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Experimental Evaluation of Square Ferrocement Panels using Polypropylene Wire Mesh

Evaluación experimental de paneles de ferrocemento cuadrados utilizando malla de polipropileno

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Abstract

Ferrocement panels are thin section comprised of hydraulic mortar reinforced with steel wire mesh, and are susceptible to micro cracks at service conditions. The moisture and rainwater may infiltrate through these cracks and cause the reduction in capacity due to the corrosion of steel wire mesh. In the present study, a polypropylene (PP) wire mesh has been used to overcome this problem. The main objective of the study is to investigate the punching shear and bending capacity of the ferrocement panels using PP wire mesh. Experimental tests conducted on 32 simply supported square slabs panels of 450x450 mm subjected to concentrated load for punching shear and four-point loading to investigate the bending capacity. The test variables were the number PP layers (volume fraction ratio) and slab thickness i.e., 20, 30 and 40 mm. Test results showed that punching capacity improved by increasing both the number of PP layers and panel thickness. However, bending strength the function of tension membrane action provided by exterior PP layers. Moreover, panels with 20 mm thickness are to flimsy and do not show sufficient capacity. In general, PP wire mesh provide adequate resistance against punching and bending for slab thickness 30mm and 40mm, and can be used as replacement of conventional steel wire mesh.

Keywords: *Polypropylene wire mesh; ferrocement panel; punching shear strength; bending strength*

Resumen

Los paneles de ferrocemento están constituidos por una sección delgada de mortero hidráulico reforzado con malla de alambre de acero y están expuestos a que se produzcan microgrietas en condiciones de servicio. La humedad y el agua de lluvia pueden infiltrarse a través de estas grietas y provocar una reducción en su capacidad debido a la corrosión de la malla de alambre de acero. En el presente estudio, se ha utilizado una malla de polipropileno (PP) para superar este problema. El objetivo principal del presente estudio es investigar la capacidad de punzonado y flexión de los paneles de ferrocemento utilizando malla de PP. Se realizaron ensayos experimentales en 32 paneles de losas cuadradas de 450x450 mm con apoyo simple sometidos a carga concentrada por punzonamiento y carga de cuatro puntos para investigar su capacidad de flexión. Las variables experimentales fueron el número de capas de PP (fracción de volumen) y el espesor de la losa, de 20, 30 y 40 mm. Los resultados de las pruebas mostraron que la resistencia a la perforación mejoró al aumentar tanto el número de capas de PP como el grosor del panel. Sin embargo, la resistencia a la flexión es función de la acción de la membrana de tensión proporcionada por las capas exteriores de PP. Además, los paneles con un espesor de 20 mm son demasiado endebles y no muestran una resistencia suficiente. En general, la malla de PP proporciona una resistencia adecuada contra perforaciones y flexiones para losas de 30 mm y 40 mm de espesor, y se puede utilizar como reemplazo de la malla de alambre de acero convencional.

Palabras clave: Malla de polipropileno; panel de ferrocemento; resistencia al punzamiento; resistencia a la flexión

1. Introduction

Ferrocement is thin wall reinforced concrete, which is comprised of closely spaced layers of thin and continuous size wire mesh and poured with hydraulic cement mortar. The reinforcing mesh may be made of metallic or any other suitable material. Ferrocement technology offers a lightweight, cheap and quick construction, which makes him more popular over traditional RC construction for low cost housing units. However, at the same time, it is of prime importance that ferrocement construction should also fulfill the desire function of strength and serviceability (Akhter el al., 2009). The availability of materials and requirement of low level technical skills have made ferrocement, a great potential for contractions in developing countries (ACI, 1997). Ferrocement materials are usually slender and flimsy but they are equally strong and aesthetic, and provide a wide range of construction solution especially for roofing system and walls construction (Pushyamitra , 2011); (Abdullah and Takiguchi, 2003).

