S. Paramasivam[1,*],
M. Rameshkumar[1],
R. Malathy[2],
C. Prakash[1]

Study of the Flexural Behaviour of Warp Knitted Reinforced Ferrocement Composites

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[1] **Sona College of Technology, Department of Fashion technology,**
Salem 636005, TamilNadu, India
* e-mail: paramasivam@sonatech.ac.in

[2] **Sona College of Technology, Department of Civil Engineering,**
Salem 636005, TamilNadu, India

Abstract

This paper presents the effect of warp knit textile reinforcement in ferrocement laminates. In general, steel wire mesh is used as ferrocement reinforcement, which is often known as chicken mesh. The need for the replacement of steel mesh is the problem of corrosion, which reduces the durability of ferrocement laminate. High performance synthetic fibres and fabrics are constantly used in various research works as reinforcement in concrete. In this paper, an attempt was made to incorporate three different nylon warp knit mesh structures in the place of chicken mesh. Ferrocement composites were produced with chicken mesh and nylon warp knit fabrics. The flexural properties of ferrocement laminates were analysed in terms of the first crack load, ultimate load, energy absorption capacity and ductility factor. Nylon square mesh with 3 layers in the reinforcement has a 2.5 kN first crack load and 3.36 kN ultimate load, which is higher than chicken mesh reinforcement in ferrocement laminate. The results show that there is an improvement in the flexural properties of ferrocement laminates reinforced with a nylon warp knit structure. The flexural parameters have a direct relationship with the number of layers used in the reinforcement.

Key words: *ferrocement, nylon, chicken mesh, laminate, warp knit.*

Introduction

Ferrocement is a form of thin wall reinforced concrete constructed on hydraulic cement mortar reinforced with small size chicken wire mesh. It is one of the cementitious composites in construction materials which have a potential to meet the increasing demand for complex structures in the construction field. Also, it provides high performance characteristics at a lesser cost with good sustainability. Physical and mechanical properties were investigated for ferrocement laminates, which proved that ferrocement laminates have excellent strength properties, impact resistance, crack control and toughness. These ferrocement elements show a good advantage over other thin construction materials [1-3]. Ferrocement laminates are used to produce relatively light weight cast elements for architectural forms for low cost housing projects. Ferrocement is used in the construction of grain storage points, water tanks and roof tops as well as in the repairing of reinforced concrete structures [4]. Ferrocement laminates are used as beams and slabs in building constructions as a cost effective alternate to conventional concrete beams [5-6]. Ferrocement laminates offer the advantages of faster construction, minimum space requirement and lesser labour skills. It also enables a reduction of reinforcement materials, such as crushed stones and steel bars, often used in concrete preparation [7-9]. The disadvantages of ferrocement concrete are the durability and corrosion issues of the chicken wire mesh. Fibre reinforced concrete is popular to research, in which conventional concrete performance is enhanced in terms of the tensile, compressive, crack control and ductility behaviour of the concrete with the addition of fibres [10]. Similar research works have been carried out on the reinforcement of fibres in ferrocement laminates.

