ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/314072282

EXPERIMENTAL STUDY FOR THE EFFECT OF CFRP AMOUNT AND LAYERS ON THE FLEXURAL BEHAVIOUR OF SPLWAC REINFORCED CONCRETE SLABS

Article · January 2016

CITATIONS
0

READS
33

2 authors, including:

Ahid ZUHAIR Hamoodi
University of Basrah

3 PUBLICATIONS **0** CITATIONS

SEE PROFILE

All content following this page was uploaded by Ahid ZUHAIR Hamoodi on 26 February 2017.

The user has requested enhancement of the downloaded file.

EXPERIMENTAL STUDY FOR THE EFFECT OF CFRP AMOUNT AND LAYERS ON THE FLEXURAL BEHAVIOUR OF SPLWAC REINFORCED CONCRETE SLABS

By; Prof. Dr. Riadh A. Abass[1] and Mr. Ahid Z. Hamoodi[2]

[1]Dept. of civil engineering, College of engineering, University of Mothana.

[2]Dept. of civil engineering, College of engineering, University of Basrah.

ARTICLE INFO

Received:

Accepted:

Keywords

CFRP, Sand-PLWAC OWS, Monotonic Loading, Variable amplitude Loading.

Abstract: A nine sand-porcelinite lightweight aggregate reinforced concrete one way slabs (SPLWAC OWS) were casted in this study. These slabs were strengthened with carbon fibre reinforced polymer (CFRP) strips and tested under monotonic and variable amplitude cyclic loading to study the effect of CFRP amount and layers on the flexural behaviour of these slabs. It has been found that the ultimate load carrying capacities of the these slabs were increased with the presence of CFRP strips compared to the control un-strengthened slabs. Also, the ultimate load carrying capacities of the slabs strengthened with double layer of CFRP strips were greater than that of slabs with single layer of CFRP strips. At the same time, the failure mode was by yielding of steel for the control un-strengthened slabs, or by yielding of steel followed by rupture of CFRP strips for the slabs strengthened with single layer or followed by debonding of CFRP strips for the slabs strengthened with double layer.

دراسة عملية لتأثير كمية وطبقات شرائح البوليمر المسلحة بألياف الكربون على تصرف الانحناء للبلاطات الخرسانية المسلحة الخفيفة

الملخص: في هذا البحث تم تحضير تسع بلاطات خرسانية مسلحة خفيفة ومقواة بشرائح البوليمر المسلحة بالألياف الكربونية. تم فحص هذه البلاطات تحت تأثير الأحمال الساكنة والمتكررة ذات المدى المتغير لغرض دراسة تأثير كمية وطبقات شرائح البوليمر على تصرف الانحناء لتلك البلاطات. لوحظ في هذه الدراسة، أن حمل الانحناء الأقصى للبلاطات يزداد بوجود شرائح البوليمر مقارنة مع البلاطات غير المقواة. كما كان حمل الانحناء الأقصى للبلاطات المقواة بطبقتين من شرائح البوليمر اكبر منه للبلاطات المقواة بطبقة واحدة. كما لوحظ في هذه الدراسة ايضا، ان طبيعة الفشل للبلاطات غير المقواة بشرائح البوليمر كان بواسطة خضوع حديد التسليح ، اما للبلاطات المقواة فكان بواسطة خضوع حديد التسليح يتبعه تمزق شرائح البوليمر للبلاطات المقواة بطبقة واحدة أو يتبعه فك الالتصاق عن سطح الخرسانة للبلاطات المقواة بطبقتين.

الكلمات المفتاحية

ألياف الكاربون, بلاطات باتجاه واحد خرسانية خفيفة، حمل ستاتيكي, حمل متغير

E-mail addresses:

mm812000@yahoo.com

Introduction

There is increased demand for extensive research work to improve the characteristics behaviour of fibre reinforced polymer (FRP) materials to establish their application acceptability in RC structural members such as, beams, slabs and columns. In particular, their practical implementations for strengthening civil structures are numerous [1]. It is important to note that although the material cost of CFRP is several times more than that of steel plates, the fact that 6.2kg of CFRP could be used in place of 175kg of steel is sufficient to explain the advantages of CFRP over steel plates [2]. One of the major problems in design and execution of buildings is the considerable weight of dead load. Using lightweight materials is an effective solution to reduce the dimensions of the supporting structure, minimize the earthquake force on buildings and finally to increase the speed, facilitate the execution and economize the project [3]. Structural lightweight aggregate concrete (SLWAC) has an in place unit weight of 1440 to 1840 kg/m^3 compared to normal weight concrete with a density of 2240 to 2400 kg/m^3. For structural applications the cylinder compressive strength should be greater than 17.0 MPa. In most cases, the marginally higher cost of the SLWAC is offset by size reduction of structural elements, less reinforcing steel and reduction in concrete volume, resulting in lower overall cost [4]. According to ACI 318-2011, sand- lightweight aggregate concrete is the concrete in which the sand is the fine aggregate while the lightweight material represents the coarse aggregate [5].