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Due to the slender nature of ferrocement slabs and panels are always susceptible to service cracks at outer surface. However, crack widths in ferrocement is normally one or two orders smaller in magnitude when compared to traditional RCC members (Naaman, 2000); (Arif et al., 1999). The width of these cracks is stabilized and controlled by the composite action provided by mesh layers. Although, these micro cracking does not affect the overall strength but it may pose durability issues to ferrocement panels. In humid and rainy environment, water may percolate through these cracks and may initiate corrosion on reinforcing steel mesh, which subsequently may compromise the performance of ferrocement construction. Researchers are using various technique to control this phenomenon either by using corrosion resisting wire meshes or by reducing the cracks in matrix. In this regards, various types of fibers made of steel, carbon, glass and polypropylene have been used to improve the properties of cement mortar and results indicated that cracking can be reduced considerable by incorporating the fibers in matrix (Patil and Prakash, 2009); (Sikdar et al., 2005).

(Sakthivel and Jagannathan, 2012) have experimentally investigate the flexural capacity of ferrocement slabs reinforced with PVC coated steel mesh, and compared the results with slabs using conventional GI-coated steel mesh by varying the number of layers. They have found that the flexural capacity of slabs with PVC-coated mesh is 90% that of specimens reinforced with GI-coated mesh, and therefore, PVC-coated mesh can be effectively used in ferrocement slabs, as noncorrosive reinforcement. Further, it has also been observed that the meshes with smaller openings lead to smaller crack widths and allow a more efficient use of high strength reinforcement (Naaman, 2000).

Inclusion of fibers in mortar mix and using galvanized or PVC-coated mesh may escalate the cost of ferrocement construction. Using a non-corrodible material like polypropylene (PP) may offer an alternative cheaper solution. A recent study (Mughal et al., 2019), PP wires mesh has been utilized in long span ferrocement slab panels to assess the performance against bending and axial loading. The study concluded that PP wire mesh improve load carrying capacity and ductility. Since the ductile nature of PP wire mesh induced large deflection in long ferrocement panel, which can be controlled by using square slab panel. Further, there is also need to assess the performance of ferrocement panel with PP mesh against punching load. The overall goal of this study is to investigate the performance of square ferrocement panels against punching shear and bending load by varying the number of PP mesh layers.

2. Materials and Methods

2.1 *Materials*

Generally, A locally manufactured Ordinary Portland cement (OPC), complying with type-1 of (ASTM, 2004) was utilized as binding agent in ferrocement panels. For fine aggregates, an equal mix of locally available sands Chenab sand (50%) and Lawrencepur sand (50%) was used in the mortar. The sand mix was having the Fineness Modulus value of 3.52 and its gradation curve is shown in (Figure 1). In order to achieve a target strength of 50 MPa, the mix design as given in (Equation 1) as used in previous similar studies was adopted (Sakthivel and Jagannathan, 2012). In (Equation 1) C, FA and W represent the cement, fine aggregates and water contents, respectively.

$$C : FA : W = 1 : 2 : 0.45 \qquad (1)$$

2.2 Polypropylene Wire Meshes

Locally available square mesh of the PP as shown in (Figure 2) was used as the reinforcement in ferrocement panels. The properties of PP wire mesh are given in (Table 1). To determine the tensile strength of PP, wires were cut from the mesh and tension test was performed using a high precision and fully calibrated universal testing machine (UTM). (Figurers 3) illustrates the PP wire cut from mesh and gripped in jaws of UTM. The load displacement curve obtained from tension test is shown in (Figure 4).

