EXPERIMENTAL INVESTIGATION ON THE FERROCEMENT SLABS WITH A SIFCON MATRIX

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Abstract

The present study conducts to investigate the effect of Slurry Infiltration Fiber Concrete (SIFCON) matrix on flexural response of Ferro cement slabs. For this purpose a total of 14 Ferro cement slabs with SIFCON of size (500*120*25 mm) are cast and tested. The major variables studied in this investigation include the number of mesh layers and various volume ratio of discrete steel fiber (2.5, 5, 7.5 and 10%). Structural performance parameters used for comparisons are load–deflection curves, ultimate load and corresponding deflection at failure, energy absorption and failure mode and crack pattern. The inclusion of SIFCON in the Ferro cement slabs can significantly improve its flexural strength and energy absorption may be concluded. Furthermore, reduction in crack width with a large number of cracks is observed in specimens contain SIFCON compared to control specimens.

Keywords: Ferro cement, SIFCON, flexural behavior, steel fiber, wire mesh, energy absorption

دراسة عملية على البلاطات الفيروسمنتية مع السيفكون

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الملخص:

اجريت هذه الدراسة للتعرف على تأثير الملاط الخرساني المتخلل للألياف الحديدية (السيفكون) على استجابة البلاطات الفيروسمنتية. و لتحقيق هذا الغرض تم صب وفحص اربعة عشر بلاطة فيروسمنتية مع السيفكون بأبعاد (500 * 120 * 25 ملم) . حيث كانت المتغيرات الرئيسية المدروسة في هذا البحث هي عدد طبقات الاسلاك المعدنية والنسب الحجمية للألياف الحديدية حيث استخدمت نسب حجوم مختلفة (2.5 و 5 و 7.5 و 10٪). كانت معايير الأداء الانشائي المستخدمة لأغراض المقارنات هي منحنيات الحمل - انحراف، التحميل الاقصى والانحراف عند الفشل، وامتصاص الطاقة ووضع الفشل ونمط التشققات. ان وجود السيفكون في البلاطات الفيروسمنتية ساعد بشكل ملحوظ على تحسين مقاومتها للانثناء والطاقة

الممتصــة لهــا. وعــلاوة علــى ذلــك، لــوحظ انخفــاض فــي عــرض التشــققات مــع ظهــور عــدد كبيــر مــن الشقوق في العينات الحاوية على السيفكون مقارنة بعينات السيطرة.

كلمات البحث: فيروسمنت، سيفكون، سلوك الانثناء، الياف حديديه، اسلاك المشبكات، امتصاص الطاقه.

1. INTRODUCTION

Ferro cement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable materials [1]. Ferro cement has a very high tensile strength-to-weight ratio and superior cracking behavior in comparison to conventional reinforced concrete. Ferro cement can be utilized in a number of practical application such as agricultural applications [2], applications in water supply and sanitation [3], housing and rural energy [4, 5, 6, 7, 8], repair [9, 10, 11, 12], rehabilitation [13], and strengthening of different concrete structural members [14, 15, 16, 17]. These are due to several advantages such as the availability of raw materials; the elements can be fabricated in any shape; low level of skill required for Ferro cement construction. In Ferro cement composites made with high reinforcement ratio or high strength meshes, the flexural failure is occur due to delamination of extreme tensile layer of reinforcement or spalling mortar cover of composites. To overcome these problems is the use of discontinuous short fibers in matrix [8]. Researchers proved that when adding fibers to matrix could help to significant increase in shear capacity and also reduced crack width and spacing [18, 19, 20]. Recently, fiber-reinforced cement composites (FRC) have received increasing attention from the research community due to their high degree of performance. Among these composites, Slurry-infiltrated fiber concrete (SIFCON) is the most promising, as far as ductility is concerned [21, 22]. SIFCON can be considered as a special type of steel fiber reinforced concrete with high fiber content. Normally, FRC contains 0.5-2% fibres by volume, whereas SIFCON contains 3-20% of fibers [23]. The other major difference is in the composition of the matrix. The matrix in SIFCON consists of cement slurry or flowing mortar as opposed to aggregate concrete in FRC. The casting process is also different for SIFCON. In most of the cases SIFCON is fabricated by infiltrating a bed of pre-placed fibers with cement slurry [24]. The infiltration is generally achieved by gravity flow assisted by external vibration, or by pressure grouting [25]. Because of SIFCON has superior properties such as ductility, crack resistance, penetration and high impact resistance that make it is the best suited to applications in the fields of new and strengthening and rehabilitation of concrete structures. Namaan and Homrich [26] presented tensile stress-strain properties of SIFCON and the results showed that SIFCON exhibits up to ten times higher tensile strength and a thousand times larger toughness than normal unreinforced concrete. Results of a study done by Naaman et al. [27] on reinforced concrete beams with a SIFCON matrix showed that the use of SIFCON might eliminate the need of stirrups in flexural members. Shannag et al. [28] conducted an experimental investigation to repair shear deficient reinforced concrete beams using SIFCON jacketing. It was observed from the experimental results that the SIFCON changed the brittle shear failure to a ductile flexural failure and increases the ultimate shear strength of the repaired beams. Sudarsana et.al [29] studied the influence of edges condition (simple and fixed) on flexural behavior of steel reinforced SIFCON two-way slabs. Elnono et al. [30] conducted testing on SIFCON corner connections subjected to opening bending moments. It was concluded that the both joint capacity and ductility were highly improved. From the above, limited researches were found that dealing with the influence of adding discontinuous fibers into wire mesh reinforcements before poured cement mortar on structural response of Ferro cement members. Therefore, this study represents an attempt to develop a new hybrid type of Ferro cement panels in which the reinforcement consist of wire meshes and discrete fibers preplaced in the moulds and then poured self-compacted cement mortar. For this purpose the hybrid specimens with dimensions (500 × 120 ×25 mm) were cast and tested under bending.