Porcelinite Lightweight Coarse Aggregate (PLWA)

Local naturally occurring lightweight aggregate (LWA) of porcelinite stone was used in this study as coarse aggregate. It was received in large lumps through the State Company of Geological Survey and Mining (SCGSM), which provide it from Al-Anbar Governorate, Akashat district, Westren Desert - Traifawi. The lumps were manually crushed into smaller sizes, screened and graded on a standard sieves series of 12.5, 9.5, and 4.75mm, complying with ASTM C330-2004 [6] as shown in Table 1 and figures 1 and 2. Since a high proportion of dust leads to segregation and causes crazing of exposed concrete [7], and due to the rapid water absorption of the LWA, the saturated surface dry (SSD) condition has been achieved by washing and spreading the aggregate in the laboratory air for a suitable time. Table (2) lists the physical and chemical properties and their corresponding proper specifications.

Behaviour of Plain Concrete, Steel and FRP Reinforcement When Subjected to Repeated (Cyclic) Loading

Slabs are sometimes subjected to repeated loading. Consequently, the performance of slabs under repeated loading is an important limit state that must be taken by the designers [9]. For plain concrete, the repeated loading causes microscopic changes. In LWAC and due to dries and shrinkage stresses, the opening and growth of micro-cracks prior to the application of load is a feature [10]. Typically, the aggregate bridging force decreases with number of cycles because of the lightweight aggregate (LWA) breakage. So, the damage to the LWA, which are generally the weakest phase in LWAC, results in aggregate bridging stress degradation and lead to repeated crack growth in concrete [11]. In materials with crystalline structure, like steel, and under repeated loading, micro-cracks initiate at a defect and propagate, forming a crack that continues to grow with each load cycle. Conversely, the individual fibres with FRP composites have relatively few defects, and any crack that forms in the composite matrix does not propagate across the fibre [12].

Figure (1): The series of the used seives.

Figure (2): The graded porcelinite aggregate.

Table (1): Selected grading of PLWA.

Sieve size (mm)	% Passing ASTM C330-2004[6]	Selected passing %
12.5	100	100
9.5	80-100	85
4.74	5-40	8
2.36	0-20	0
1.18	0-10	0

Table (2): Chemical and physical properties of PLWA [7, 8].

Property	Specification	Result
Specific gravity	ASTM C127-88	1.44
Absorption, %	ASTM C127-88	35
Dry loose unit weight, kg/m^3	ASTM C29-89	772
Dry ridded unit weight, kg/m^3	ASTM C29-89	830
Aggregate crushing value, %	BS 812 part 110-1990	16
Sulfate content (so_3), %	BS 3797 -part 2-1981	0.34
Staining materials:	ASTM C 641-82	No stain

Details of The Experimental Program

The experimental program consisted of nine one-way slabs of length 1500 mm, 300 mm width and 80 mm depth. A bottom concrete cover of 20 mm was used for all slabs. The slab specimens were casted using sand-PLWAC of grade 20 MPa. After casting, the specimens were allowed to cure for about 28 days which helps the concrete to stabilize its own properties like compressive strength and modulus of elasticity. Table 3 presents the mix proportions and properties of ingredients of concrete. Tables 4,5, and 6 present the mechanical properties of steel reinforcement, physical properties of the used cement and physical properties of the used sand respectively, where all tests were carried out in the material Lab. Civil engineering department, college of engineering, Basrah university.

Table (3): The mix proportions and ingredients of the selected sand-PLWAC mix.

Mix proportion (by weight)	1:1.031:0.978
W/C (by weight)	0.41
Cement (kg/m$^{3)}$	518
Sand (kg/m^3)	534
PLWAC (kg/m$^{3)}$	506
Water (kg/m$^{3)}$	212
f_{cu} 28-day (MPa)	24.4
f_c' 28-day (MPa)	20

Table (4): Properties of steel reinforcement.

