Webology, Volume 18, Number 5, 2021
ISSN: 1735-188X
DOI: 10.29121/WEB/V18I5/43

Innovative Composite Material Reinforcement in the Structural Behavior of Concrete Beams with Holes

Sanjeev Kumar[1], Nikhil Garg[2], Anoop Bahuguna[3]

[1]Department of CivilEngineering,Graphic Era Deemed to be University, Dehradun, Uttarakhand India, 248002
[2]Department of Civil Engineering,Graphic Era Deemed to be University, Dehradun, Uttarakhand India, 248002
[3]Department of Civil Engineering,Graphic Era Hill University, Uttarakhand India

ABSTRACT

The purpose of this study is to improve the structural behaviour of perforated Ferro-cement beams. The goal was reached by a rigorous programme of experimental work. Additionally, mathematical models from theory were explored. Casting and testing fourteen 200x100x2000mm beams of reinforced concrete was part of the experimental programme. Beam B1 in Group 1 is the control beam, and it was cast with typical reinforcement consisting of two steel bars, 12 mm in diameter at the bottom and 10 mm in diameter at the top. A total of 16 of the 8mm steel stirrups. Beam B2 is identical to beam B1, except that polypropylene fibres have been added to the concrete matrix. Beams B3, B4, and B5 are the ones that are cast in the second group. Beam B3 was similarly strengthened to B2, but it included two apertures measuring 10 by 20 centimetres and positioned at equal distances from the beam's terminus. Both B4 and B5's beams were strengthened with two steel bars of 12mm diameter at the bottom and two steel bars of 10mm diameter at the top, sandwiched between two and four layers of welded steel meshes. Beams B6 and B7 are strengthened with one and two layers of expanded steel meshes, respectively, and include two apertures measuring 10x20cm that are spaced equally from the beam's ends. Beams B8 and B9, reinforced with one and two layers of fibre glass mesh for durability reasons, respectively, make up Group 4. These beams were cast and tested. Beams B10 and B11 in group five each have three holes and are reinforced with either four layers of welded steel meshes or two layers of expanded steel meshes. Beams B12, B13, and B14 in group 6 each have three apertures and are reinforced with either four layers of welded steel meshes, two layers of expanded steel meshes, or three layers of welded steel meshes. Beams with a span of 180 millimetres were subjected to four line loads. Strength, stiffness, cracking behaviour, ductility, and energy absorption qualities of the test beams were studied. The produced beams' behaviour was evaluated in comparison to the control beams'. The produced composite beams required two different analytical models to be tailored to them: one to estimate the first crack load using conventional strength of materials principles, and another to establish the ultimate strength and failure mode using ultimate strength theory. The testing findings demonstrated that the suggested beams could achieve high ultimate and serviceability loads, excellent fracture resistance management, high ductility, and strong energy absorption qualities. There is a close agreement for all beams between the experimental data and the results derived from the theoretical model. Because of this consensus, we know this model is sound.

Keywords: Ferro-cement; Beams with openings; Experimental program; Structural behavior; Analytical model.

INTRODUCTION

Virtual One of the most rapidly expanding industries in both industrialised and emerging nations is the construction and housing industry. It uses up a lot of government funds, has spillover effects on other industries, and is a good barometer of a country's socioeconomic standing. There are 92 different professions and occupations in Egypt that rely on the construction industry, and 8.3 percent of the country's entire formal labour force is directly employed in construction. Therefore, in the last several decades, there has been a rise in the need for secure, cost-effective, and environmentally-friendly building practises to facilitate social and economic growth. Therefore, cutting-edge strategies, products, and building practises are required for long-term sustainability (Mehlab 2005). Ferrocement is a relatively recent material used in building. According to the American Concrete Institute, "Ferrocement is a form of reinforced concrete generally made of hydraulic cement mortar reinforced with closely spaced layers of very tiny wire diameter mesh." Metal or other appropriate materials may be used to make the mesh. A mortar matrix should have a fineness and composition that are suitable for encapsulating the opening and tightness of the reinforcing system. "There may be broken fibres in the matrix." In contrast to traditional reinforced concrete, ferrocement is made up of layers of mesh or thin reinforcing bars that are densely packed and fully soaked with cement mortar. The end product is a composite material with thinner walls and a larger steel volume percentage than traditional reinforced concrete. The mechanical properties shown are distinct from those of regular concrete in terms of strength and deformation, but they are similar to those of a homogeneous material. This result is similar to that attained by using fibre glass reinforced polymers. The average acceptable cover for reinforcement is 2mm, and the maximum cover is 5mm, therefore the walls may be substantially thinner than they would be with traditional reinforced concrete (ACI Manual of Concrete Practice 1998). In the 1840s, J.L. Lambot built a rowing boat out of a ferrocement composite made of wires and cement, marking the beginning of this technology. Standard reinforced concrete was being developed at the same time. However, the original notion of ferrocement was revived by Pier Luigi Nervi in the early 1940s, which led to further development. Although ferrocement has been successfully employed for various applications, including roof systems and silos, its development and utilisation have mostly occurred in the boat construction sector.