2. EXPERIMENTAL INVESTIGATION

The experimental program consists of testing of 14 specimens to explore the flexural behaviour of hybrid Ferro cement slabs with SIFCON. The main variables considered in the test were the number of wire mesh layers (0, 2, 4, and 6) and addition of steel fibers with different ratios (2.5, 5, 7.5, and 10%). The cast slabs dimensions were (500 × 120 ×25 mm). Specimen details and main study parameters were summarized in **Table (1)**. Load–deflection curves, ultimate load and corresponding deflection at failure, crack pattern and energy absorption were observed throughout the study.

2.1 Materials and Mixing Proportions

Welded square wire mesh with a wire diameter of 1.0 mm and 12.5 mm spacing was provided as reinforcement for Ferro cement slabs. The mesh was tested according to th design guide on construction and repair of Ferro cement reported by the **ACI committee 549, 1999**[1]. The yield strength of the wire mesh was determined to be 405 MPa. The average ultimate strength of the wire mesh and modulus of elasticity was found to be 600 MPa and 95 GPa, respectively. Mortar matrix consisted of ordinary Portland cement locally available and natural sand passing through sieve No. 30. In the mix, 10% by weight of cement was replaced by silka fume. The water and sand to binder ratios by weight were chosen to be 0.3 and 1.0 respectively. Supper plasticizer type (**Sika Viscocrete 5930),** was used as high range water reducer. The dose of superplasticizer used to obtain self-compacted mortar was 3% by total binder weight. Potable water was used in the experimental work for both mixing and curing. The steel fiber with hook ended was used in this study and having unit weight of 7850 kg/m³ with tensile strength 1150 MPa. A steel fiber of 1.0 mm diameter and 60 mm length was manufactured in Chain.

Table 1: Details of specimens

Groups	Slab No.	No. of wire mesh layers	Volume fraction of wire mesh (Vf %)	Volume fraction of steel fiber (%)	Specimen description
A	P	0	0	0	Plain
B	P2.5	0	0	2.5	SIFCON
	P5			5	
	P7.5			7.5	
	P10			10	
C	2P	2	1.01	0	Ferro cement
	2P2.5			2.5	Ferro cement + SIFCON
	2P5			5	
	2P7.5			7.5	
	2P10			10	
D	4P	4	2.01	0	Ferro cement
	4P2.5			2.5	Ferro cement+ SIFCON
	4P5			5	
E	6P2.5	6	3.02	2.5	Ferro cement + SIFCON

2.2 Fabrication of Test Specimens

The wooden molds dimensions were (500x120x25 mm). The desired mesh layers were tied by fine steel wires and then placed inside the molds and then steel fibers with desired amount were placed in the molds. Fresh self-compacted mortar mix was then poured into the wooden molds as shown in **Fig. (1)**. **Table (2)** shows the fresh self-compacted mortar properties that confirms with EFNARC specification [31]. Along with the slabs, a total of six (50x50x50 mm) mortar cubes and three (40x40x160 mm) mortar prisms were molded. The mortar specimens were used for compressive and flexure strength tests. The matrix characterized by an average compressive of 67 MPa. Molded specimens were cured in mold for 48 hour and then removed from their molds, and immersed in the curing tank for 28 days. Before the testing day, the slab was cleaned and painted with white paint on surfaces, to achieve clear visibility of cracks during testing. The slab was carefully placed on the simple supports.

