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Flexural Behaviour of Reinforced Concrete Beams Rehabilitated With Ferro-cement Laminate

Mohammed Salman[1], Syed Anees ur Rahman[2], Faizan khan[3], KanchalaNanchari[4]

[1, 2, 3] UG Students, Department of Civil Engineering [4] HOD Dept of Civil Engineering
ISL Engineering College, Hyderabad, Telangana, India

Abstract *Ferro cement is a versatile construction material formed by using hydraulic cement mortar into closely spaced layers of a small sized wire mesh. The mesh may be of metallic or other materials. It has a high tensile strength to properties and predict flexural behaviour of Ferro cement laminates by replacing cement with industrial wastes to some extent. Portland cement weight ratio better cracking resistance behaviour when compared to reinforced concrete. The main aim of this research work is to increase the normal beam strength and also extend the old beam life span by using Ferro cement laminate with effective utilization of fly ash and silica fume are optimum weight of cement. The flexural characteristics of various specimens were obtained experimentally. The specimens are reinforced with different layer of chicken mesh, and formed by different replacement proportion*

Keywords — Chicken mesh, Epoxy resin, Fly ash, Ferro cement laminate, Flexural test, silica fume.

1. INTRODUCTION

Cement is a versatile construction material formed by filling hydraulic cement mortar into closelyspaced layers of small sized wire meshes over a small thickness. The mesh may be of metallic or any othermaterials. It has a higher tensile strength to weight ratio and better cracking resistance behaviour when compared to reinforced concrete. It requires less skill and provides low cost serviceability without the loss ofstructural integrity. Ferro cement is identified as an eco-friendly technology. Ferro cement has proven tobe less polluting technology that uses all resources in amore sustainable manner. It handles waste products in a more acceptable manner than other construction technologies. Ferro cement is truly sustainable and eco-friendly as it uses minimum natural resources, thus mitigating the effects of global warming. These potential advantages and the novelty of the concept make Ferro cement, an attractive material for construction purpose. Ferro cement originally started with boat building and presently it has got very wide applications, in the fields of agriculture, water supply, sanitation, housing rural energy, repair and rehabilitation of structures etc. The use of industrial by-products as partial replacement of cement in the mortar improves certain characteristics (Selcuk turkel & yigit altuntas 2009).

The maintenance, rehabilitation and upgrading of structural members are perhaps some of the mostcrucial problems in civil engineering applications. Moreover, a large number of structures constructed in the past using the earlier design codes in different parts of the world are sometimes structurally unsafe according to the current design standards. Since replacement of such deficient elements of structures incurs a huge amount of money and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service durability. Infrastructure decay caused by premature deterioration of buildings and structures hasled to the investigation of several processes for repairing or strengthening purposes. One of the challenges in strengthening of concrete structures isthe selection of a strengthening method that will enhance the strength and serviceability of the structurewhile addressing limitations such as constructability,building operations, and budget. Strengthening may beneeded to allow the structure to resist loads that were not anticipated in the original design. This may be encountered when structural strengthening is required for loads resulting from wind and seismic forces or to improve resistance to blast loading. Thus a completeunderstanding of Ferro cement material behaviour would lead to an innovative technique for strengthening of reinforced concrete beams.

1.1 Need for Replacement

In Ferro cement the meshes serve as reinforcement and mortar serves as matrix resulting as an integral product. Engineers are continually pushingthe limits to improve the performance of the mortar with the help of innovative chemical admixtures and supplementary cementitious materials. The development of new construction materials and technology can partly relieve pressures on the existing building material supply and help to arrest the spiraling rise in cost of these materials and also mayreduce in-situ construction activities. The main benefits of fly ash and silica fume are their ability to replace certain amount of cement in the matrix and still able to display cementitious property. They reducethe cost of using Portland cement. The fast growth inindustrialization has resulted in tones of by-product orwaste materials such as fly ash and silica fume. Theuse of these by-products not only helps to utilize these waste materials but also enhances the properties of mortar in fresh and hydrated state.