Usman et.al [11] investigated the effect of the addition of polypropylene fibres on the flexural strength of ferrocement. In this experiment, three different proportions: 0%, 1% and 1.5% of polypropylene fibres were added in the mortar during the preparation of ferrocement specimens. The ferrocement laminates produced in the experiment were with 2, 4 and 6 layers of steel mesh wire. The flexural strength result shows that the matrix gives improved performance with respect to flexural behaviour with a 1-1.5% addition of polypropylene fibres. This experiment proves that the fibre reinforcement in ferrocement laminate improves the flexural performance. The same author conducted an experiment to investigate the effect of the addition of polypropylene fibre on the torsional strength of ferrocement. The percentage of polypropylene fibres added in the experiment was 0%, 0.3%, 0.6% and 0.9%. The torsional strength results proved that 38% improvement is attained by the addition of polypropylene fibres. These two experiments above are evidence of crack reduction, and improvement in the flexural and torsional strength of ferrocement with the addition of polypropylene fibres. In the subsequent step, the research focussed on textile reinforced mortar for the strengthening of concrete beams. Varma et.al [13] studied the effect of different types of meshes in the flexural performance of ferrocement panels. The types of mesh used in the experiment were expanded metal mesh, galvanised woven mesh and welded mesh, with the size of openings of 20 x 35 mm, 10 x 10 mm and 15 x 15 mm, respectively. Experimental results show that welded mesh with a 15 x 15 mm opening size exhibits greater flexural strength than the other two, which proves that size of the opening in the mesh also has some impact on flexural performance. Hence, it is evident that a change in the type and size of mesh has an impact on the flexural performance of ferrocement laminates. Peled et.al [14] studied the influence of bundle and loop size on the tensile properties of textile reinforced cement elements and on the bond strength between the cement matrix and fabric. The fibre types used in the experiment were high density polyethylene, polypropylene, AR – glass and aramid. Experimental results proved that a combination of small bundle size with large stich size exhibits greater bond strength and tensile characteristics of the fabric cement matrix. This shows that the filament thickness and stitch length of warp knit fabric has an impact on the tensile performance of the fabric cement matrix. Qeshta et.al [15] investigated the effect of a wire mesh epoxy composite on the flexural performance of concrete beams in comparison with carbon fibre and a hybrid mesh – epoxy – carbon composite. The experimental results show that the mesh – epoxy composite performs better in flexural strength and ductility than a carbon fibre sheet. Hence it is proven that the application of epoxy resin with wire mesh results in the enhancement of the flexural strength properties of the composite. Muhammad et.al [16] investigated the replacement of steel wire mesh with synthetic fibre mesh to overcome the durability issue with steel wire mesh in ferrocement slabs. In the experiment, ferrocement laminates were produced with four types of meshes, such as welded steel wire mesh, AR – glass mesh, basalt mesh and plastic mesh. Slabs of 1 m x 1 m x 0.5 m were prepared with the meshes, and the breaking load was determined using the point load concept. Among these four types of mesh, the basalt mesh slab withstands a higher breaking load and the glass mesh slab shows brittle failure. This experiment shows that wire mesh can be replaced with textile mesh to improve the performance of ferrocement slabs. Wang et.al [17] investigated the bending response of ferrocement thin plates reinforced with steel mesh and Kevlar FRP mesh with polyester fibres. The parameters assessed in the experiment were the modulus of rupture, shear capacity, crack spacing, ductility behaviour, the toughness index. The experimental results show that fibre reinforced Kevlar FRP mesh shows good ductile behaviour, an increased toughness index, improved shear capacity and an increased modulus of rupture. This proves that the application of polymer mesh instead of steel mesh gives higher performance properties of ferrocement laminates. Bhikshma et.al [18] studied the improvement in durability of ferrocement laminates with the addition of polymer ash and fly ash. In this experiment, a conventional ferrocement laminate was compared for durability with a flyash, polymer mixed ferrocement laminate. Cylinders and prisms were cast to assess the durability. An impressed current voltage test was conducted to accelerate the corrosion, which was monitored continuously. Experimental results show that regular ferrocement laminates have higher permeability, less time for initiation of the first crack, a high chloride content of cement mortar at the top of the specimens, and the modified laminates show good performance in the parameters mentioned earlier. This experiment is proof of the lesser durability of the regular chicken mesh reinforced ferrocement laminate.

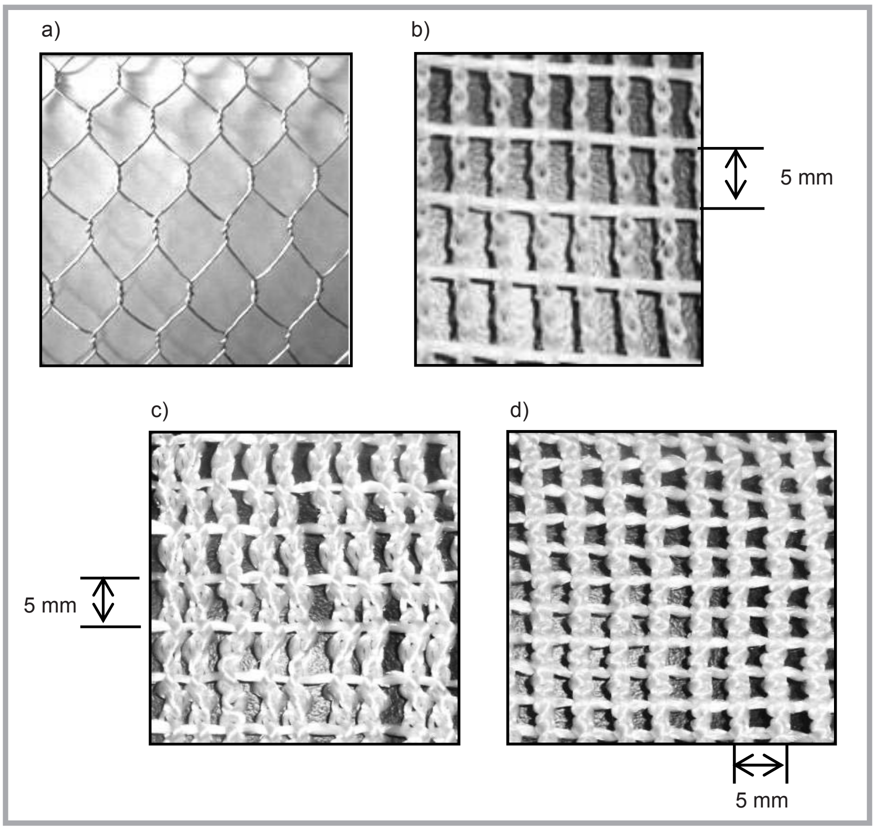

Figure 1. *Chicken wire mesh (a) and warp knit samples of 93 tex (b),187 tex (c), 280 tex (d).*