(a) Casting of SIFCON

(b) Casting of Ferro

Figure (1) Fabrication and cast of specimens

Table 2. Fresh properties of self-compacting mortar

	Tested value of fresh mortar	EFNARC Specification (2002)
Mini Slump (mm)	259	Between (240 – 260) mm
Mini V-funnel (sec)	8.6	Less than 11 seconds

2.3 Specimens Testing

All specimens were tested under centre-point loading method with an effective span of 350 mm. Load was applied in equal increments and maintained constant at each load level at the mid-span of the slab using a hydraulic jack having a capacity of 5.0 Ton. The slab was supported on two steel rods. Dial gauge was placed on the mid-point0s of mid span of the slab to measure the deflection while a calibrated load cell was used to record the load.

3. RESULTS AND DISCUSSION

3.1 Load-Deflection Relationships

The load-deflection curves for all the specimens tested are shown in **Fig. (2)** To **Fig. (6).** as can be seen from these figures, all load–deflection curves have a similar trend. The load-deflection relationships can generally be divided into three stages. In the first stage, the specimens behave elastically and can be denoted as pre-cracking stage. The deflection is linearly proportional to the applied load. The applied load is resisted by matrix in this stage. After this stage, cracks initiation to occur in the tensile face of specimens and the load-deflection relationship becomes nonlinearly. Also, in this stage the numbers of cracks are increased. The matrix at the cracked section does not carry any tension and the reinforcement (wire meshes and/or steel fiber) resist the load entirely. As the load increased the multiple cracks are occurred and these cracks are widening gradually and the reinforcement steel (wire mesh and fiber) is continued to sustained loads into the yielding. When the load reached a value that caused inelastic straining of the reinforcement, the deflection is increased and cracks are propagated quickly, then the load is slightly increased so that the cracking of compression face of matrix under loads occurred. The failure cracks are occurring under the point of applied load. The load-deflection behavior of the Ferro cement slabs with SIFCON is similar with those got by other previous researchers [19, 32, 33].

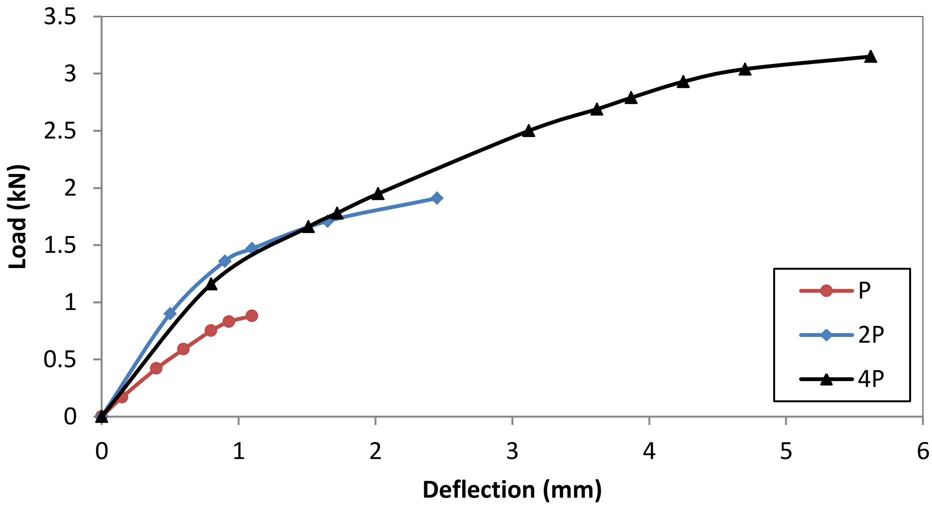

Figure (2): Load–deflection relationships of (specimens P, 2P, and 4P).