Production of one ton of Portland cement releases 0.9 tons of CO2 into the atmosphere correspondingly, thereby impacting the environment. Portland cement is a highly energy intensive material.

In India, about 100 million tons of fly ash is accumulated every year which is generated as wastefrom thermal plants. This is causing enough concern asits disposal involves design and installation of ash ponds covering large areas at each plant site. In spiteof concerted efforts on a national scale, only a very small fraction (around 6%) of the fly ash is put to usein India, compared to its utilization to a greater extent in other countries (Md Emamul Haque 2013). Silicafume is also a waste by-product from the silicon metaland ferrosilicon alloy industries. An effort has been made to industrial byproducts as the substitutes for partial replacement of cement and to reduce waste pollution.

1.2 Research Significance

The wide application of admixtures with partial replacement of cement, reduction in embodied CO2 content and sustainability of the waste materials reuse have been the driving force for researchers to carry out extensive work in Ferro cement technology. Ferro cement is a cost effective and versatile material. Only certain types of materials locally available in bulk quantity can be used. There is a need for evaluating admixtures as replacement and simultaneously fulfilling advantages like low cost, abundance etc. for Ferrocement applications. There is also a demand for identifying and evaluating the admixture proportion of Ferrocement that should possess good ductility, less cracking and maximum strength. They should provide a sustainable technology to reuse industrial waste like fly ash, rice bran, wheathusk, silica fume along with cement paving the wayfor reducing CO2 emissions. The combined use of mineral admixtures and super plasticizers with cement resulted in synergistic effects. It led to modification enabled durable mortars to be used in a variety of conditions. The increased strength has to be thoroughly validated. So there is a need to study the flexural behaviour and impact resistance of Ferrocement laminates with material replacement. There has been a dearth of research work on studying flexure and the impact behaviour of Ferrocement laminates made from cement mortar, partially replaced with fly ash and silica fume at differing volume fraction of mesh. The reinforced concrete beams get strengthened with the use of the Ferrocement laminates. The research proposes an abundant, cost effective, strong and sustainable eco friendly construction material for the future through the use of Ferrocement technology.

1.3 Objectives and Scope Of Current Study

- To explore the salient features of many constituents for the composition of Ferrocement laminates and to select the suitable materials to be used in Ferrocement laminate preparation.
- To develop cementitious matrix containing asuitable combination of silica fume, fly ash, and superplasticizer, to be used in thin Ferro cement laminates that are applied for structural repair and strengthening applications.
- To study experimentally the flexural and impact characteristics for the different chickenmesh specimens of chosen size with different proportions of replacement.
- To formulate mathematical models that will compare the experimentally obtained ultimate moment capacity of Ferro cement laminates reinforced with chicken mesh.

2. REVIEW OF LITERATURE

Ayub et al. experimentally investigated and made an assessment on the effectiveness of ferrocement strengthening techniques i.e., cast in situ Ferro-mesh layers and precast ferrocement Laminate. Totally ten reinforced concrete beams including one control beam was intentionally designed and detailed to fail in flexure. Prior to strengthening, beams were tested under two-point loading till service limit. Beams were strengthened in the flexural dominant region and tested to failure under the same loading arrangement. The parameters for structural behaviour was limited to stiffness, load carrying capacity, failure mode and ductility of the beams by varying number of wire mesh layers, development length and technique of application, i.e. cast in situ ferro-mesh layers and precast ferrocement laminate. It was concluded that strengthening through cast in situ Ferro-mesh layer is the most efficient technique, whereas strengthening of the beams by using precast Ferrocement Laminate is not only easy to implement at household level, but is also promising in terms of enhancing load carrying capacity, stiffness and ductility.