Reference: (1998 edition of the ACI Manual of Concrete Practice). Manufacturing structural components including walls, beams, slabs, and roofing systems, as well as using ferrocement as a repair material for various concrete elements, have all risen since ferrocement's first debut. As a result, ferrocement has several uses and is widely distributed around the globe. In Malaysia, prefabricated ferrocement wall panels have been utilised for affordable housing, in Indonesia and Jordan, ferrocement has been used to create mosque domes, and in India, Cuba, and Bangladesh, ferrocement has been used to construct both unusual and beautiful structures. Currently, there are two ferrocement boat manufacturers in Malaysia. Ferrocement's outstanding fracture control, impact

Webology, Volume 18, Number 5, 2021
ISSN: 1735-188X
DOI: 10.29121/WEB/V18I5/43

resistance, and toughness may be attributed, in large part, to the material's tightly packed and evenly distributed reinforcing. The versatility of ferrocement in meeting the needs of a broad range of customers with varying requirements and budgets is one of its primary benefits. Roofing materials, in particular, have seen a rise in interest in ferrocement's potential as a building material recently (National Academy of Sciences 1973). The physical and mechanical characteristics of this material, as well as a wealth of test data used to determine its performance standards for building and repair of structural parts, have been the subject of a great deal of research, most notably by Fahmy et al (1999 and 2008).

EXPERIMENTAL PROGRAM

Casting and testing fourteen 200x100x2000mm reinforced concrete beams was part of the experimental programme. Structured into six distinct groups, these beams groups, Beam B1 in Group 1 was strengthened with two steel bars, 12 mm in diameter at the bottom, and 10 mm in diameter at the top. A total of 16 of the 8mm steel stirrups. Beam B2 is identical to beam B1, except that polypropylene fibres have been added to the concrete matrix. Beams B3, B4, and B5 are the ones that are cast in the second group. Beam B3 was similarly strengthened to B2, but it included two apertures measuring 10 by 20 centimetres and positioned at equal distances from the beam's terminus. Both B4 and B5's beams were strengthened with two steel bars of 12mm diameter at the bottom and two steel bars of 10mm diameter at the top, sandwiched between two and four layers of welded steel meshes. Beams B6 and B7 are strengthened with one and two layers of expanded steel meshes, respectively, and include two apertures measuring 10x20cm that are spaced equally from the beam's ends. Beams B8 and B9, reinforced with one and two layers of fibre glass mesh for durability reasons, respectively, make up Group 4. These beams were cast and tested. Beams B10 and B11 in group five each have three holes and are reinforced with either four layers of welded steel meshes or two layers of expanded steel meshes. Beams B12, B13, and B14 in group 6 each have three apertures and are reinforced with either four layers of welded steel meshes, two layers of expanded steel meshes, or three layers of welded steel meshes. We subjected the test specimens to four line loadings while they were spanned across 180 centimetres as simple beams. Strength, stiffness, cracking behaviour, ductility, and energy absorption qualities of the test beams were examined.

MATERIALS

A. Cement utilised was the Ordinary Portland cement, type manufactured by the Suez cement mill. Its chemical and physical qualities fulfilled the Egyptian Standard Specification (E.S.S. 4756-1/2009) [1].

B. Fine aggregate employed in the experimental programme was natural siliceous sand. Its qualities fulfil the (E.C.P. 203/2007) [2], (E.S.S. 1109/2008). It was pure and almost free from contaminants with a specific gravity 2.6 t/m3 and a modulus of fineness 2.7.