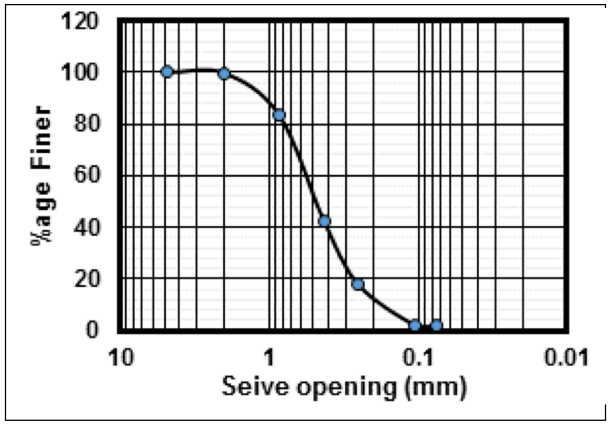

Figure 1. *Gradation curve of fine aggregate*

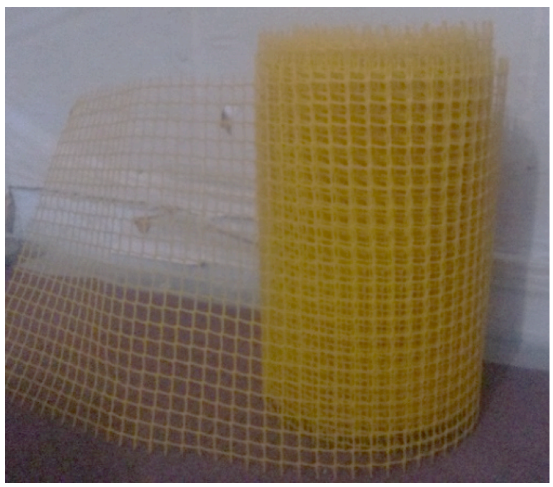

Figure 2. *Polypropylene wire mesh*

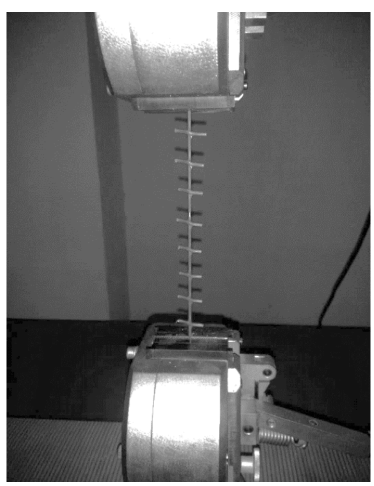

Figure 3. *Polypropylene wire in UTM for tension test*

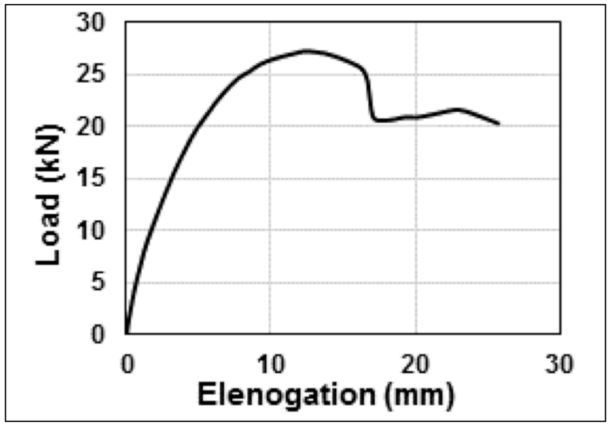

Figure 4. Load vs elongation curve of polypropylene wire

Table 1. *Polypropylene properties*

Properties	*Values*
Average x-sectional area	*2.71 mm²*
Average opening size	*13.8 mm x 13.8 mm*
Peak load	*27.22 kN*
Tensile Strength	*10 MPa*

2.3 Specimen Matrix

In all total 32 ferrocement slab panels, 16 each for bending and punching test were cast. Three different panel thickness i.e., 20mm, 30mm and 40mm were selected. Since previous studies on punching shear strength of ferrocement panel, using steel wire mesh has indicated that punching shear load decreases as effective span is increased (Mansur et al., 2001). Therefore, short and square slab panel of 450x450mm was opted for all thicknesses. Description of all test specimens with their thicknesses, number of reinforcing PP mesh layers and their corresponding volume fraction ratio is given in (Table 2). The volume fraction of reinforcement is the ratio of volume of reinforcement to the volume of composite. The Volume fraction ratio is computed by diving the volume of reinforcing mesh to volume of mortar (slab panel) volume. A typical specimen in (Table 2) is described as P20-2, where "P" represents punching test condition, 20 implies the thickness of slab panel as 20 mm, and suffix 2 indicates the number of reinforcing mesh layers. Similarly, a case B30-4, illustrates the specimen of thickness 30mm with 4-layers of PP mesh for bending (B) test. To avoid the congestion, the numbers of mesh layers were limited to three for 20mm thick panels, whereas, for other specimens maximum 4-layers were considered for experimental program.