Bashandy evaluated the efficiency of strengthening reinforced concrete beams using three valid strengthening materials and techniques. The first is based on using concrete layer while the second is based on using mesh reinforced concrete layer and the third is based on using steel plates. Samples are divided in to three groups, a group strengthened using 2cm thickness concrete layer only (two types), another group is strengthened using 2cm thickness concrete layer reinforced with meshes (steel and plastic) and a group of beam is strengthened using steel plates. The initial cracking load, ultimate load and crack pattern of tested beams are illustrated. Economically, steel meshes costs less compared to steel plates by about 60 %.

Shaheen et al. studied the structural behaviour of ferrocement concrete composite channels reinforced with various types of reinforcing materials. The thickness of the two webs and base were kept constant as 25 mm. The test specimens were loaded under four point loadings until failure. Determined the mechanical properties of the used steel and wire meshes and the ultimate load, flexural behaviour, ductility ratio, energy absorption and mode of failure at collapse of the control beams which were reinforced with steel and the results were compared with the conventionally reinforced ferrocement beams reinforced with expanded metal mesh, welded metal mesh and glass fibre mesh. Employing polypropylene fibres in mortar mix increase in the first crack load, serviceability load, ultimate load, and energy absorption, higher stiffness However, it resulted in a decrease in the ductility ratio, less deflection at the corresponding load levels. Increasing the number of the steel mesh layers in the ferrocement forms increases the first crack load, service load, ultimate load, and energy absorption decreases.

Vidivelli et al revealed the work associated with the behaviour of strengthening the predamaged reinforced concrete beams by using ferrocement plates. The study elaborated the mechanical properties of ferrocement with three different volume fractions of reinforcements. Ferro cement laminates are introduced to enhance the overall performance of reinforced concrete beams. Eight beams were cast and tested for flexure. Out of eight beams two beams were treated as control beams and the remaining six beams were loaded to a predetermined damage level, and strengthened by fastening ferrocement laminates. Fastening of ferrocement laminates onto the surface of the predamaged beam was done by using epoxy resin adhesive. The strengthened beams were again tested for ultimate load carrying capacity by conducting flexural test. A comparative study was made between the control beams and the predamaged beams strengthened by ferrocement laminates. The test results have shown that ferrocement can be used as an alternative strengthening material for the reinforced concrete beams damaged due to overloading.

3. METHODOLOGY

The methodology of present study is explained by the properties of cement, fly ash, silica fume, fine aggregate, chicken mesh are studied. The compressive strength of mortar was studied at 1:2 by weight andwith water binder ratios of 0.35. At water binder ratio, partial replacement of cement with fly ash content wasvaried from 10%, 15%, 20%, 25% and 30% togetherwith a constant 5% silica fume by weight of cement.Ferrocement laminates of sizes 100 mm x 25 mm x 500 mm, 1:2 mix ratio, 0.35 water binder ratio, partialreplacement of cement with fly ash content varying from 10%, 15%, 20%, 25% and 30% together with a constant 5% silica fume by weight of cement were prepared The flexure test was conducted with the load applied at one two point.

The reinforced concrete beams with simplysupported span lengths of 1.22 m, and a cross-section of 150 x 100 mm were cast with M25 grade concreteof mix ratio 1:1.5:3 by weight and the water cementratio of 0.45. The beam was reinforced with two steel bars of 10 mm diameter with two-legged stirrups of 6 mm diameter at 75 mm c/c. Ferro cement laminates were used to strengthen the beams. The ferrocementlaminates were sized 1220 mm x 100 mm x 25 mm with the mortar mix of cement sand ratio of 1:2 and a water binder ratio of 0.35.

3.1 MATERIAL INVESTIGATION

In this investigation cement which is of the ordinary Portland cement 53 grade, locally available river sand and coarse aggregate of good quality was used.

Table 1: Physical properties of Cement.

S. No.	Characteristics	Value obtained
1	Standard Consistency	35
2	Initial Setting Time	36 minutes
3	Final Setting Time	400 minutes
4	Specific Gravity	3.15

Table 2: Physical properties of Fine aggregate.