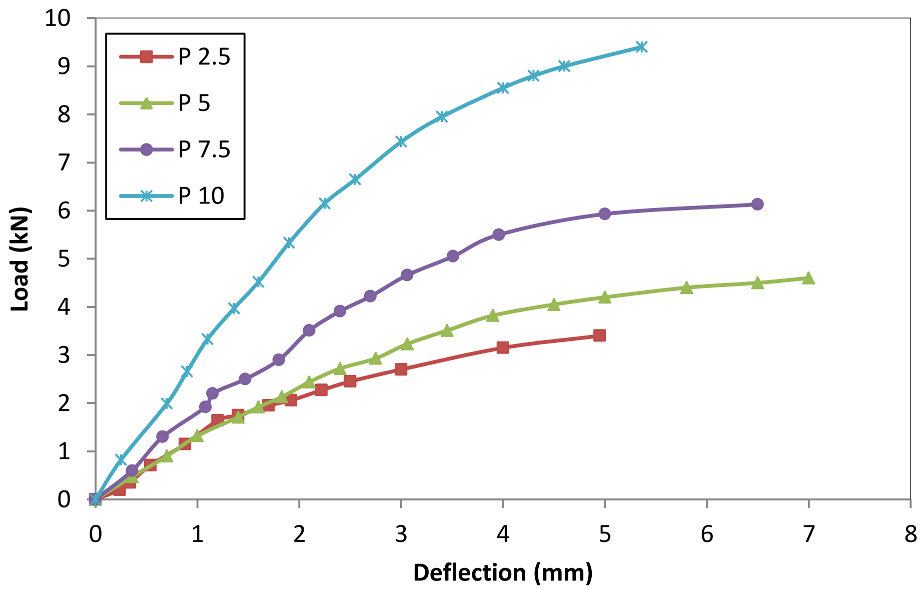

Figure (3): Load–deflection relationships of SIFCON specimens (P2.5, P5, P7.5, and P10).

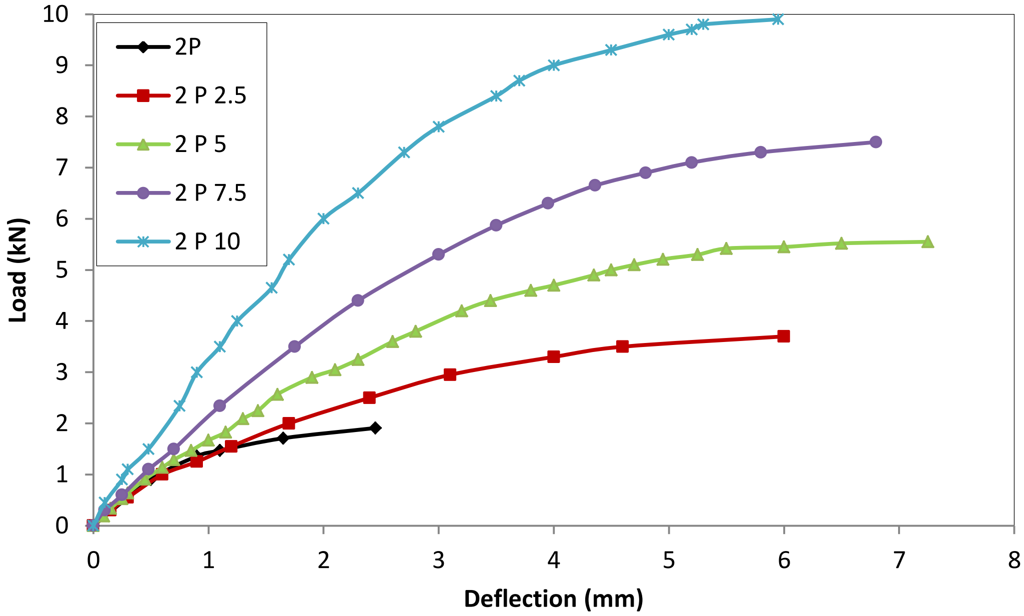

Figure (4): Load–deflection relationships of Ferro cement-SIFCON specimens (2P, 2P2.5, 2P5, 2P7.5, and 2P10).