C. Super Plasticizer utilised was a high rang water reducer HRWR. It was employed to increase the workability of the mix. The admixture used was developed by Sika Group under the marketing name of ASTM (Sikaviscocrete), It satisfies the standards of ASTM C494 (type A and F) [3]. The admixture is a brown liquid with a density of 1.18 kg/litre at room temperature. The quantity of

Webology, Volume 18, Number 5, 2021
ISSN: 1735-188X
DOI: 10.29121/WEB/V18I5/43

HRWR was 1.0 percent of the cement weight.

D. Water was employed, clean drinking fresh water free from pollutants was used for mixing and curing the tested plates according to the Egyptian Code of Practices (E.C.P. 203/2007)[4].

E. Reinforcing Materials

A) Reinforcing Steel Bars
1. High tensile deformed steel bars manufactured from the Ezz Al Dekhila Steel - Alexandria was utilised. All of its chemical and physical properties are up to par with the E.S.S. 262/2011 [5], the Egyptian Standard Specification.

All the concrete beams were reinforced with high tensile deformed steel bars (nominal diameter 10 mm), whose tensile strength was 600 MPa and whose yield stress was 400 MPa.To reinforce the plates in the tangential direction, 8 mm diameter mild steel bars were employed. The material had a tensile strength of 350 MPa and a yield strength of 240 MPa.

Mesh Reinforcement (Plan B) 1. Expanded metal mesh: Expanded metal mesh was used to strengthen ferrocement plates. According to the Egyptian Standard Specification (E.S.S. 262/2011) [6], its chemical and physical properties are acceptable.

Galvanized welded metal mesh was used, and it was imported from China. The Egyptian Standard Specification (E.S.S. 262/2011) for chemical and physical properties has been met. The picture, mechanical characteristics, and detailed specifications for welded metal mesh are included Polyethylene meshes Two varieties of Polyethylene meshes, CE121 and CE131, were employed; both were purchased from the Al Shrouk Company of synthetic fibres. High density polyethylene is used to create this kind of mesh. To put it another way, "Geogrid" were implemented. The attributes and images of these meshes are shown

MORTAR MATRIX

When the concrete mortar used to cast the plates had aged for 28 days, it had reached its desired ultimate compressive strength of (350 kg/cm2), 35 MPa. Both the American Concrete Institute's (ACI) Committee 549 Report (2008) and the Egyptian Code Practices (E.C.P.) 203/2007 were used to inform the selection of the mix characteristics for the mortar matrix. The laboratory employed a mechanical mixer for all mixtures.

when the volume of the combined substances was measured to be less than or equal to 0.05 m3. Dry mixing the components, then adding the mix water and re-mixing the whole patch, is the standard procedure. Each sample was mechanically compacted. Mortar Ingredients Cement Sand/Cement Water/Cement Salt/Cement Percentage [7]

COMPOSITION SILICA FUME

Micro silica, volatilized silica, and condensed silica fume are all names for the same thing. It's waste from making silicon metal and ferrosilicon alloy. A extremely thin powder, whose spherical

Webology, Volume 18, Number 5, 2021
ISSN: 1735-188X
DOI: 10.29121/WEB/V18I5/43

particles are around one hundred times smaller than Portland cement or fly ash. The diameters average 0.1 m from the range of 0.02 to 0.5 m. Approximately 85–95 percent of the silicon dioxide in silica fume is in the form of non-crystalline particles[8].

It was in Kentucky in 1982 when silica fume was first used in the US. Concrete with silica fume has the following characteristics:

High strength and enhanced sulphate resistance, low heat of hydration, decreased permeability, delayed alkali-aggregate reaction, and decreased freeze-thaw damage and water erosion are some of the benefits. Silica fume has the chemical composition and physical characteristics described [9].