S. No.	Physical property	Value obtained
1	Fineness modulus	2.75
2	Grading zone	I
3	Specific Gravity	2.74
4	Moisture Content	0.5%
5	Water Absorption	1.5%

Table 3: Physical properties of Coarse aggregate.

S. No.	Physical property	Value obtained
1	Fineness modulus	7.07
2	Nominal size	20 mm
3	Specific Gravity	2.65
4	Moisture Content	Nil
5	Water Absorption	0.5%

The quality of water is important, because impurities in it may interfere with the setting of the cement and it may adversely affect the strength of the concrete or cause staining of its surface and may also lead to corrosion of the reinforcement. Water used for mixing and curing shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic material they may be deleterious to concrete or steel permissible limits.

3.2 Fly Ash

Ash produced in small dark flecks by the burning of powdered coal or other materials and carried into the air.

Table - 4 Properties of fly ash

Description of test	Result obtained	Requirement As per 1s 3812
Specific surface area (m^2/kg)	312 m^2/kg	320 m^2/kg
Soundness	0.65	0.8

3.3 Silica Fume

Silica fume is a byproduct of producing siliconmetal or ferrosilicon alloys. One of the most beneficialuses for silica fume is in concrete. Because of its chemical and physical properties, it is a very reactive pozzolan. Concrete containing silica fume can havevery high strength and can be very durable.

Table – 5 Properties of silica fume

Description of test	Result obtained	Requirement As per 1s 3812
Bulk density(m^2/kg)	546 m^2/kg	480-720 m^2/kg
ecific surfacearea (m^2/g)	19	>15

3.4 Wire Meshes

Hexagonal chicken wire meshes locally available wereused as the reinforcement in ferrocement laminate.

Table – 6 Properties of wire mesh

Description	Chicken mesh
Raw material	Steel
Width(m)	1
Mesh opening size (mm)	15X10
Thickness(mm)	1.5
Diameter (mm)	0.5
Mesh shape	Hexagonal
Density (kg/m^3)	7850
Yield strength (N/mm^2)	310

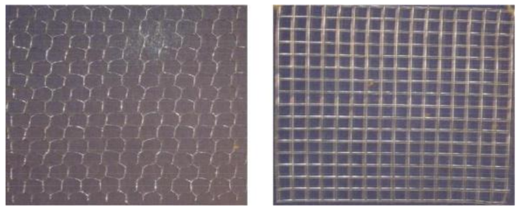

Figure-1: Wire mesh

3.5 Epoxy Resin

The epoxy resin is a two part epoxy system consisting of a resin and a hardener. It has a mix ratio of 1: 2 by weight with a long work life of 40-50 minutes. It can be cured at room temperature. Epoxyresin exhibits low shrinkage during curing. The cured epoxy has high chemical, corrosion resistance but good mechanical and chemical properties.

Table-7 Epoxy resin strength values

Description	Strength (N/mm^2)
Compressive strength (ASTMD 695)	75
Tensile strength at 7 days (ASTM D 638)	38
Pull out Adhesion at 3 days	2.91
Pull out Adhesion strength at7 days	15.4

3.6 Reinforcement of Beam

The longitudinal reinforcement for beams weretwo steel bars of 10 diameter and yield strength of 500 N/mm^2 in tension. The two-legged stirrups were of 6mm diameter at 75 mm c/c.