2.4 Casting of Specimens

Batching of mortar for ferrocement was carried out according to the mixed proportion already mentioned in (Equation 1). Special wooden formwork was designed to attain the required size and thickness of test specimens. All the reinforcing mesh layers are equally spaced within the specified thickness of panel by maintaining a clear cover of 3mm in all test specimens. Skeletal steel rods of 5mm diameter and spacers were used to form the skeleton of reinforcing mesh layers. Since skeletal steel is places along the edges and at the center of thickness (neutral surface), therefore its contribution towards bending and punching shear is ignored as skeletal steel only influences the axial strength only. Due to the same reason skeletal steel volume was also ignored in computing the volume fraction ratio. Casting of specimens was done layer by layer and specimens were vibrated after poring mortar in each meshing layers. (Figure 5) shows the specimen during and after completing of casting. Formwork was opened after 24 hours and specimens were cured with wet jute bags for 28 days. From each mixed batch, two cubes of 50 *mm size were also cast for the determination of compressive strength. An average value of mortar from all batches after 28 days was found to be 54 MPa.*

3. Test setup

For punching shear test, a special steel frame of 25mm thickness was designed to support ferrocement panel along periphery. Punching was induced at the center of panel using a steel plunger of size 100x100 mm. In order to produce pure bending moment, four point loading arrangement was used in bending test. For this purpose two steel plates as edge supports and two steel pins were used to induce the pure bending moment in slab panels.

Table 2. *Description of test specimens*

Thickness (mm)	No. of Mesh Layers	Volume fraction Ratio, V_f (%)	Nomenclature of specimen	
			Punching test	Bending test
20	2	3.5	P20-2	B20-2
	3	5.2	P20-3	B20-3
30	2	2.3	P30-2	B30-2
	3	3.5	P30-3	B30-3
	4	4.6	P30-4	B30-4
40	2	1.7	P40-2	B40-2
	3	2.6	P40-3	B40-3
	4	3.5	P40-4	B40-4

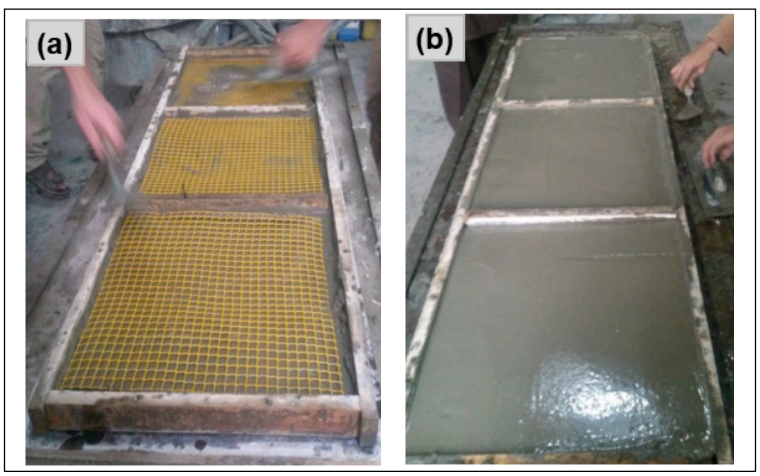

Figure 5. *Casting of ferrocement panels; (a) During casting, (b) After completion*

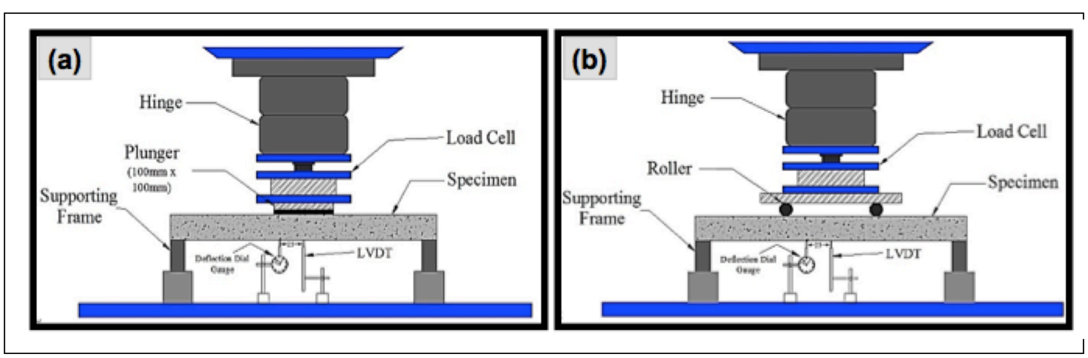

Figure 6. *Schematic diagram for test setup; (a) Punching shear test (b) Bending shear test*