Analyses and Characteristics
Quantity Percentage of the Total Mass
Loss on ignition formula: SiO2 90.2%, Al2O3 1.7%, Fe2O3 0.4%, Ca2O 2.1%, MgO 1.7%, sodium oxide 0.7%, potassium oxide 0.7%, sulphur trioxide 0.5%. (LOI)
Surface Area (cm2/g) 2.5
The Specific Gravity of Water at 200000 Bars is 2.21

BEHAVIOR OF FERROCEMENT BEAMS

The stated beam tests were conducted with three line loadings, and the deflection at each load increment was recorded at the mid span. All of the beams' load deflection curves were shown. For each sample, we also tracked the onset and development of the first fracture. What follows are discussions of how various study parameters affect things like ultimate moment, maximum deflection at ultimate load, ductility ratio, energy absorption, and cracking behaviour. The test program's experimental outcomes and subsequent discussions are reported. Each of the four investigated parameters—the presence of apertures, the nature of the reinforcing materials, the number of layers of mesh reinforcement, and the volume percent of delivered steel reinforcement—is compared across the test groups. The strengths at first crack, serviceability loads, and their corresponding ultimate loads, as well as the impacts of these parameters on the structural response of the constructed beams, were determined. The energy-absorbing capabilities and ductility ratio were measured Cracking

First crack, serviceability, ultimate loads, ductility ratios and energy absorption properties of all the tested beams.The acquired values for ultimate load, deflection at ultimate load, ductility ratio, and energy absorption, as well as the first crack load and service load. Using the load-deflection diagram, we were able to calculate the first crack load, service load, ductility ratio, and energy absorption of each beam, in addition to measuring and obtaining the ultimate load and deflection at ultimate load throughout the test [10]. From the load deflection curve, we were able to pinpoint the first fracture load, which occurred when the load-deflection relationship began to depart from a linear connection. In this study, the Service load (also called the flexural serviceability load) is defined as the load at which the deflection is equal to Span/250. First crack load, serviceability load, ultimate load, ductility ratio, and energy absorption for all tested beams

Webology, Volume 18, Number 5, 2021
ISSN: 1735-188X
DOI: 10.29121/WEB/V18I5/43

How the Test Samples Fare

Uniform reinforcement distribution along the section, geometry of reinforcement, reinforcement type, specific surface area, volume fraction of reinforcement, and number of openings all contribute to the distinct behaviour of conventionally reinforced concrete and that reinforced with closely spaced wire steel mesh. The controllability of loads and deflections, the behaviour of cracks, the ultimate strength, the ductility ratio, and the ability to absorb energy are all affected by these variables. Qualities of Deformationup to the first breaking, a) elasticity. At this point, the relationship between load and deflection is linear. At this point, the slope of the load-deflection curve changes depending on the test specimen. The break from linearity marks the conclusion of this phase. The duration of this step varied depending on the composition and thickness of the steel gratings used.

The projected drop in stiffness of the specimens owing to repeated cracking causes a progressive change in the slope of the load-deflection curve in stage two. As the reinforcement's volume percentage rises, the slope of the load-deflection curve steepens.

Stage 3: Yielding of reinforcing bars and steel meshes in ferrocement beams led to significant plastic deformation. The test specimens failed, hence this phase is over.

Linearity in the load-deflection relationship was seen for the control specimens up to around 10kN of load, after which the connection turned nonlinear. The influence of the polypropylene fibres utilised meant that the transition from the second to the third stage was not clear for this set of specimens, and the first fracture load occurred at a force equal 15KN for beam B2. Beam B1's midspan deflection was 17.72mm and beam B2's was 13.78mm at failure. Beams B3, B4, and B3 from Group 2 saw maximum deflections of 15, 14, and 18 millimetres at their respective ultimate loads, with a deflection of 1.5 millimetres at first crack loads. beams B6 and B7 in group 3 with two end apertures had initial crack deflections of 5.52mm and 3.92mm, respectively, at the same loads. Although 32mm and 17mm were reported as the largest deflections at ultimate stresses. Beams B8 and B9 in Group 4 with two and three apertures had deflections of 1.95mm and 3.55mm at first crack loads, respectively. When the highest deflections were measured, they were 18 and 20 millimetres. At initial crack loads of 4.87 and 5.85 millimetres, beams B10 and B11 in group 5 with three apertures bowed 4.87 and 5.85 millimetres, respectively. Maximum deflections of 19 mm and 19.5 mm were recorded. Group 6 consists of beams B12, B13, and B14, all of which had three holes, and their deflections at first crack loads were 5.42mm, 3.25mm, and 1.25mm, respectively.

and 5.41mm in total. Maximum deflections of 13.57 mm, 13.74 mm, and 14.57 mm were recorded. Open-ended ferrocement beams' performance