Peled et.al [19] investigated the effectiveness of knitted fabrics for the reinforcement of cementitious composites. In this experiment, warp knit fabrics were produced with Kevlar, polyethylene and

Table 1. *Nylon multi-filament yarn characteristics.*

S.No.	Fineness	No. of filaments	Breaking load, N	Extension at break, %	Tenacity, grams/tex
1	93 tex	136	76.5	15.6	8.1
2	187 tex	280	103	13.04	5.4
3	280 tex	320	122.6	11.7	4.3

Table 2. *Warp knit sample characteristics.*

Sample code before resin coating	Raw material	Denier of filament	Structure of sample	Size of mesh	Resin coated sample code
1	Nylon multi-filament yarn	93 tex	Square mesh warp knit	5 mm x 5 mm	1R
2		187 tex	Square mesh warp knit	5 mm x 5 mm	2R
3		280 tex	Square mesh warp knit	5 mm x 5 mm	3R

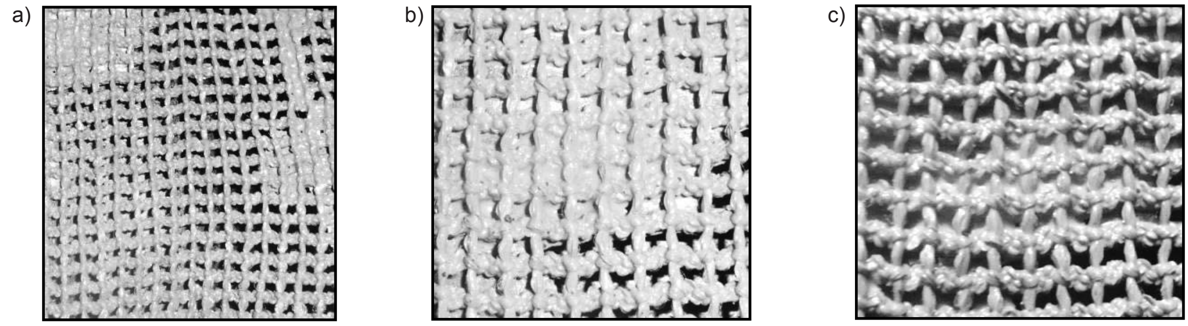

Figure 2. Warp knit samples of a) 93, b) 187 and c) 280 tex after resin coating.

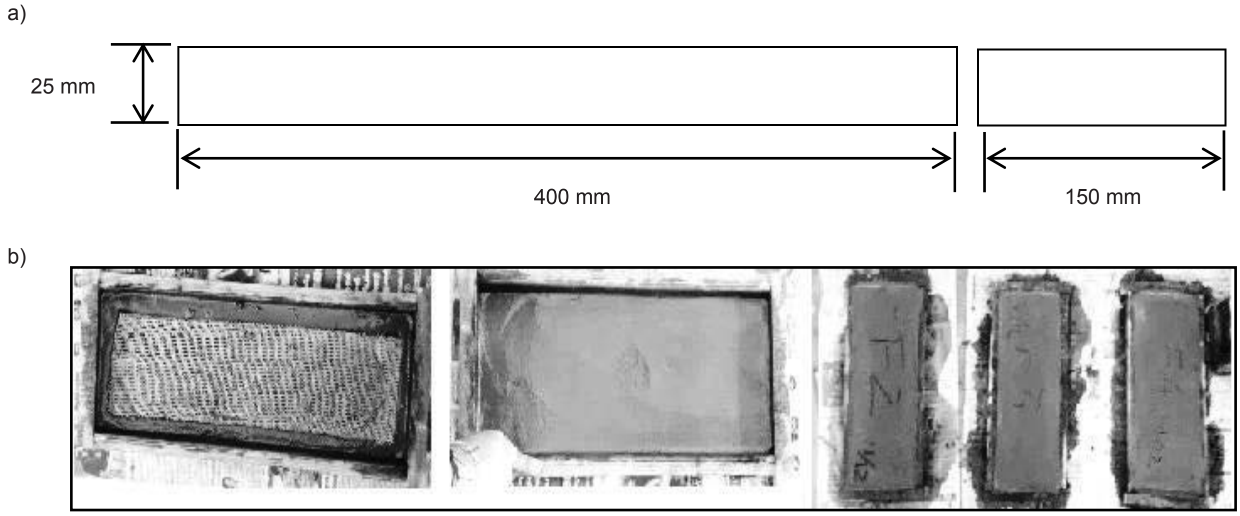

Figure 3. a) Ferrocement laminate size specification, b) ferrocement laminate preparation process.

polypropylene materials. The warp knit fabric performance was evaluated for flexural properties and the bond to the matrix and compared with woven fabrics. The experimental results concluded that the continuous and aligned yarns in warp knit fabric make it more suitable to use as a reinforcement material in composites as compared to woven fabrics.