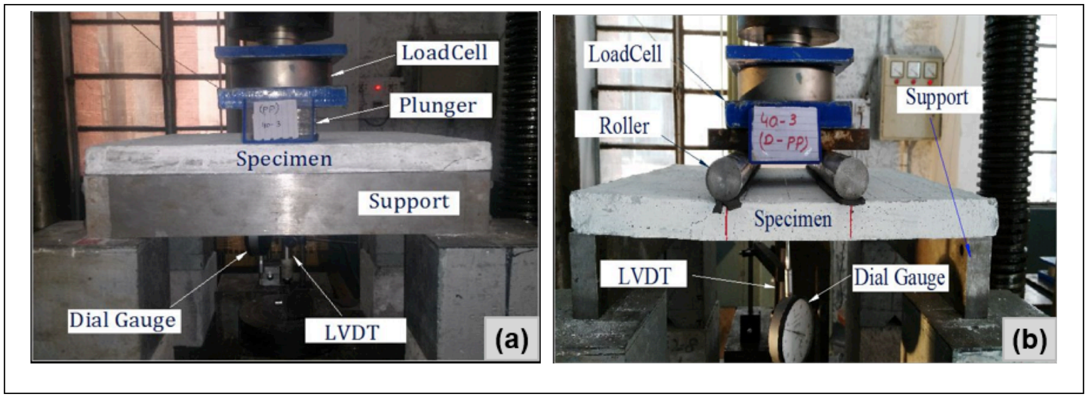

Figure 7. *Experimental test setup; (a) Punching shear test (b) Bending shear test*

In both punching and bending test, a displacement load was applied using 1000 kN UTM at loading rate of 1 mm/min. Applied load and vertical deflection were measured by a load cell and a linear variable displacement transducer (LVDT) respectively, using a data acquisition system. (Figure 6) and (Figure 7) show the layout and experimental setup of both punching and bending test assembly, respectively.

4. Results and discussion

4.1 Punching Shear Test

To study the behavior of ferrocement panels against punching, load-deflection curve were plotted for all specimens as shown in (Figure 8), which reveals that punching resistance increases with both number of the reinforcing mesh layers (volume fraction ratio) and thickness of slab panels. (Figure 8(a)) shows that 20 mm thickness does not provide any significant punching strength, and only 1.53 kN load in case of 2-layers and 1.64 kN in case of 3- layers was observed. In this case is the punching strength is mainly contributed by mortar only, and brittle cracks occur in transversal directions before the propylene mesh takes any load. (Figure 9(a)) shows cracks in both transversal direction for P20-3.

For slab panels with 30 mm thickness the punching strength improves with increase of number of mesh layers as shown in (Figure 8(b)) further it also changes the failure behavior of slab panels. Firstly, transversal cracks appear in the central zone of slab, which causes the loss of stiffness due to fracture of mortar. After cracking occurs at outer surface, the strength is contributed by the PP mesh, which also change the failure behavior from brittle to ductile. (Figure 9(b)) for P30-2 case illustrated the transformation of transversal cracks into diagonal cracks after fracturing of mortar. The ultimate punching load for 30mm thick panels was observed as 4.24kN, 5,71kN and 5.95kN for 2-layers, 3-layers and 4-layers, respectively.

(Figure 8(c)) indicates that for 40mm slab panel the ultimate capacity improve substantially with the increase in number of mesh layers as compared to 20mm and 30mm thick panels. In 40mm thick panel the ultimate capacity was detected as 5.68kN, 5,71kN and 8.31kN for 2-layers, 3-layers and 4-layers, respectively. It was also observed that for a higher thickness of ferrocement panel, the failure behavior completely changed to ductile without transversal cracks. A typical failure mode for P40-20 shown in (Figure 9(c)) indicates smeared cracking in diagonal direction without any transversal crack.