Steel Reinforcement	Test Results	ASTM A615/A615M-04b, Standard[13]
Diameter, mm	8.0	-
Yield Tensile Strength, MPa	450	Not less than 420
Ultimate Tensile Strength, MPa	675	Not less than 620
Modulus of Elasticity, MPa	200000 (**Assumed value**)	-
Elongation, %	16	Not less than 9

Table (5): Physical properties of the cement.

Physical Properties	Test Result	Limits of IOS 5:1984[14]
Fineness (m^2/kg)	312	$\geq$ 230
Setting Time Initial (hrs:min) Final (hrs:min)	 2:10 4:00	 $\geq$ 45 min $\leq$ 10 hrs
Compressive Strength 3 days (MPa) 7 days (MPa)	 20.5 28.8	 $\geq$ 15 $\geq$ 23

Table (6): Physical properties of fine aggregate.

Physical Properties	Test Result	Limits of IOS No. 45/1984 [15]
Specific Gravity	2.65	-
Sulphate Content (SO_3) %	0.33	$\leq$ 0.5
Absorption %	1.1	-
Loose bulk density kg/m^3	1645	-

CFRP Installation

The mechanical properties of CFRP and epoxy resin were presented in Tables 7 and 8. The Installation of CFRP strips was conducted under the Manufacturer Specifications [16, 17]. The concrete surface of the slabs tension face was cleaned from lousy materials by a surface cleaning machine as shown in figure 3. Firstly, the two-parts of epoxy (A and B) was mixed in 4:1 ratio and the resulting material was gray paste. The epoxy mixer has been applied to the surface of concrete at location of CFRP strips to fill the cavities and to applied the CFRP strips at the surface of concrete.

Table (7): Properties of CFRP strips [16].

Material Type: Sika Warp Hex – 230C				
Tensile Strength MPa	Elongation at failure %	Tensile Modulus GPa	Thicknes s mm	Weight (g/m2)
3500	1.5	230	0.13	225

Table (8): Properties of epoxy resin (Sikadur-330) [16].

Appearance	Density (kg/l) mixed	Pot live (minute)	Tensile strength (MPa)	Flexural modulus (MPa)
Com A: white Com B: Gray	1.31	15C:90min 35C:30min	30	3800
Mixing Ratio by Weight, A:B = 4:1				

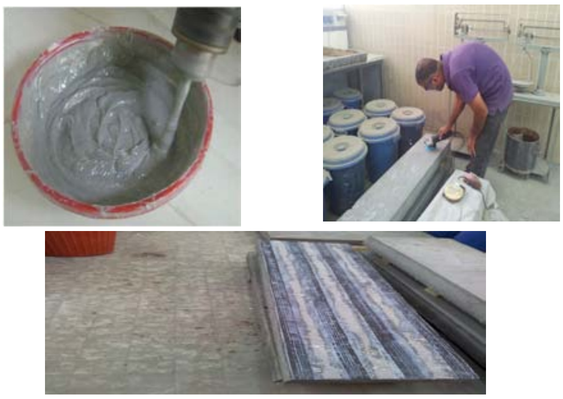


Fig. (3): Preparing and application of CFRP strips.

Experimental Set up for Static and Repeated Conditions

Nine simply supported one way slabs were tested under two line loads as shown in figures 4 and 5. Six slabs were tested under static loading and the other were tested under variable amplitude repeated loading. All slabs were tested using a hydraulic universal testing machine with a capacity of 2000 kN. A dial gauge was used at mid-span to monitor the deflection. Crack widths were measured using hand crack detection microscope. Under monotonic loading, the load was applied at a rate of 10 kN per step. By applying the variable amplitude repeated loading scheme, the slabs were subjected to five amplitudes with five cycles in each amplitude. In each amplitude, slabs were subjected to load cycles between a minimum amplitude load level (0 kN) and a maximum amplitude load level (ex. 20% of ultimate statics load in the first amplitude) in a slow rate about 1 kN per step. This procedure was followed up for all slabs till failure.