The literature review above describes the basics of the ferrocement concept, its merits and demerits. Further discussion analyses the durability issue in conventional ferrocement and alternatives to enhance the durability and performance of ferrocement laminates. The gap to be filled in the research is to identify a warp knit fabric with a suitable mesh type and filament thickness to use as a reinforcement in ferrocement laminate. The present work investigates the performance behaviour of resin coated nylon warp knit fabric reinforced ferrocement laminates to optimise the filament thickness as well as the structure and number of layers to be used in the reinforcement.

Table 3. Epoxy resin characteristics.

S. No.	Property	Value
1	Compressive strength	50 MPa
2	Tensile strength	20 MPa
3	Flexural strength	35 MPa
4	Shear strength	25 MPa

Experimental methods

Nylon warp knit fabrics

The main aim of this research was to study the improvement in the performance properties of a synthetic mesh reinforced ferrocement laminate. In this attempt, square mesh warp knit samples were produced with three different deniers of nylon multi-filament yarns of 93 tex, 187 tex and 280 tex. Yarn specifications are detailed in ***Table 1***. The samples were produced on a 12 gauge warp knitting machine (Robaczynski Corporation, Brooklyn, USA) working at a speed of 60 rpm. The structure produced in this work was a square mesh open grid structure, with a mesh size of 5 mm x 5 mm. Two guide bars were used in the production of this square mesh structure. Characteristics of the warp knit samples are given in ***Table 2***. ***Figures 1*** and ***2*** show the chicken wire mesh warp knit samples before and after resin coating.

The warp knit fabric was coated with Fosroc Nito Bond EP epoxy resin concrete bonding agent with a hand brush manually. This epoxy resin comprises two parts: epoxy resin and hardener. Both the resin and hardener were mixed in the ratio of 1:1 and applied on the fabric. The purpose of this resin coating was to enhance the strength properties of the warp knit fabrics. Characteristics of the resin (supplier details) are given in ***Table 3***.

Fabrication of ferrocement laminates

Ordinary Portland cement and regular river sand were used to prepare ferrocement mortar. The ratio of cement to sand was 1:2 and the water to cement – 1: 0.38 in the mortar preparation. The size of the mould used for the laminate preparation was 400 mm (length) x 150 mm (width) x 25 mm (thickness). The warp knit sample was kept inside the mould 5 mm from the edge of the mould. The moulds were greased before casting the specimens for an easy demoulding process. Fabric layers were placed at the centre of the mould and the remaining portions filled with mortar. The mould was kept in an open space for one hour for setting, and then the laminates were demoulded. After demoulding, the ferrocement laminates were given an identification mark for all the laminates and then placed in a water tank for curing for 28 days. Prior to testing, the test samples were stored for 28 days at 23 °C temperature in a 95% R.H. environment [14]. ***Figure 3.a*** represents the size specification of the ferrocement laminate and ***Figure 3.b*** – the ferrocement laminate preparation process.

Figure 4. *Testing of warp knit samples.*

Figure 5. *Testing of ferrocement laminates.*

Table 4. *Ferrocement laminate reinforcement details.*

Details of material reinforcement	Ferrocement laminate codes		
	2 layer reinforcement	3 layer reinforcement	4 layer reinforcement
Chicken mesh	CFC2	CFC3	CFC4
Warp knit structure 1 (93 tex)	1NFC2	1NFC3	1NFC4
Warp knit structure 2 (187 tex)	2NFC2	2NFC3	2NFC4
Warp knit structure 3 (280 tex)	3NFC2	3NFC3	3NFC4

Details of the 12 ferrocement laminates and their reinforcement mode are given in ***Table 4***. CFC2, CFC3 & CFC4 represent 2 layer, 3 layer and 4 layer chicken wire mesh reinforced ferrocement laminates, respectively. 1NFC2, 1NFC3 & 1NFC4 represent 93 tex nylon mesh reinforced ferrocement laminates with 2, 3 and 4 layers of fabric, respectively. The other codes represent 187 tex and 280 tex samples in the same manner as quoted previously.

Testing of warp knit sample specimen

Tensile properties of the warp knit fabrics with and without resin coating were tested using an Instron tester at the A.C. College of Technology, Anna University, Chennai. The samples were tested with a gauge length of 200 mm, base length of 50 mm. and loading rate of 300 mm/min. The tests were performed as per ASTM standard 5034-09 (2017). Tensile parameters such as the maximum load, extension at the maximum load, tensile stress, tensile strain at the maximum load and young's modulus were measured in the testing procedure. Tensile testing of the warp knit samples is shown in ***Figure 4***.