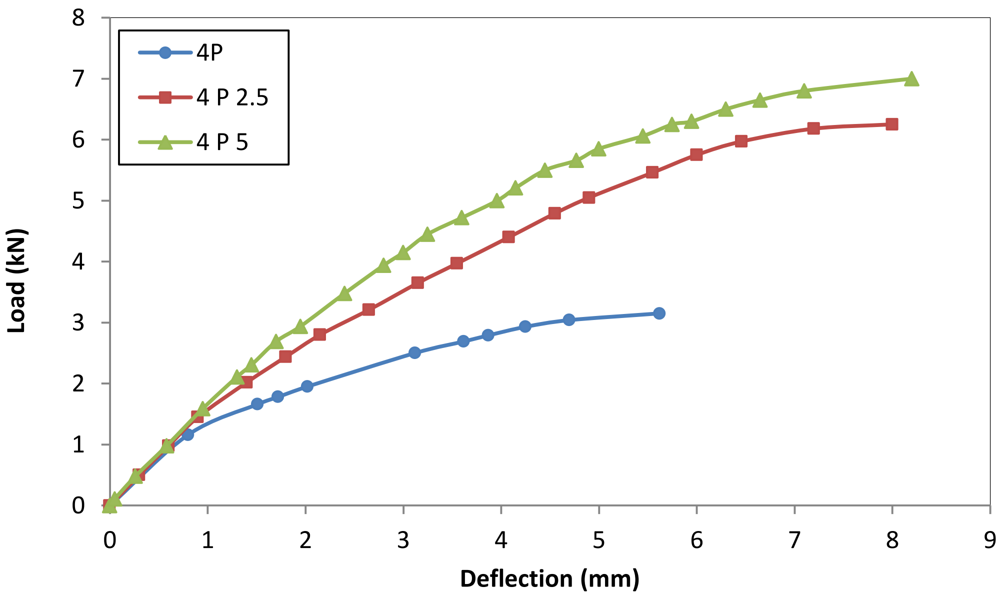

Figure (5): Load–deflection relationships of Ferro cement-SIFCON specimens (4P, 4P2.5, and 4P5).

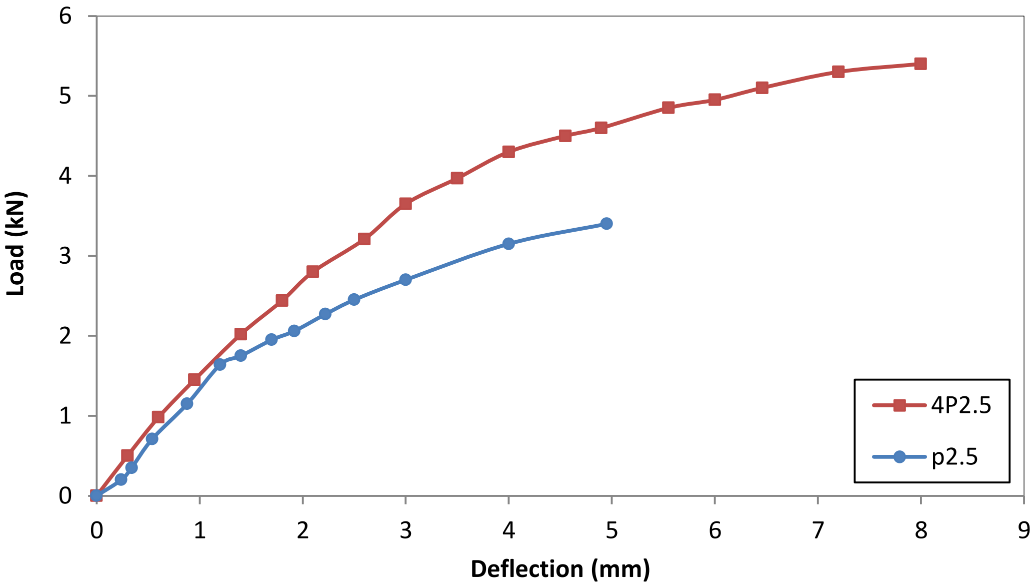

Figure (6): Load–deflection relationships of specimens P2.5 and 4P2.5

The failure of plain specimen occurs suddenly when initiate of crack at the tension face and then specimen broke into two pieces. **Fig. (2)** Shows comparison of load-deflection curve of Ferro cement slabs contains wire mesh only. It is clear that an Increase of volume fraction of wire mesh (number of wire mesh layers) has no considerable effect on load-deflection curve during the linear deformation stage and its effect becomes more influences after this stage. The ultimate loads and corresponding deflections are increased with an increase of volume fraction and the Ferro cement panels become more ductile. The tensile strength increased in the tension face and crack propagation is prevented by wire mesh that provided in specimen. Increasing the number of wire mesh from two layers to four layers leads to exhibit improvement in both flexural strength and ductility of Ferro cement specimen at failure with a magnitude of (65% and 129%) respectively, as can be shown in **Table (3)**. The load-deflection curves for SIFCON specimens are illustrated in **Fig. (3).** from this figure, it can be noted that the ultimate load and deflection at failure are increased with an increase of steel fiber. Changing the ratio of steel fiber from (2.5 %) to (10 %) caused to significant improves of maximum load of slabs with ratio (176%). **Fig. (4)** and **Fig. (5)** Show the effect of fibers (SIFCON) on the load-deflection curves of Ferro cement panels. It can be seen from these figures that the addition of steel fiber has an insignificant effect on flexural behavior before first crack appearance while its effect becomes clear after the occurrence of first crack. It can be noticed from that figures, the addition of steel fiber can delay the initiation of crack. Also, during post cracking deformation condition of Ferro cement panels with steel fibers have significantly increasing of ultimate carrying capacity, ductility and energy absorption of specimens compared with control specimen. And an increase of steel fiber ratio exhibited higher of stiffness of these specimens.**Fig. (4)** Is denoted the load–deflection relationships of hybrid Ferro cement- SIFCON panel with various fiber ratios in comparison with Ferro cement panel reinforced with wire mesh only (2 layers of wire mesh). When adding fiber of ratio (2.5, 5, 7.5, and 10 %) respectively, the ultimate load increases (94, 191,293, and 418 %) respectively, as shown in **Fig. (4)** and **Table (3)**. The effect of addition of steel fiber on the Ferro cement slab is shown in **Fig. (6)** For (4P2.5) and (P2.5), for example. The figure illustrates the addition of steel fiber exhibit enhancement in both ultimate load and deflection. The enhancement of load and deflection are around 84% and 62%, respectively.