Crack initiation and propagation were observed for each test specimen, and three beams were tested under four lines of loadings, with the deflection at each load increment recorded at two places on the tested beams in order to build the load-deflection curves. What follows are discussions of how various study parameters affect things like ultimate moment, maximum deflection at ultimate load, ductility ratio, energy absorption, and cracking behaviour. Maximum Weight

Webology, Volume 18, Number 5, 2021
ISSN: 1735-188X
DOI: 10.29121/WEB/V18I5/43

Welded galvanised steel mesh, fibre glass mesh, and expanded metal mesh used to reinforce ferrocement beams with apertures in series designations 2, 3, 4, 5, and 6 are much more successful than any other reinforcements formation in increasing the ultimate load of the beams. While beam B3's Vr equals 3.48 percent, beam B4's Vr equals 2.544 percent shows a far greater ultimate load. Interestingly, increasing the number of layers of welded steel mesh causes the ultimate load of beam B5 to be higher than that of beam B4 by Vr equal 2.862 percent. Beam B7, which is strengthened with two layers of expanded metal mesh, can withstand a higher ultimate load (Vr = 3.287%) than beam B6 (Vr = 2.756%). Beams B8 and B9 benefitted from a 38% reduction in ultimate load because to the use of fibre glass mesh as reinforcement. When comparing the highest loads attained by beams B10 and B11 with three apertures, it is clear that the latter has much higher values (Vr equal 3.4747 percent, or around 16 percent more than B10). When the three-holed beams B12, B13, and B14 were tested to their limits, the results were 33, 38, and 40 KN. It's worth noting that the impact of using is substantial in raising maximum loads achieved, regardless of the mesh type utilised. Ratio of Deflection to Ductility

A standard three-stage load against mid-span deflection relationship was seen in all tests of open-web beams. The relationship between load and deflection was linear under initial loading all the way up to the breaking load. During the second phase, characterised by cracking section behaviour, the steel reinforcement exhibits linear elastic behaviour. The third phase of behaviour is characterised by non-linear material behaviour and a yielding of the tensile reinforcement. Large increases in deformation with relatively small increases in applied load characterise the behaviour of a beam after yielding of tension steel. At ultimate stress, all of the tested beams deflected significantly, demonstrating excellent ductility. Central deflection under load curves for all the tested beams. Beams in series 2, 3, 4, and 5 had deflection values more than the allowable 7.2 mm, and this trend was evident across the whole series.

Beams with series 2, 3, 5, and 6 apertures have the potential to achieve greater serviceability loads. The maximum ductility ratio was achieved by beam B5 in series designation 2, which was strengthened with steel bars and four layers of welded galvanised steel mesh. Beams in the series 1 were tested using a range of ductility indices, from 9.134 for beam 1 to 6.856 for beam B2, all of which used conventional reinforcing. The ductility ratios of 10, 3.544, and 15.385 were achieved by the B3, B4, and B5 beams of the series designator 2, each of which had two holes and was reinforced with steel bars, two layers of welded steel mesh, and three layers of welded steel mesh, respectively. Beams B6 and B7 from Series 3 with one and two layers of expanded steel mesh reinforcement, respectively, had ductility ratios of 5.797 and 5.167, according to the calculations. Beams B8 and B9 from series 4 were reinforced with one layer and two layers of fibre glass mesh, respectively, and their ductility ratios were determined to be 9.231 and 5.634. Calculated ductility ratios of 3.901 and 3.248 were achieved by series designation 5 beams B10 and B11, which were reinforced with four layers of welded steel mesh and two layers of expanded steel mesh, respectively. Ductility ratios of 2.504, 4.228, and 2.693 were estimated for series designation 6 beams B12, B13, and B14, each having three apertures and reinforced with three layers of welded steel mesh, four layers of welded steel mesh, and two layers of expanded steel mesh, respectively. It is important to note that regardless of the kind of reinforcing materials used, the resultant ductility ratio decreases as the volume percent of reinforcement increases.