Testing of ferrocement laminates

After 28 days of curing process, the ferrocement laminates were tested in a universal testing machine with two point loading, as shown in ***Figure 5***. A dial gauge of 0.01 mm accuracy was fixed at the bottom of the specimen to measure the deflection at the mid-point for each 0.5 kN increment load. Flexural parameters such as the first crack load, ultimate load, load – deflection characteristics, energy absorption capacity and the ductility factor were measured on a Universal testing machine. The first crack load is the load value noted at the first crack formation. The ultimate load is the load experienced by the ferrocement laminate till failure occurs. A load deflection curve is obtained by plotting the load value in the y axis against the deflection values in the X axis. This curve gives an overview of the behaviour of the ferrocement lami-

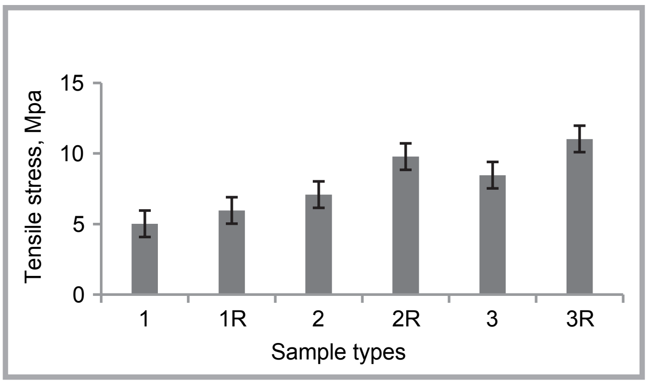

Figure 6. *Tensile stress at maximum load of warp knit samples.*

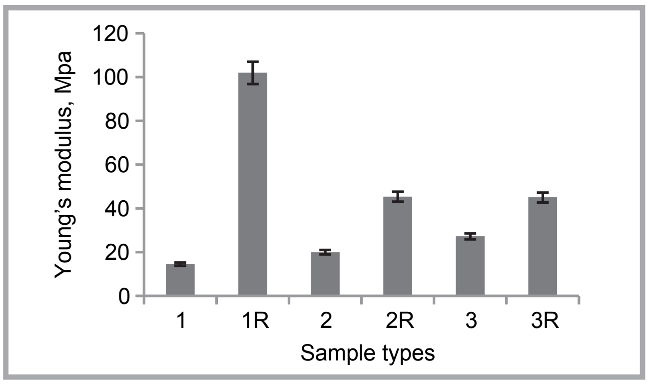

Figure 7. *Young's modulus of warp knit samples.*

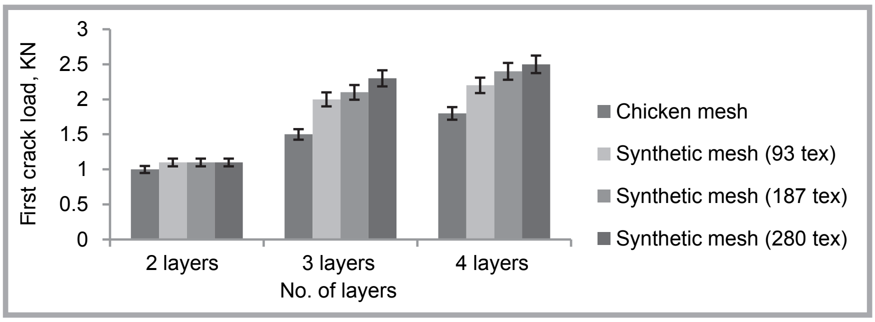

Figure 8. First crack load analysis of ferrocement laminates.

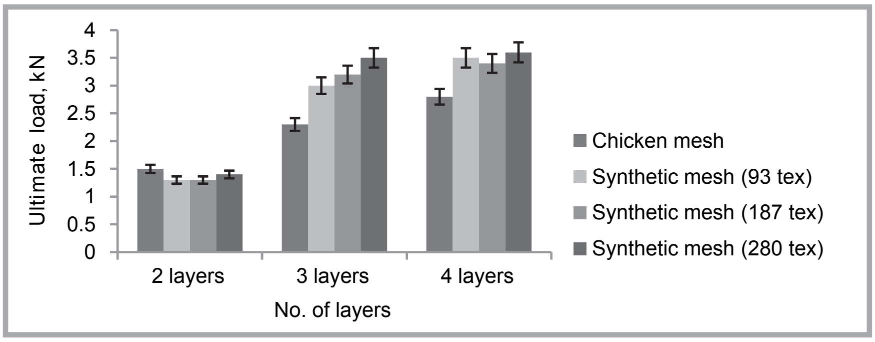

Figure 9. Ultimate load analysis of ferrocement laminates.