Table (3): Summary of test results

Groups	Specimen	Ultimate load (kN)	Deflection at failure (mm)	Energy absorption* (N.m)
A	P	0.88	1.1	0.573
B	P2.5	3.4	4.95	11.0
	P5	4.6	7.0	21.71
	P7.5	6.13	6.5	27.44
	P10	9.4	5.36	33.1
C	2P	1.91	2.45	3.36
	2P2.5	3.7	6	15.43
	2P5	5.55	7.25	28.42
	2P7.5	7.5	6.8	34.55
	2P10	9.9	5.95	40.24
D	4P	3.15	5.62	12.1
	4P2.5	6.25	8	32.25
	4P5	7	8.2	37.85
E	6P2.5	7.6	7.86	37.61

*** The energy absorption is determined by the area under the load-deflection curve**

Fig. (5) Illustrates the load-deflection response of specimens reinforced with four layers of wire mesh and fibers with ratios (2.5 and 5%). This figure shows flexural strength capacity increased (98 and 122 %) respectively, while the maximum deflection increased (42 and 46%) respectively. **Fig. (3)** and **Fig. (4)** Are clearly illustrated the effect of steel fiber upon sections flexural stiffness with remarkable difference due to fiber different ratios. **Fig. (7**) Shows the load–deflection relationships of sections with various number of wire mesh layers (2, 4 and 6) and the same fiber ratio (2.5%). The changing of volume. Fraction of wire mesh from (1.01%) to (3.01%) leads to significant improves of flexural strength and ductility of panels with ratios (105% and 31%), respectively. **Fig. (8)** Shows the variation of load-deflection response for specimens (2P10) and (P10). It can be seen that the both curves are approximately identical. It can be concluded that, when using wire mesh layers with high percentage of steel fiber, the effect of the wire mesh has slightly influence on the behavior of specimen.

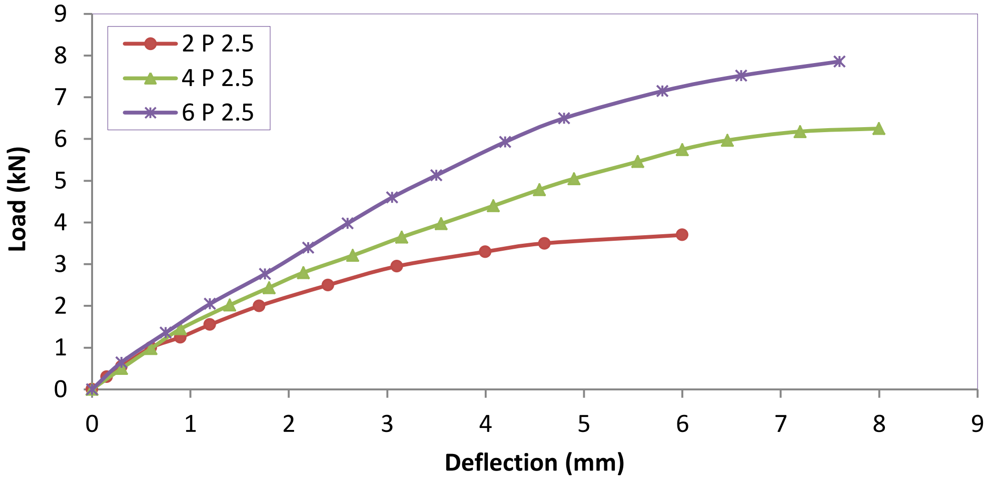

Figure (7): Load–deflection relationships of Ferro cement-SIFCON specimens (2P2.5, 4P2.5 and 6P2.5).