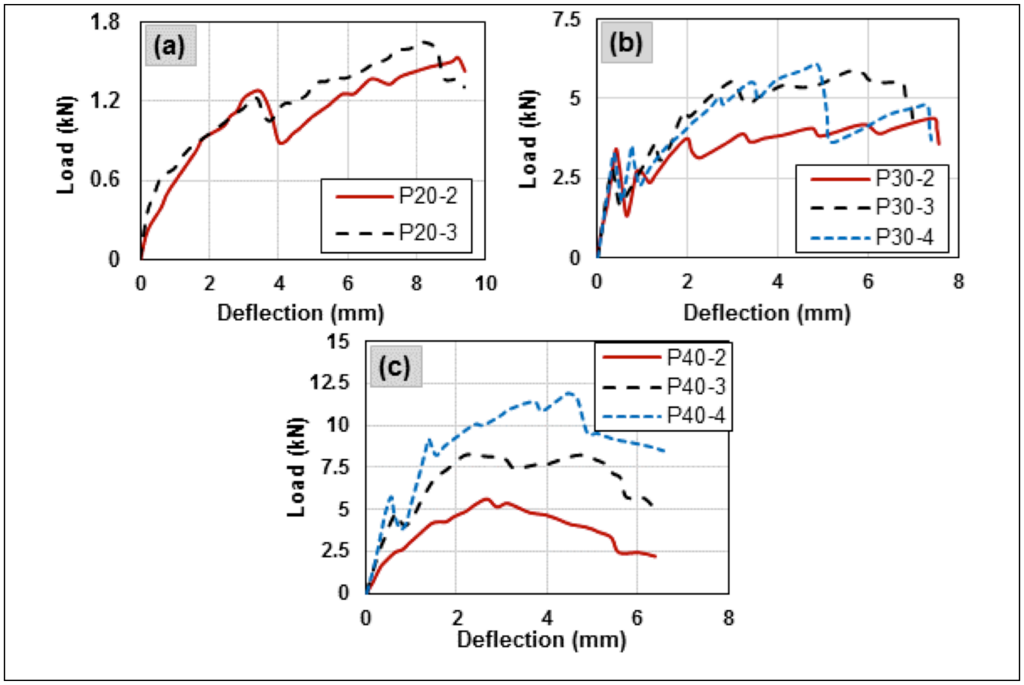

Figure 8. *Load vs deflection for punching shear test; (a) 20 mm thickness, (b) 40 mm thickness, (c) 60 mm thickness*

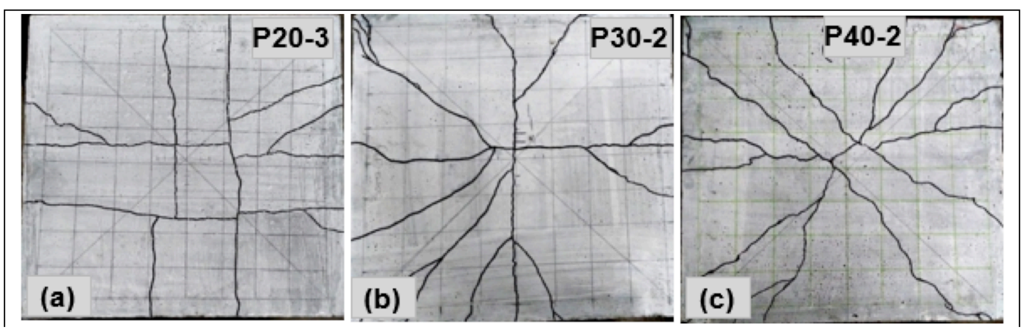

Figure 9. *Cracks at bottom face in punching shear test; (a) Transversal cracking, (b) Transversal and diagonal mixed cracking, (c) Diagonal smeared cracking*

4.2 Bending Test

For flexure behavior, four-point loading was considered and vertical deflection was measure in center at the bottom face of ferrocement panels. Due to very less flexural stiffness of 20mm thick panel, a very small loads value of 0.7kN and 0.91kN were observed for B20-2 and B20-3 cases, respectively as shown in (Figure 10(a)). The failure was attributed to pure flexure cracks in central zone of pure bending moment and can be seen in (Figure 11(a)) for B20-3 case.

(Figure 10(b)) shows that when thickness of panel is increases to 30mm the bending strength also increases remarkably as compared with 20mm thickness case. It is due to a higher flexural stiffness of composite section and contribution of reinforcing mesh toward the bending resistance due to a larger lever arm. In that case, the ultimate load taken by theses specimen was 5.07 kN, 7.79 kN and 8.34 kN for B30-2, B30-3 and B30-4 specimens, respectively. The specimens B30-2 and B30-3 revealed the pure flexure cracks parallel to loading pins at the bottom of slab, similar to the crack as shown in (Figure 11(a)) but in in case of B30-4 some minor shear cracks also appeared near the edges as depicted in (Figure 11(b)).