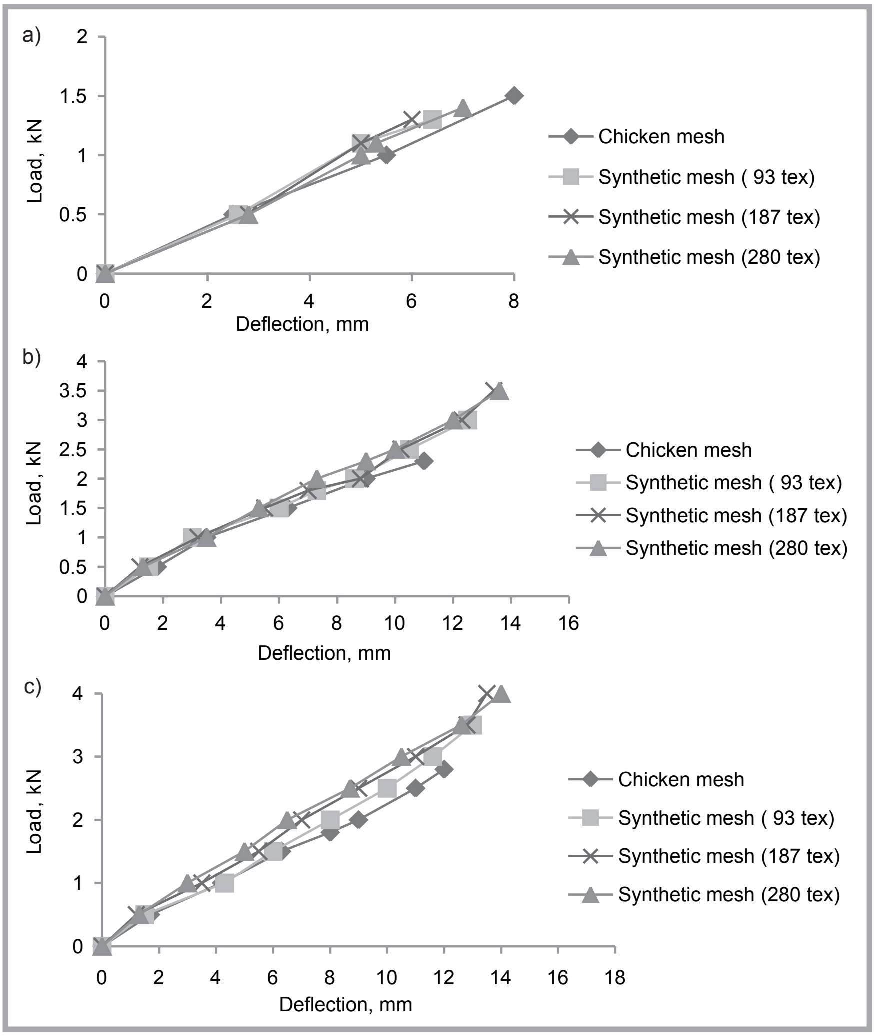

***Figure 10.** a) Load deflection behaviour of 2 layer ferrocement laminates, b) load deflection behaviour of 3 layers ferrocement laminates, c) load deflection behaviour of 4 layer ferrocement laminates.*

nate during the testing process. The energy absorption capacity is measured from the area under the load deflection curve. The ductility factor is the ratio of deflection at the young's modulus to that at the ultimate load. ***Figure 5*** shows the three point loading testing set-up for ferrocement laminates to determine the flexural properties.

Results and discussion

Tensile properties of warp knit samples

The tensile stress and young's modulus of warp knit fabrics before and after resin coating are shown in ***Figures 6*** and *7*. As can be seen from the values, the tensile properties show good improvement among the samples. The behaviour shows that there is an increase in both the tensile stress and young's modulus as the thickness of the filament yarn increases.

Resin coating over the warp knit fabric has a good impact on both tensile stress and young's modulus. The percentage of increase in tensile stress due to epoxy resin coating is 19%, 38% and 30% for 93 tex, 187 tex and 280 tex nylon warp knit samples, respectively. The percentage of increase in young's modulus due to epoxy resin application is 600%, 126% and 65% for 93 tex, 187 tex and 280 tex nylon warp knit samples, respectively. Hence, it is proven that the warp knit fabric tensile properties were improved with the application of resin coating. Resin coating forms an interfacial bond between the filament and resin, enhancing the tensile strength of the warp knit fabrics. Rajwin et.al [20] studied the tensile properties of twisted yarns impregnated in composites. In the experiment, it was proven that the interfacial bonding improves the tensile and flexural properties of twisted yarn impregnated composites. The interfacial bonding between resin and filament aids in the improvement of the tensile strength of warp knitted fabrics.

Flexural properties of ferrocement laminates

First crack load and ultimate load

First crack load analysis of the ferrocement laminate samples produced from chicken mesh and warp knit fabric reinforcement is represented in ***Figure 8***. It is evident from the graphs that as the filament denier in the fabric structure increases, resistance to the load also increases.

The first crack load of the 2NFC3 and 3NFC3 ferrocement laminate samples is 40% and 53% higher than for the CFC3 ferrocement laminate sample, respectively. Also the first crack load of the 2NFC4 and 3NFC4 ferrocement laminate samples is 33% and 39% higher than for CFC4 sample, respectively. This results show that an increase in the number of layers of reinforcement decreases the load bearing capacity.

