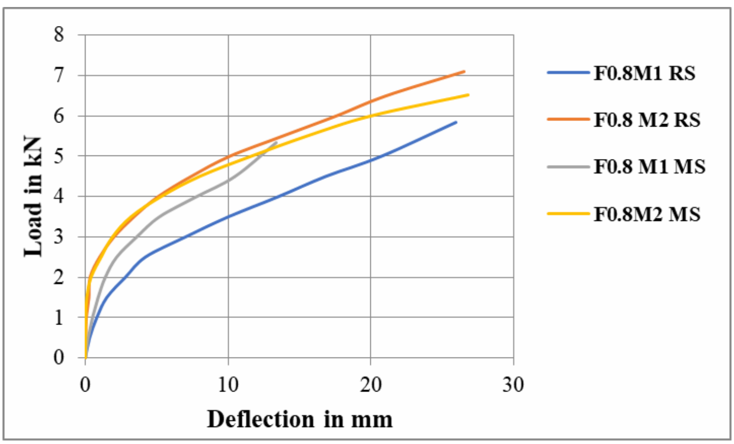
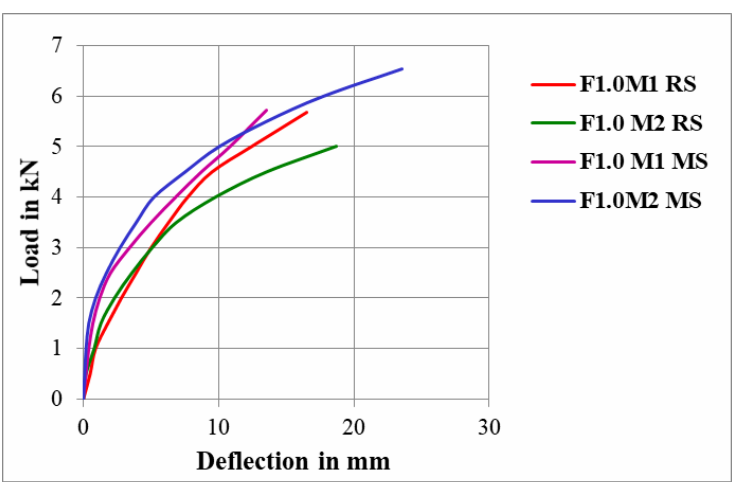


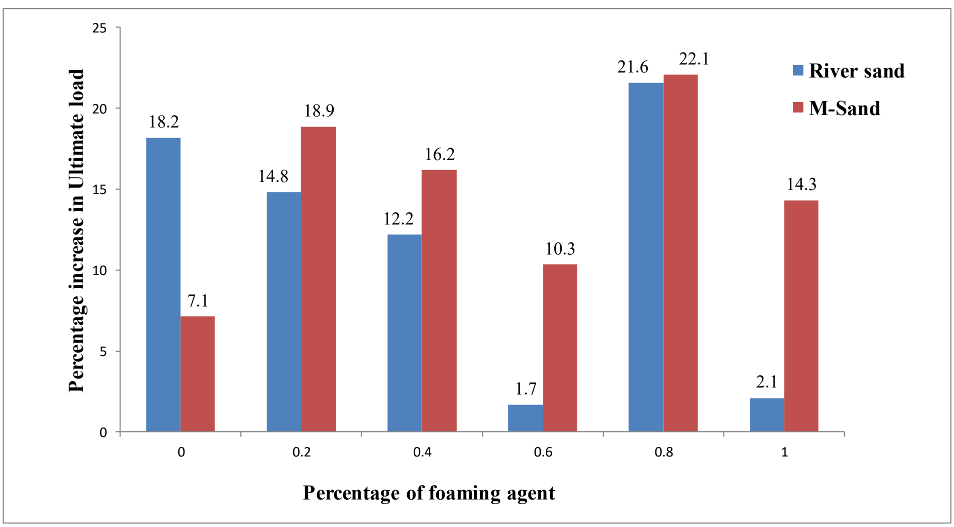
Figure 8 Load vs. deflection: 1% foaming agent (see online version for colours)



From the maximum deflection values, it can be seen that in most of the cases, due to the addition of foaming agent, slabs undergo large amount of deformation and as the percentage of foaming agent increases, the maximum deflection values also increase. Large values of deflection indicate that slabs exhibit enhanced ductility due to the addition of foaming agent. Maximum deflection of 25.9 mm and 26.5 mm were observed at 0.8% foaming agent for slabs with river sand for one and two layers of mesh. In case of slabs with M-Sand, maximum deflection of 21.7 mm was noticed at 0.4% foaming agent for single welded mesh layer and a deflection of 26.8 mm was noticed at 0.8% foaming agent for double layer of mesh.

In general, as the number of layers of mesh increases from one to two, ultimate load increases. In case of slabs without foaming agent, as the number of layers of mesh is increased from one to two, ultimate load increased by 18.2% and 7.1% for river sand and M-Sand respectively. For slabs with river sand and M-Sand, the ultimate load increases by 14.8% and 18.9%, 12.2% and 16.2%, 1.7% and 10.3%, 21.6% and 22.1% and 2.1% and 14.3% for 0.2, 0.4, 0.6, 0.8 and 1% foaming agent respectively as shown in Figure 9. Also increase in number of layers of mesh from one to two exhibited good ductility by showing a considerable increase in ultimate deflection values before failure.