Webology, Volume 18, Number 5, 2021
ISSN: 1735-188X
DOI: 10.29121/WEB/V18I5/43

Absorption of Energy

Experimental data showing that beams absorb more energy as their volume fraction increases. beam B6 in series designation 3, strengthened with steel bars and one layer of expanded steel mesh, had the largest energy absorption at 638.15 KN.mm. Beams in the series 1 with conventional reinforcement had their energy absorption reduced from 447.125 KN.mm for beam B1 to 435.55 KN.mm for beam B2. Series 2 designation beams B3, B4, and B5 absorbed 271.6, 250.45, and 348.3 KN.mm of energy, respectively; these beams had two holes and were reinforced with steel bars, two layers of welded steel mesh, and three layers of welded steel mesh, respectively. Series 3 designation B6 and B7 beams, strengthened with one layer and two layers of expanded steel mesh, respectively, absorbed 638.15 and 487 KN.mm of energy. A total of 286.1 and 376.75KN.mm of energy were absorbed by Beams B8 and B9 of Series 4 that were reinforced with one and two layers of fibre glass mesh, respectively. There was an estimated energy absorption of 405.7 KN.mm and 463.4 KN.mm for series designation 5 beams B10 and B11, which were reinforced with four layers of welded steel mesh and two layers of expanded steel mesh, respectively. Beams B12, B13, and B14 of designation 6 have been estimated with three, four, and two layers of welded steel mesh and expanded steel mesh, respectively, for their respective three holes.

The values at which the energy was absorbed were 302.5, 326.54, and 2.69349.225 KN.mm. It is important to note that the achieved energy absorption increases with the volume proportion of reinforcement, regardless of the kind of reinforcing materials used. Dynamic uses benefit greatly from materials with high ductility and energy absorption.

FAILURE MODES

Flexural failure occurred for every series designation of tested beams. The ultimate stress of the reinforcing steel mesh was reached, causing the failure of the test specimens. There were no breaks in the mesh bars, hence the strain in the steel mesh was below its ultimate strain. Each test ended with the specimen being taken out of the testing machine and the mortar cover being taken off to reveal the steel reinforcement mesh. Visual inspection of the steel mesh showed that there was no visible damage to the bars. All of the steel reinforcement meshes remained intact. The breadth, quantity, and propagation orientations of cracks varied among the different classifications as a result of their unique physical features. The following part delves into the specifics of how each classification manifests in terms of fracture patterns and distributions.

The tensile fracture patterns of all the tested beams, both with and without apertures. The specimens of designation (1) developed flexural fractures around the midspan. Whenever the load was increased, fractures spread vertically and additional flexural cracks formed quickly. The fissures became bigger as the strain on the specimens got closer to the point of collapse. The crack width was measured, and it was found that the use of steel bars had caused the fissures to widen considerably.

It is worth noting that vertical flexural fractures developed in the middle of the span for (2) designator beams 3, 4, and 5. Most of the generated fractures did not continue propagation as the load increased, however other cracks occurred and the crack at mid-span began to propagate vertically towards the top surface of the specimen. Crack widths were far less than expected (1).

Webology, Volume 18, Number 5, 2021
ISSN: 1735-188X
DOI: 10.29121/WEB/V18I5/43

This could be because steel mesh helps keep cracks from spreading too far. The flexural fractures of beams B6 and B7 from series 3, which were reinforced with one and two layers of expanded metal mesh, respectively, were less than those of beams from series 1. Even though the fractures were smaller than the previous classification, they were evenly spaced over the centre two-thirds of the span, which is an interesting observation. When compared to crack widths of Designation 1, the observed values were much less. This may be because steel mesh is effective at limiting fracture expansion. In beams of series 4, B8, and B9, reinforced with one and two layers of fibre glass mesh 8, flexural fractures became diagonal as the load neared the failure load, and a final diagonal crack emerged at the end. Beams with series 5 designation are B10 and B11, respectively reinforced with four layers of welded steel mesh and two layers of expanded steel mesh. At failure, very narrow flexural cracks were developed compared with beams in the previous series.

Series 6 beams had reinforcements of three layers of welded steel mesh, four layers of welded steel mesh, and two layers of expanded steel mesh at the three apertures (B12, B13, and B14). Over time, more fractures appeared and were spread evenly over the whole width than had been noted in prior classifications. We found that the measured crack widths were much less than the preceding series.

CONCLUSIONS

Based on the findings of the present testing programme, it is clear that the produced ferrocement beams with apertures and reinforced with novel reinforcing materials have excellent strength, improved deformation characteristics, fracture resistance, high ductility, and energy absorption capabilities. All configurations, including those with varying numbers of holes in the steel mesh, outperformed traditional reinforced concrete beams in terms of mechanical strength. Results also indicated that, unlike with solid concrete, fine fracture widths at failure were seen in ferrocement concrete beams having apertures.