Same trend follows in the ultimate load of the ferrocement laminates. ***Figure 9*** represents a comparative analysis of the ultimate load of all the ferrocement laminates of the experiment. The ultimate load of the 2NFC3 and 3NFC3 ferrocement laminate samples is 39% and 52% higher than for the CFC3 ferrocement laminate sample, respectively. Also, the first crack load of the 2NFC4 and 3NFC4 ferrocement laminate samples is 26% and 35% higher than for the CFC4 sample, respectively.

This is due to the less penetration of mortar across the four layers of fabric. The bonding characteristic of the mesh had a good impact on the load bearing capacity of the ferrocement laminate. Peled et.al [14] supported warp knitted textile reinforcement in a cement matrix. Moreover, it was proven that the reinforcing efficiency of warp knit fabric reinforcement is inadequate in a cement matrix, which is similar to the outcome of the first crack load and ultimate analysis in this experiment.

Load deflection characteristics

Load deflection characteristics of the 2 layer, 3 layer and 4 layer reinforced ferrocement laminates produced with chicken mesh wire reinforcement and warp knit mesh reinforced ferrocement laminate are represented in ***Figures 10.a***, ***10.b*** and ***10.c***.

The comparative line chart reveals that the load deflection behaviour of the warp knit mesh reinforced ferrocement laminate is good as compared to the chicken mesh reinforced ferrocement laminate. Among the three different warp knit synthetic mesh structures, the structure produced with 187 tex and 280 tex filament performs well in load-deflection behaviour during flexural testing

Energy absorption capacity

A comparison of the energy absorption capacity of ferrocement laminates reinforced with chicken mesh and a warp knit mesh structure is represented in ***Figure 11***. Warp knit mesh reinforcement gives a better energy absorption capacity than chicken mesh reinforcement. The analysis has two variables, namely the filament thickness and number of layers in the reinforcement. In the case of two-layer reinforcement, the energy absorption capacity of warp knit mesh reinforced samples shows no more improvement than for the chicken mesh reinforcement ones. With the 3 layer reinforcement, the 1NFC3, 2NFC3 and 3NFC3 sampled are 22%, 33% and 50% higher than for the 3 layer chicken mesh reinforced ferrocement laminate. With the 4 layer reinforcement, the 1NFC4, 2NFC4 and 3NFC4 samples are 9%, 19% and 23% higher than for the 4 layer chicken mesh reinforced ferrocement laminate. The comparison shows that the number of layers in the ferrocement laminate has an inverse relationship with the energy absorption factor, which is due to the positive correlation of this parameter with the ultimate load and load deflection behaviour of the ferrocement laminate samples.

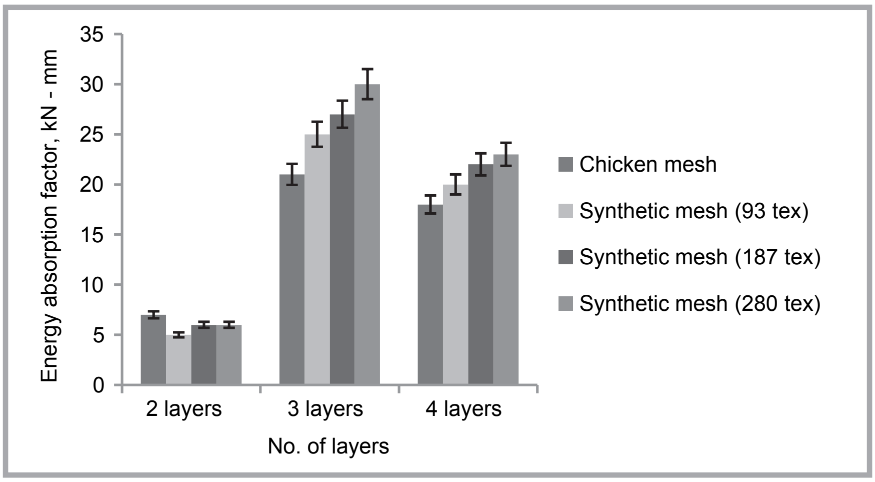

Figure 11. *Energy absorption capacity of ferrocement laminates.*

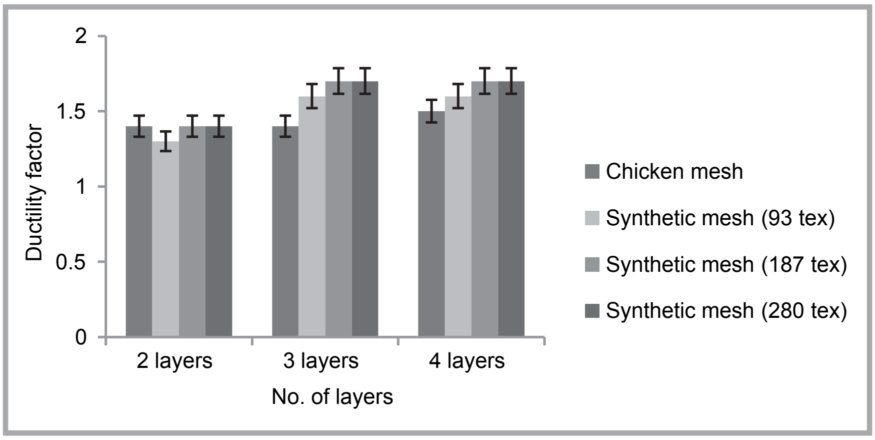

Figure 12. *Ductility factor of ferrocement laminates.*

Ductility factor

The ductility factor of ferrocement laminates with chicken mesh and warp knit mesh reinforcement is represented in ***Figure 12***.