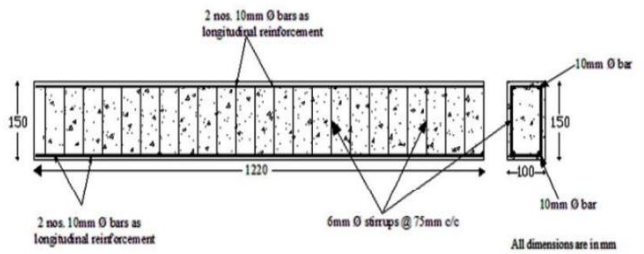

Figure 2- Reinforcement of Beam

4. EXPERIMENT RESULTS

In this chapter, the results based on the experimental investigations which were carried out onoptimized mortar matrix are discussed. The flexural characteristics of ferrocement laminates, with differentproportion of fly ash and silica fume together with cement, reinforced with chicken mesh of single, double, three and four are presented. The results arecompared with conventional mortar specimens of ferrocement laminates. The experimental investigation on strengthened reinforced concrete beams with ferrocement laminates of conventional mortar and optimized mortar containing silica fume, fly ash andcement reinforced with chicken mesh of four layer also presented. The experimental results in flexural capacity of ferrocement laminates and strengthening ofreinforced concrete beams are compared.

4.1 Mortar for Casting Ferrocement Laminates

Mix proportion for casting ferrocement laminates was selected from the results of compressive strength. Ferro cement laminate of sizes 150 mm x 25 mm x 500 mm, 1:2 mix ratio, 0.35 water binder ratio, partial replacement of cement with fly ash content 20% together with 5% silica fume by weight of cement were prepared. The dosage of super plasticizer used was 0.6% by weight of the total binder. Thus the specimens were cast by placing the mortar and leveling it in the mould, initially to a depth of 4 mm. Then, the required type of mesh was placed after which the cement mortar was spread again, leveled and compacted to the required thickness. The ferrocement slabs thus cast were de-moulded after 24 hours of casting. They were placed immediately in a curing tank containing water. The details of ferrocement laminate are shown in Figure. 3 a & b

(a) Placing the mortar on mesh

(b) Spreading the mortar on mesh

The beams and laminates were cured for 28 days. After curing, all the specimens were allowed to surface dry for 24 hours at room temperature. The tension side of the beams and bonding face of the ferrocement laminates were roughened using wire brush to remove the surface laitance and to expose the rough surface. After surface preparation, the adhesive component i.e. epoxy resin was mixed thoroughly in accordance with the manufacturer's instructions and applied to the prepared surface of beams and ferrocement laminates using a brush. Then, ferrocement laminates were placed in position. The air bubbles trapped in the concrete were eliminated. Of the 10 beams, four beams were strengthened with ferrocement laminate made from conventional mortar and four more were strengthened with the optimum replacement mortar and reinforced with galvanized weld mesh of volume fraction 1.761% and 2.348%. The beams strengthened with ferrocement laminates were allowed to be cured in air for 24 hours. Figure shows the application of Epoxy Resin on beam and laminate and Figure 3.15 shows the strengthened beam.

Figure-4 Application of epoxy resin on beam and Strengthened beam

Details of test specimens are given. CB denotes the control beam. SB3CM refers to the beam strengthened with ferrocement laminate of conventional mortar reinforced with 3 layers of weld mesh. SB3BM designates the beam strengthened with ferrocement laminate of optimum replacement mortar mix of 20% fly ash together with 5% silica fume reinforced with 3 layers of weld mesh. SB4CM signifies the beam strengthened with ferrocement laminate of conventional mortar reinforced with 4 layers of weld mesh. SB4BM denotes the beam strengthened with ferrocement laminate of optimum replacement mortar mix of 20% fly ash together with 5% silica fume reinforced with 4 layers of weld mesh.