Figure 9 Effect of number of layers of mesh on ultimate load (see online version for colours)



This increase is attributed to the increase in the specific surface area of the mesh and also due to the resistance provided by the mesh under flexure. As the number of layers of mesh is increased, there is a good control over the formation and propagation of cracks that leads to the delay in the formation of first crack and the subsequent flexural cracks. In general slabs with two layers of mesh offered good crack control mechanism through the formation of uniformly distributed thin cracks at a steady pace ensuring the sufficient elongation of the wire meshes that leads to an enhanced ultimate load and ductility.

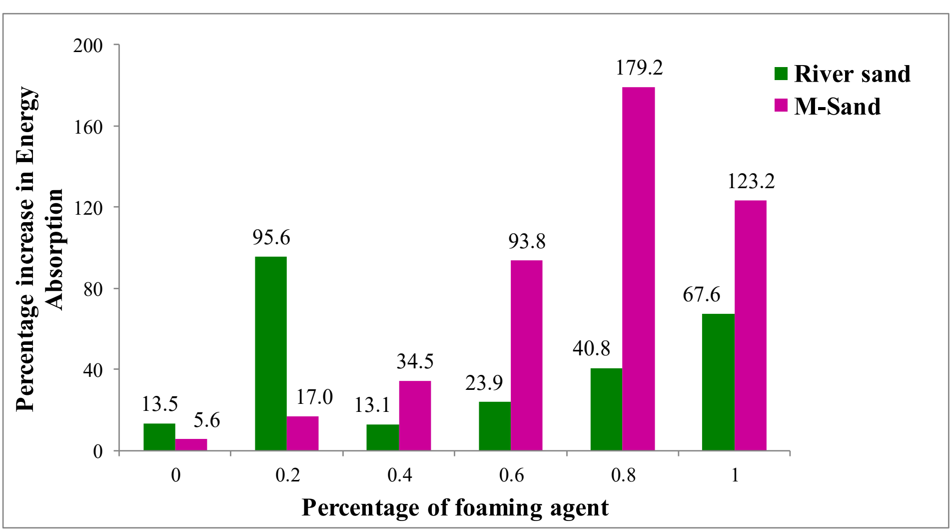
3.4 Energy absorption

From the load vs. deflection graphs drawn for each of the slabs, energy absorbed by each slab was calculated by finding the area under the curve and the values in Joules are given in Table 6. Out of all the slabs tested, least energy absorption value of 36.48 J is noticed for slabs with river sand having one layer of mesh and 0.2% foaming agent. Maximum energy absorption value of 138.11 J is noticed for slabs with river sand having two layers of mesh and 0.8% foaming agent. It can be seen that the energy absorption values are higher for slabs with two layers of mesh as compared to the slabs with single layer of mesh. In case of slabs without foaming agent, as the number of layers of mesh is increased from one to two, energy absorption increased by 13.5% and 5.6% for river sand and M-Sand respectively. For slabs with river sand and M-Sand, the energy absorption increases by 95.6% and 17%, 13.1% and 34.5%, 23.9 % and 93.8%, 40.8% and 179.2% and 67.6% and 123.2% for 0.2, 0.4, 0.6, 0.8 and 1% foaming agent respectively as shown in Figure 10.

Table 6 Energy absorption

Percentage of foaming agent	*Energy absorption (J)*			
	River sand		*M-Sand*	
	One layer	*Two layers*	*One layer*	*Two layers*
0	62.1	70.47	63.4	66.94
0.2	36.48	71.34	79.57	93.08
0.4	81.00	91.65	82.15	110.51
0.6	70.3	87.12	59.49	115.29
0.8	98.06	138.11	47.99	134
1.0	61.59	103.21	51.57	115.09

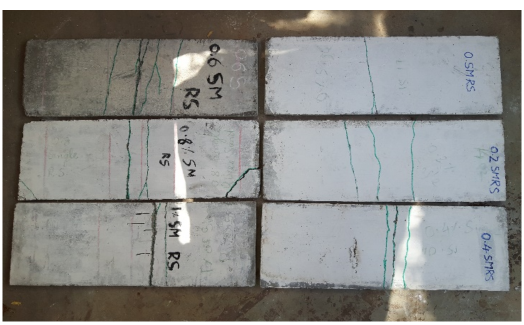
Figure 10 Effect of number of layers of mesh on energy absorption (see online version for colours)