The samples with 4-layers show two peak before ultimate load first peak is corresponding to fracture of mortar layer and second is due to the yielding of exterior PP mesh layer. Failure mode in 40mm thick panels exhibited shear cracks along with flexural cracks as shown in (Figure 11(c)) for B40-2 case. Which indicates that larger thickness increases flexural rigidity and thus improves the ultimate capacity of ferrocement panels. The ultimate load taken by the specimens B40-2, B40-3 and B40-4 was 9.02 kN, 10.05 kN and 10.57 kN respectively, as can be seen in (Figure 10(b)).

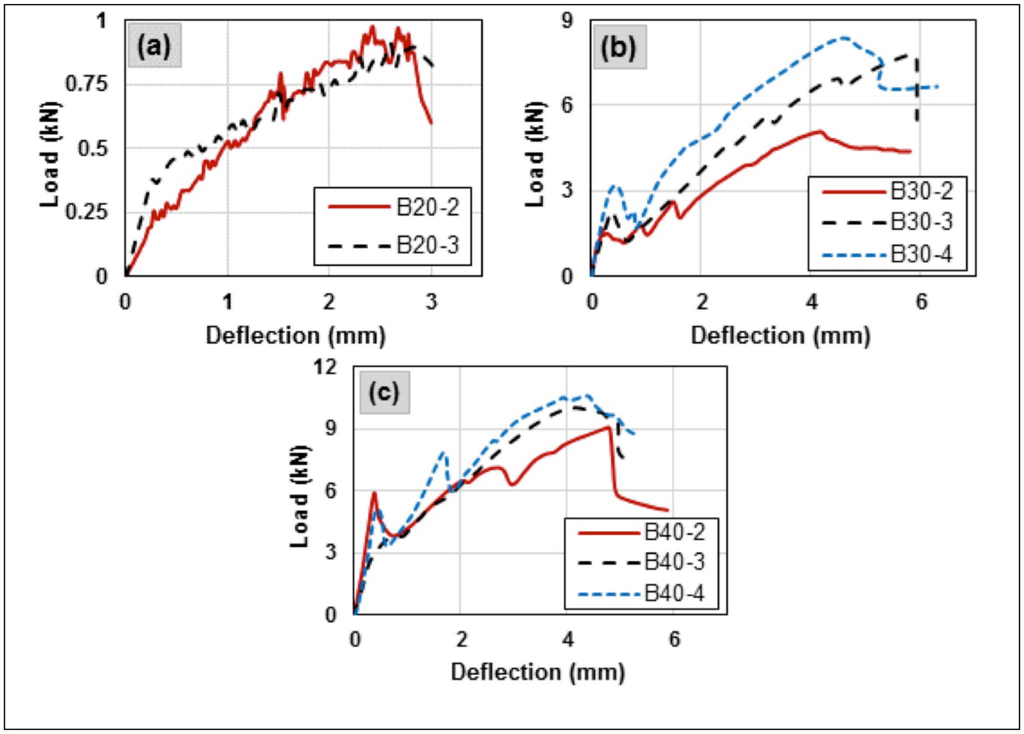

Figure 10. *Load vs deflection for bending test; (a) 20 mm thickness, (a) 40 mm thickness, (a) 60 mm thickness*

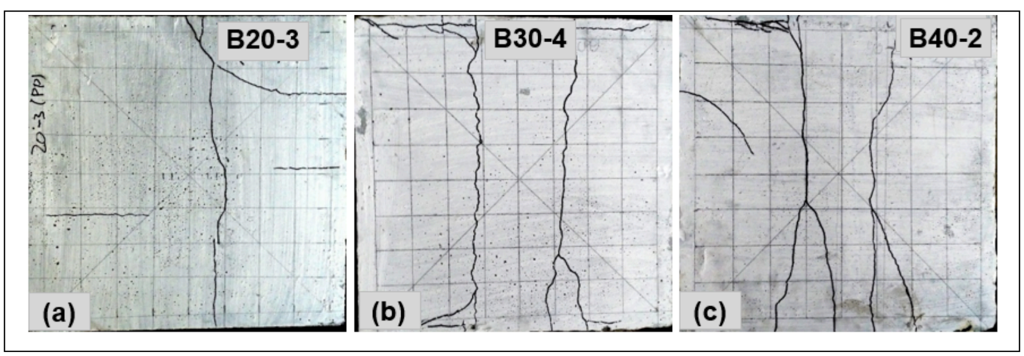

Figure 11. *Cracks at bottom face in bending test; (a) Flexure cracks, (b) Flexure cracks with minor shear cracks, (c) Flexure and shear crack*