4.2 Load Deflection Characteristics

The load deflection of all the beams was recorded. The mid span deflection of each beam was compared with that of their respective control beams. It was noted that the behaviour of flexure when strengthened with ferrocement optimized blended mortar laminates was better than the corresponding conventional mortar beams. The mid span deflection was much lower when strengthened with ferrocement optimum blended mortar laminate with weld mesh of volume fraction 2.348%. The load deflection behavior of beams in flexure is shown in Figure. The use of ferrocement laminates delayed crack formation. The load deflection curves of all the beams were linear upto the first crack load and then the curve deviated from linearity upto the ultimate load. At a load of 28kN, initial crack started appearing on the CB beam. With further increase in load, crack propagation took place. At the load of 60kN, the beam completely failed in flexure. For beam SB3CM, at a load of 34.2kN initial cracks appeared and reached an ultimate load of 81.5kN which is greater than that of beam CB. For beam SB3BM, at a load of 35.1kN, initial cracks started appearing and reached a greater ultimate load of 84.2kN compared to both beams CB and SB3CM. For beam SB4CM, at a load of 37kN initial cracks appeared and reached an ultimate load of 95kN which is greater than that of beam CB. For beam SB4BM, initial cracks started at 46kN and reached the greater ultimate load of 117kN compared to both beams CB and SB4CM. The descending order of the beams on the basis of deflection undergone was CB, SB3CM, SB3BM, SB4CM and SB4BM. Of these deflections undergone by the beam CB was the highest.

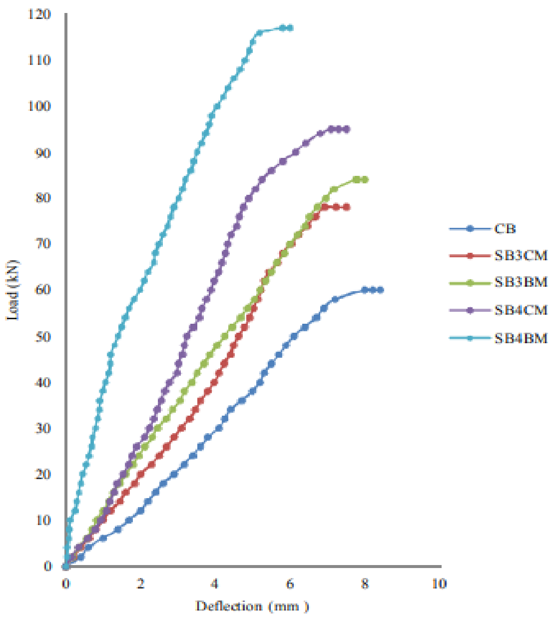

Figure-5 Graph shows the deflection of beam

4.3 General Failure Characteristics

The reinforced concrete control beam failed due to yielding of tension steel followed by crushing of concrete at mid span. After failure, flexural cracks were observed in the beam throughout the span length. The typical appearance of control beam and strengthened beams after failure are shown in Figure 5.54. Flexural cracks observed were initiated randomly in the constant moment region. As the load was increased, cracks were observed along the entire length of the beam. The initial cracks started at higher load for beam SB4BM compared to CB and SB4CM. With further increase in loading, crack propagation took place. Finally, the beam failure happened after flexure and crushing of concrete. In strengthening of beams till the failure, it has not delaminated. It is found to be intact. The difference in load deflection curves shows compatibility between RC beams and laminated beams. The application of ferrocement layer has given adequate confinement for the reinforced concrete beams. A flexible epoxy bonding system ensured that bond line in strengthened beam participated fully in the structural resistance of the strengthened beams and did not break before failure.