3.5 Failure modes and crack patterns

The failure modes and deflected shapes of ferrocement slabs M_1RS (single layer, river sand), M_2RS (two layers, river sand), M_1MS (single layer, M-Sand), M_2MS (two layers, M-Sand) are shown in Figure 11, Figure 12, Figure 13 and Figure 14, respectively. In general, all the ferrocement slab panels failed due to formation of flexural cracks. In F_0M_1RS, failure takes place showing crack along a single line of fracture. In $F_{0.2}M_1RS$, we can see multiple lines of cracks (three lines) that are spaced at a wider spacing whereas in $F_{0.4}M_1RS$, the same pattern of cracking was observed except that they are spaced closely with the enlarged crack width seen in the centre line of fracture. In $F_{0.6}M_1RS$, failure takes place after the formation of cracks along four lines with three thin line cracks and the crack that was first visible widens further on application of load. Due to increase in crack width, secondary cracks started to form. In $F_{0.8}M_1RS$, failure is due to the formation of cracks along two lines with the first crack getting wider and wider on application of load. Delamination of mortar layer was also noticed at the mid portion of the slab panel due to enlargement of cracks. In addition to this failure was also seen at one of the supports. In $F_{1.0}M_1RS$, failure is due to development of a wider crack at the centre accompanied by a right-side thin line crack.

Figure 11 (a) Crack pattern: M_1RS (b) Deflected shapes: M_1RS (see online version for colours)

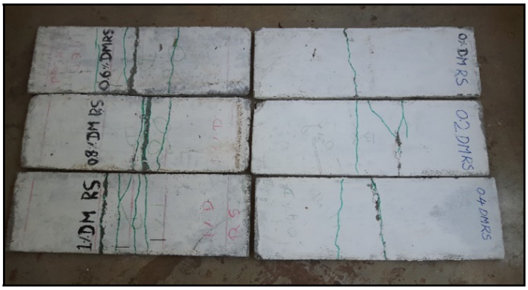


(a)

(b)

The failure mode of F_0M_2RS is very similar to that of F_0M_1RS in which failure takes place along a single line of fracture. In $F_{0.2}M_2RS$, failure takes place by forming cracks along two lines with a considerable spacing between them with secondary cracks originating from one of the main crack lines. The failure mode of $F_{0.4}M_2RS$ is almost similar to that of $F_{0.2}M_2RS$ without the formation of secondary cracks. In $F_{0.6}M_2RS$, $F_{0.8}M_2RS$ and $F_{1.0}M_2RS$, flexural cracks which originated first becomes wider and wider on increasing the loads. In addition to this, $F_{0.6}M_2RS$ and $F_{1.0}M_2RS$ have three thin line cracks and $F_{0.8}M_2RS$ has two thin line cracks which were formed very closer. Failure modes of slabs with M-Sand are somewhat different from the slabs with river sand.

Figure 12 (a) Crack pattern: M_2RS (b) Deflected shapes: M_2RS (see online version for colours)



(a) (b)

Figure 13 (a) Crack pattern: M_1MS (b) Deflected shapes: M_1MS (see online version for colours)

(a) (b)

Failure of F_0M_1MS, $F_{0.2}M_1MS$, $F_{0.4}M_1MS$ and $F_{0.8}M_1MS$ slabs are very alike by the development of cracks along a single line which widens gradually on increasing the load. $F_{0.6}M_1MS$ failed by forming multiple hairline cracks which are very much closely spaced. In $F_{1.0}M_1MS$, there are two crack lines out of which the first formed crack widens on the increase of load whereas the other one is a thin hairline crack. In $F_{0.6}M_1MS$, $F_{0.8}M_1MS$ and $F_{1.0}M_1MS$, failures were somewhat brittle which was indicated by minimum values of ultimate deflection. In slab panels made of M-Sand and two layers of mesh, almost all the slabs failed by the development of multiple thin hairline cracks. Wider cracks were not seen in any of the slabs which also reveal that the development of cracks is slow and steady. Sufficient elongation of mesh layers has taken place which makes the failure ductile by showing enlarged deformation before failure.

Figure 14 (a) Crack pattern: M_2MS (b) Deflected shapes: M_2MS (see online version for colours)

(a)

(b)

4 Conclusions

From the investigations carried out, the following conclusions are arrived at:

- Addition of foaming agent has superficial benefit in reducing the self-weight which may lead to savings in the cost of foundation involved. As the percentage of foaming agent increases, self-weight decreases.
- Type of sand has no significant effect in terms of load carrying capacity of ferrocement slabs. Similarly, percentage of foaming agent has no effect on the ultimate load of slab panels.
- As the number of layers of mesh increases from one to two, ultimate load carrying capacity of ferrocement slab increases. An Increase in number of layers of mesh from one to two exhibited good ductility by showing a considerable increase in maximum deflection values.
- Energy absorption values are higher for slabs with two layers of mesh as compared to the slabs with single layer of mesh. This is applicable for both river sand and M-Sand.
- Ferrocement slab panels exhibit enhanced ductility due to the addition of foaming agent.
- It is understood that there is a huge scope for further studies on foamed concrete with various types of synthetic and protein based foaming agents as only one type of synthetic agent is considered in the present study. Further studies are required for optimising contents of synthetic and protein type foaming agents and assessing their stability characteristics for effective utilisation in practical applications. Explorations could also focus on the use of alternative cementitious materials and or mineral admixtures for the manufacturing of foamed concrete and their feasibility in making of ferrocement products. Studies could also be extended in ferrocement slabs with

foamed concrete employing different types of meshes to assess the suitability of mesh types for a wide variety of ferrocement applications.

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