The following findings and suggestions are within the bounds of the research's parameters, scope, theoretical, and analytical investigations, as well as the experimental investigation's test results and observations.

For long-term savings on reinforcing steel, consider using welded galvanised steel mesh, expanded metal mesh, or fibre glass mesh. In terms of steel weight, the savings were around 20%-30%.

Second, the beams made with ferrocement forms and a high strength mortar matrix had increased first crack load, serviceability load, ultimate load, and energy absorption.
Beam B5, which had two apertures at each end and was reinforced with four layers of galvanised welded steel mesh and steel bras without stirrups, had the highest ductility ratio of all of the tested beams at 15.385.

Among the tested beams, the one with the highest energy absorption was beam B6, which had the most apertures (two) and was reinforced with one layer of expanded metal mesh and steel bras (without stirrups) at a volume fraction of 2.756%.

Fifth, the first crack load, service load, maximum load, and energy absorption all improve as the

ISSN: 1735-188X
DOI: 10.29121/WEB/V18I5/43

number of steel mesh layers in ferrocement forms grows. Nonetheless, it reduces the beam's ductility.

No matter the kind of steel mesh or the number of holes, using steel mesh to reinforce concrete beams is an effective way to enhance the beams' strength, deformation properties, and cracking behaviour while also significantly reducing the amount of reinforcement required.

The reduction in stress concentration around the apertures in all of the tested beams was the most noticeable effect on the failure cracking control without spalling of the concrete cover.

By using theoretical methodologies, we can accurately forecast both the ultimate load and the beam's mechanism of failure before the first fracture appears.

In addition to the predicted economic and durability qualities, the proposed beams using beams with apertures strengthened with unique reinforcing materials might effectively replace the typical reinforced concrete beams. Especially for the beams supplied with four and five apertures, further study is needed to arrive at good suggestions for practical application.

REFERENCES

1. Mustafa, S. A., & Hassan, H. A. (2018). Behavior of concrete beams reinforced with hybrid steel and FRP composites. *HBRC journal*, *14*(3), 300-308
2. Abed, F., & Alhafiz, A. R. (2019). Effect of basalt fibers on the flexural behavior of concrete beams reinforced with BFRP bars. *Composite Structures*, *215*, 23-34.
3. Sun, Z., Fu, L., Feng, D. C., Vatuloka, A. R., Wei, Y., & Wu, G. (2019). Experimental study on the flexural behavior of concrete beams reinforced with bundled hybrid steel/FRP bars. *Engineering Structures*, *197*, 109443.
4. Kim, S., & Kim, S. (2019). Flexural behavior of concrete beams with steel bar and FRP reinforcement. *Journal of asian architecture and building engineering*, *18*(2), 89-97.
5. Tahir, M., Wang, Z., Ali, K. M., & Isleem, H. F. (2019, December). Shear behavior of concrete beams reinforced with CFRP sheet strip stirrups using wet-layup technique. In *Structures* (Vol. 22, pp. 43-52). Elsevier.
6. Viet, N. V., & Zaki, W. (2019). Analytical investigation of the behavior of concrete beams reinforced with multiple circular superelastic shape memory alloy bars. *Composite Structures*, *210*, 958-970.
7. Hadi, M. N., Sarhan, M. M., & Teh, L. H. (2018). Behavior of concrete beams reinforced with steel plates. *ACI Structural Journal*, *115*(5), 1307-1315.
8. Kaszubska, M., Kotynia, R., Barros, J. A., & Baghi, H. (2018). Shear behavior of concrete beams reinforced exclusively with longitudinal glass fiber reinforced polymer bars: Experimental research. *Structural Concrete*, *19*(1), 152-161.
9. Słowik, M. (2019). The analysis of failure in concrete and reinforced concrete beams with different reinforcement ratio. *Archive of applied mechanics*, *89*(5), 885-895.
10. Jin, L., Xu, J., Zhang, R., & Du, X. (2017). Numerical study on the impact performances of reinforced concrete beams: a mesoscopic simulation method. *Engineering Failure Analysis*, *80*, 141-163.