4.3 Effect of PP layers on Punching and Bending Strength

To study the influence of PP reinforcing layers on ultimate capacity, the results of various mesh layers were arranged in different thickness groups as depicted in (Figure 12). The results were normalized with reference to lowest number of layers (i.e., 2-layer) in each thickness group. (Figure 12(a)) shows that for panel thickness 30mm and lesser, there is no appreciable improvement in punching shear strength but ultimate capacity increase *significantly for P40 panels. (Figure 12(a)) shows that punching capacity is enhanced by 46% and 110% when number of PP layers increases from 2-layers to 3-layers and 4 layer, respectively. However, improvement in punching shear was only 35% and 40% for P30-3 and P30-4 panels respectively, which is due to crushing of mortar and less composite action provided by PP mesh as compared to 40mm thick panels.*

(Figure 12(b)) reveals that number of meshing layers improves the bending strength in all specimens, which is due to enhanced tensile membrane action provided by PP mesh layers. It was also observed that there was no remarkable improvement in bending strength when number of PP layers increased from 3-layers to 4-layers. This behavior may be due to extra ductile nature of the PP mesh as exterior PP layers goes to large deformation and most of mortar has already been cracked before interior mesh comes in to action. Bending strength was improved by 15%, 54% and 11% for B20, B30 and B40 cases when number of layers were increased from 2-layers to 3-layers. However, this improvement was only 9% and 6% for B30 and B40 cases when number of layers were increased from 3-layers to 4-layers, which is quite evident from (Figure 12(b)). This small increment in strength affirms that bending strength of ferrocement elements is primarily a function of the tensile strain in the extreme layer of mesh (Naaman, 2000).

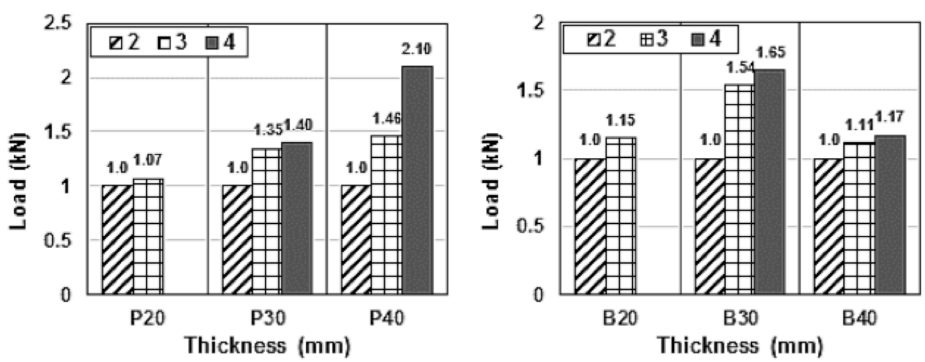

Figure 12. *Effect of PP layers*

5. Conclusions

Based on experimental study the following conclusion are established.

- *The study concluded thickness of ferrocement panels should not be used less than 30mm as panels with 20 mm thickness did not performed well majorly fails in flexure rather than to fail due to Punching Shear. . However, for larger thickness (i.e., 30mm and 40mm), the ferrocement panels with PP wire mesh depicted appreciable resistance against both punching shear tests and bending test.*

- *The punching shear strength increase both with the increase of panel thickness and number PP layers and transversal cracks changes to smeared cracks in diagonal direction, which indicates good energy absorption characteristic of PP mesh in ferrocement panels.*

Load carrying capacity is not increased significantly, when number of PP-layers are increased more than three, keeping the thickness constant this is due to the fact that bending strength of ferrocement elements is primarily the function of the tensile strain in the extreme mesh layer.

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