In the case of 2 layer reinforcement, there is no improvement in the ductility factor of warp knit structure reinforced ferrocement laminates, irrespective of the denier of the filament yarn. The 1NFC3, 2NFC3 and 3NFC3 samples are 14%, 21% and 21% higher than for the 3 layer chicken mesh reinforced ferrocement laminate. The 1NFC4, 2NFC4 and 3NFC4 samples are 6%, 13% and 13% higher than for the 4 layer chicken mesh reinforced ferrocement laminate. The ductility factor of the 3 layer reinforcement is good due to the better bonding of the mortar with the warp knit samples, which is absent in the 4 layer reinforcement. Puranik et.al [21] proved that an increase in the

Table 5. *Statistical analysis using ANOVA.* ***Note:*** *[*]Significant for α = 0.05.*

Source of variation	SS	DF	MS	F	*p*-value*	F Critical
Dependent variable: Tensile strength of warp knit fabrics						
Effect of resin coating	0.083	3.000	0.028	3.667	0.042	4.757
Effect of filament denier	0.222	2.000	0.111	14.778	0.005	5.143
Error	0.045	6.000	0.008			
Total	0.349	11.000				
Dependent variable: Young's modulus						
Effect of resin coating	70.388	2.000	35.194	3.164	0.041	19.000
Effect of filament denier	803.051	1.000	803.051	72.198	0.044	18.513
Error	22.246	2.000	11.123			
Total						
Dependent variable: First crack load analysis						
Between layers	0.480	3.000	0.160	6.030	0.0305	4.760
Between reinforcement materials	2.930	2.000	1.460	54.870	0.001	5.140
Error	0.160	6.000	0.030			
Total	3.570	11.000				
Dependent variable: Ultimate load						
Between layers	0.930	3.000	0.310	2.820	0.018	4.760
Between reinforcement materials	9.880	2.000	4.940	45.000	0.002	5.140
Error	0.660	6.000	0.110			
Total	9.920	11.000				
Dependent variable: Energy absorption factor						
Between layers	32.333	3.000	10.778	2.380	0.168	4.757
Between reinforcement materials	843.500	2.000	421.750	93.147	0.000	5.143
Error	27.16667	6.000	4.528			
Total	903.000	11.000				
Dependent variable: Ductility factor						
Between layers	0.060	3.000	0.020	3.429	0.093	4.757
Between reinforcement materials	0.152	2.000	0.076	13.000	0.007	5.143
Error	0.035	6.000	0.006			
Total	0.250	11.000				

number of layers reduces the effectiveness of the load carrying capacity of RC beams, which is similar to the relationship between the number of layers and flexural properties, which is analysed in this experiment.

Statistical analysis

The SAS System (version 8 for Windows) was used to evaluate the experimental data and analysis of variance (ANOVA) at a 95% confidence level. The effect of the filament denier and number of layers on the flexural properties of ferrocement laminates was revealed via statistical analysis performed using two-way ANOVA (analysis of variance) at a significance level of 0.05.

ANOVA analysis shows that there is a significant difference in the tensile strength of the warp knit fabrics before and after resin coating. The filament denier has a significant effect on the tensile strength of the warp knit samples. There is no significant difference in the young's modulus of warp knit samples of different deniers before and after resin coating. There is a significant difference in the first crack load, ultimate load, energy absorption factor and ductility factor parameters due to the number of layers in the reinforcement and type of reinforcement material.

Conclusions

From the results and discussion above, the following conclusions were made with respect to the ferrocement laminates.

- Warp knitted textile structures can be used as a replacement for chicken wire mesh to resolve the durability and corrosion issue.
- In general, the resin coated warp knitted textile reinforced ferrocement laminate sample performs better than the chicken mesh reinforced ferrocement sample with 3 and 4 layers, and an increase in the number of layers does not bring about an enhancement in the flexural properties of ferrocement laminate due to the inadequate bonding of mortar with the 4 layers of warp knit mesh in the laminate.
- The filament denier has a direct relationship with the flexural properties of ferrocement laminates.
- Statistical analysis using the ANOVA technique supports the conclusions.

From the points above, it can be concluded that warp knit fabrics of nylon synthetic textile provide better performance than chicken mesh wire in ferrocement. The filament denier and number of layers in the reinforcement have an impact on the flexural behaviour of ferrocement laminates.

Acknowledgements

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