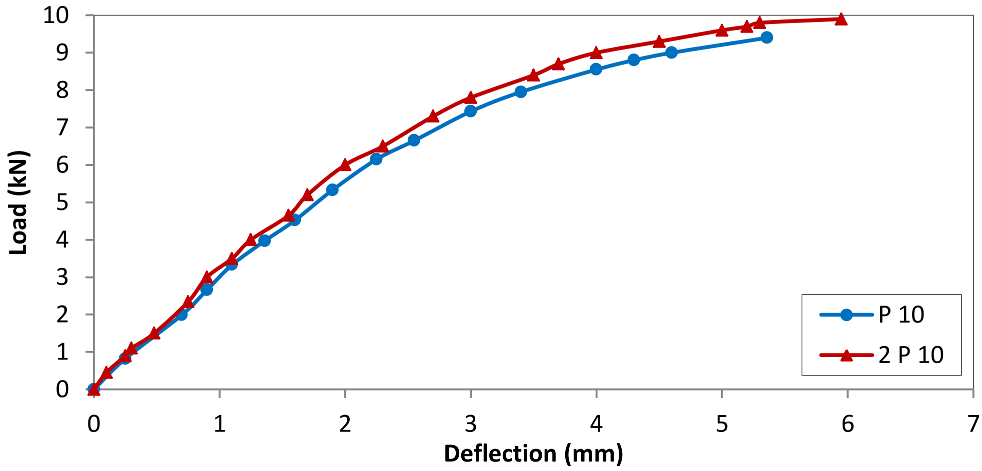

Figure (8): Load–deflection relationships of specimens P10 and 2P10

3.2 Energy Absorption of Test Specimens

The energy absorption of all specimens tested in this study is investigated by the load versus deflection curve as shown in **Table (3)**. The energy absorption is determined by the area under the load-deflection curve. The plain specimen failed immediately after the initiation of crack at bottom face, and the failure is sudden and without any cracks before the final fracture of the specimen as mention earlier. On the other hand, all specimens with reinforcement (wire mesh, steel fiber, and wire mesh-fiber composite) failed due to yield of reinforcement. These specimens exhibited higher loads, increase deflection and greater energy absorption values compared to the control specimen. **Table (3)** shows that increasing the amount of wire mesh layers increase energy absorption. Also the same findings are obtained with increasing the amount of steel fiber. The presence of steel reinforcement leads to delay of cracks and improvement of the yield load. Where, the large increase in the energy absorption relates with increment in the load and improvement in the stiffness after yielding. Specimens (2P2.5), (2P5), (2P7.5), and (2P10) have an increase in energy absorption of about 40%, 31 %, 26 % and 22 % over the (P2.5), (P5), (P7.5) and (P10) respectively. Hence, it can be concluded that the use of the steel fiber for the Ferro cement panels provide an improvement of energy absorption and the ductility for the specimens. From **Fig. (9)** it can be seen the specimens 2P10 shows a higher increase in energy absorption. In addition, it found that specimens 4P5 and 6P2.5 show a close amount of energy absorption capability.