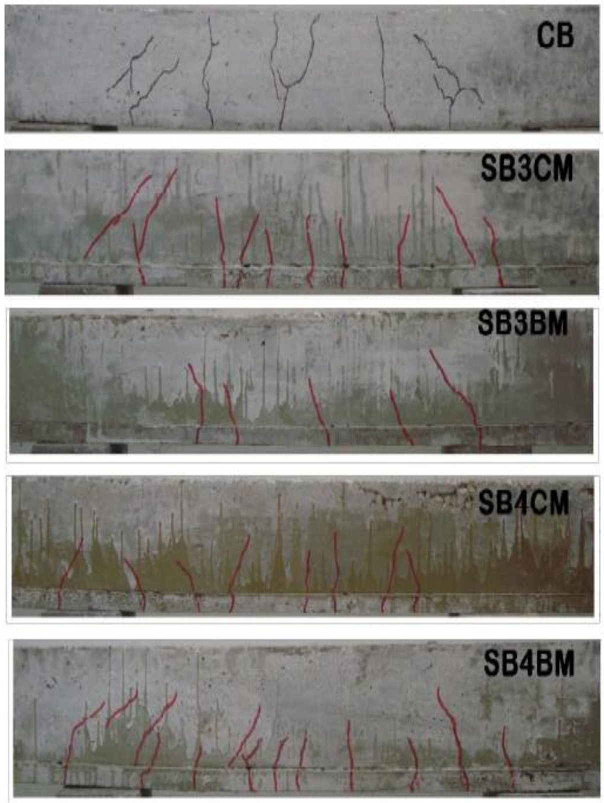

Figure-6 Cracks in a beam

4.4 Energy Absorption Capacity

The energy absorption was calculated from the area under the load deflection curve. The beam SB3CM and SB4CM had 27% and 39% increase in energy absorption compared to control beam. The beam SB3BM had 35% and 65% increase in energy absorption compared to CB and SB3CM. Beam SB4BM had 41% and 21% increase in energy absorption compared to CB and SB4CM. The variation of energy absorption capacity with a specimen is shown in Figure 5.55. The increase in percentage of energy absorption capacity with respect to control beam is shown in Figure.

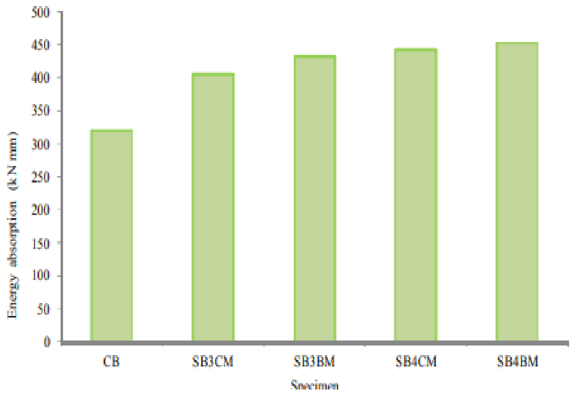

Figure- 7 The increase in percentage of energy absorption capacity with respect to control beam

5. CONCLUSION

Based on the experimental investigations on flexural strength behaviour of Ferro cement laminates cast by partial replacement of cement with fly ash content varying from 10%, 15%, 20%, 25% and 30% together with a constant 5% silica fume by weight of cement and reinforced with chicken mesh.

- The mortar mix was found to have a composition of 1:2 mortar mix, 0.35 water binder ratio with partial replacement of cementwith fly ash 20% together with a 5% silica fume is gives the good results, so it is suitablefor casting Ferro cement elements.
- The first crack load of 4 layer chicken meshspecimen is 60.6% greater than single layer specimen. The 4 layer chicken mesh specimenultimate load is 44% of greater then single layer chicken mesh specimen.
- The first crack load of strengthening beam is 75% of greater than conventional beam. The ultimate load of strengthening beam is 64% ofgreater than conventional beam.
- The Ferro cement laminate use to increase the beam strength and lifespan of beam.
- This method is also suitable for old buildings repair techniques.

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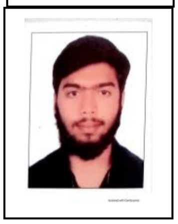
BIOGRAPHIES

Mohammed Salman
(UG Student, Department of Civil Engineering,
ISL Engineering College,
Hyderabad, Telangana)



Syed Anees ur Rahman
(UG Student, Department of Civil Engineering,
ISL Engineering College,
Hyderabad, Telangana)

Faizan Khan
(UG Student, Department of Civil Engineering,
ISL Engineering College,
Hyderabad, Telangana)

Kanchala Nanchari
(HOD, Department of Civil Engineering,
ISL Engineering College,
Hyderabad, Telangana)