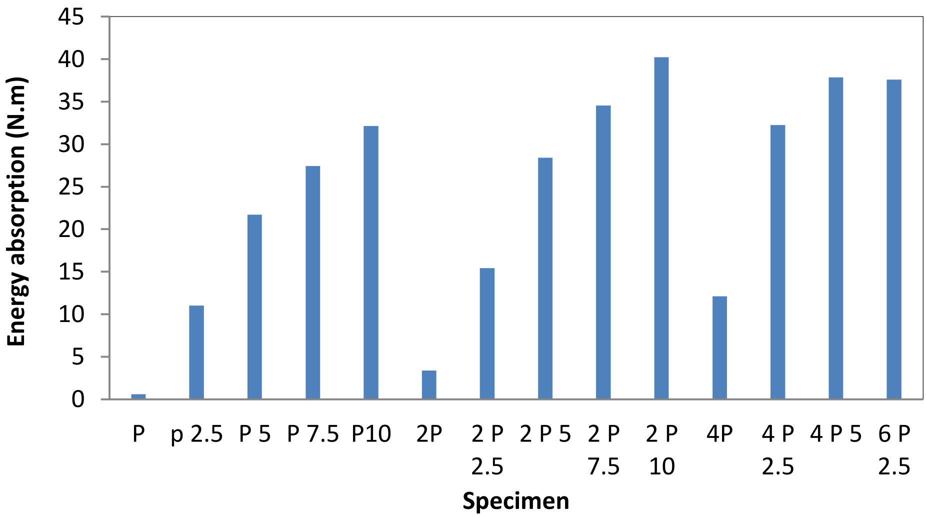

Figure (9): Energy absorption of tested specimens

3.3 Failure Modes and Cracks Patterns of Test Specimens

Failure mode and crack pattern of the test Ferro cement panels are shown in **Fig. (10**), for all tested specimens no crushing of matrix is observed on the compression face of cross section. All cracks initiated at the bottom face of the specimens. The main cracks generally commenced and concentrated at the middle zone of the panel under applied loads. It may be seen from that figure the spacing between cracks is smaller and the cracks are finer and a large number of cracks for specimens with an increase of volume fraction of wire meshes. It indicates that the volume fraction of wire mesh plays the major effect on the crack patterns. The addition of steel fibers with different ratios on ferrocement slabs are shown in **Fig. (10-g)** to **Fig. (10-i)**. An increase of fibers leads to formation of more cracks in tension face of the region under the point of applied load with smaller width and better distribution of the cracks in this zone when compared with control slabs as shown in **Fig**. **(10-g),** and **Fig. (10-i).** Also, the presence of steel fibers prevent of spalling cover of the matrix.

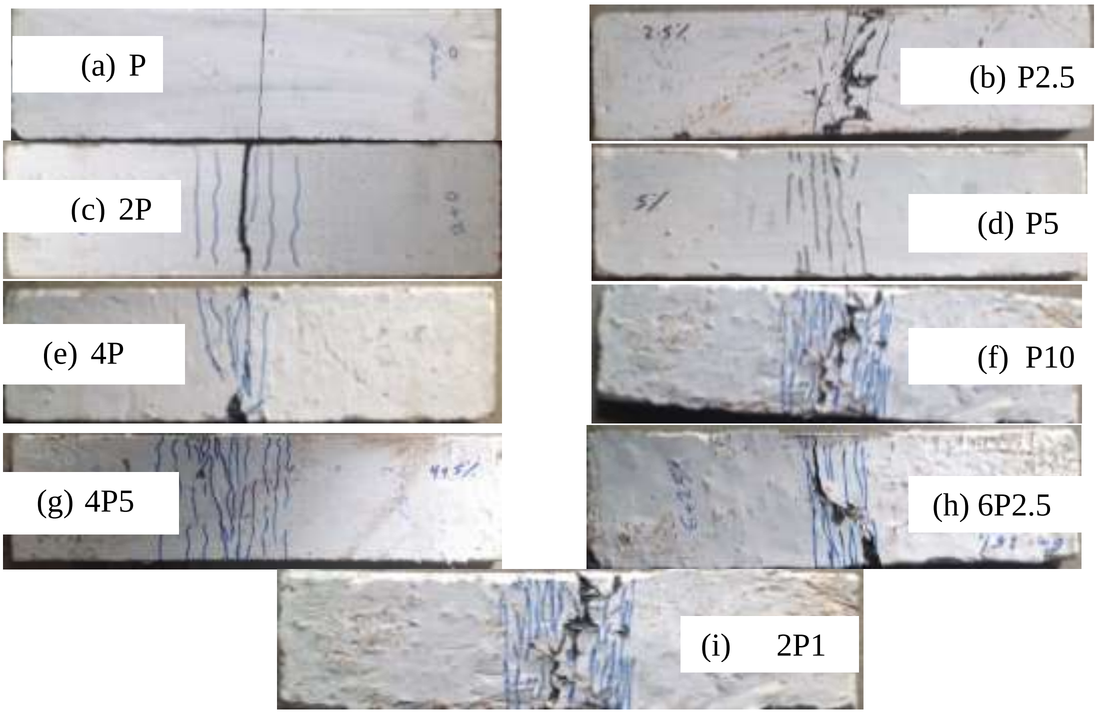

Figure (10): Failure mode of Ferro cement and SIFCON panels

4. CONCLUSIONS

The following conclusions can be drawn from the test results of this study:

1. Increasing wire mesh layers in specimens has significantly effect on ultimate flexural strength and ductility. When the number of wire mesh increases from two layers to four layers the flexural strength and ductility of increased (65% and 129%) respectively.
2. The addition of steel fibers to the Ferro cement specimen can delay the initiation of crack and led to a significantly increasing of ultimate carrying capacity, ductility and energy absorption of specimens.
3. It can be conclude that the spacing between cracks is smaller and the cracks are finer and a large number of cracks are appeared in specimens have large number of wire mesh layers and/or have steel fibers.
4. The presence of steel fibers in ferrocement panels can prevent spalling of cover of the matrix.
5. The effect of the wire mesh has slightly influence on the behavior of specimen contains high percentage of steel fiber.

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