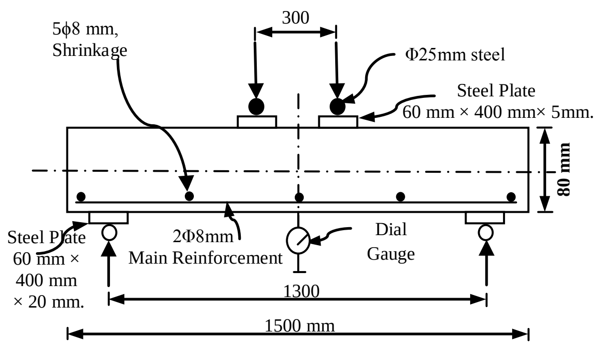
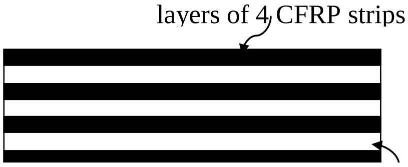


Fig. (4): Dimensions, Loading, Reinforcement Scheme

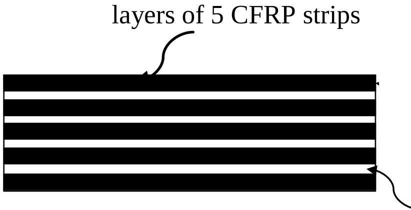
Fig. (5): Picture of the slab in the testing machine.

Details of Slabs

As shown in figure 6 below, the slabs details can be described as: **1. SS** and **SR**: Control un-strengthened sand-PLWA one way slab (OWS) under static and repeated loading respectively; **2. SS1CF4** and **SR1CF4**: Sand-PLWAC OWS strengthened with one layer of four CFRP strips of 30 mm width under static and repeated loading respectively; **3. SS1CF5** and **SR1CF5**: Sand-PLWAC OWS strengthened with one layer of five CFRP strips of 30 mm width under static and repeated loading respectively; **4. SSCF**: Sand-PLWAC OWS strengthened with one layer of CFRP strip of 300 mm width under static loading; **5. SS2CF4**: Sand-PLWAC OWS strengthened with two layers of four CFRP strips of 30 mm width under static loading; and **7. SS2CF5**: Sand-PLWAC OWS strengthened with two layers of five CFRP strips of 30 mm width under static loading.

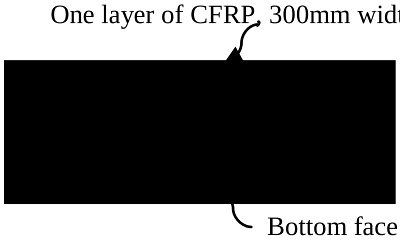


(a) SS1CF4, SR1CF4 and SS2CF4.



(b) SS1CF5, SR1CF5 and SS2CF5.

Fig.(6): CFRP Details.



(c) SS1CF

Fig. (6): Continued.

Static Test Results

1. General Behavior

Static first visible cracking loads, ultimate loads and failure modes are presented in Table 9. Under static loading, the first visible flexural cracks noticed at (30.2% to 36.5%) of failure load. These cracks appeared at the bottom surfaces whenever the tensile stresses exceed the modulus of rupture of concrete. For control un-strengthened slabs, the first crack appeared at the middle of the slab and developed across the width of the slab (i.e. parallel to the support). Further development of flexural cracks occurred parallel to this crack and propagated throughout the thickness of the slab on increasing the applied load. The flexural cracks were vertical smooth cracks initiated and propagated through the lightweight aggregates (LWA) and not around it. This is attributed to the smaller toughness of LWA, where the interfacial transition zone (ITZ) has higher tensile strength than LWA.

In strengthened slabs and with increasing the applied load, the cracking phenomenon at the soffit of the slab is degenerated in a multicracking pattern with much more closely-spaced cracks. This phenomenon increased with increasing the amount of CFRP strips, with the formation of secondary cracks (small diagonal branching cracks around the flexural cracks) as a result to the relative sliding between the CFRP strips and the adjacent concrete. This behaviour is very coincident with the results obtained by Bonaldo et al.[18]. In some strengthened slabs and outside the region between the applied loads, flexural – shear cracks were formed and extended towards the applied loads. Crack pattern and failure modes for the OWS are shown in figure 7.

Slabs strengthened with one layer of CFRP strips (SS1CF4, SS1CF5 and SSCF) failed by yielding of steel followed by abrupt rupture of CFRP strips. This is because that, at failure, the tensile strains developed in the CFRP strips attained its ultimate strain capacity. In some cases, the rupture of CFRP strengthened slabs accompanied by delamination of concrete cover within the region between the two applied loads. This may be attributed to the lower bond characteristics of the LWAC and the bond stress (interfacial shear stress at the concrete cover-internal reinforcement interface) that was too high to develop a shear / tension failure of the concrete attached to the CFRP strip at the edge.

Slabs strengthened with two layers of CFRP strips (S1D and S1E) failed by yielding of steel followed by debonding of CFRP strips that initiated near the center of the slab and propagates towards the end of the CFRP strip. This is due to the formation of the flexural cracks through the LWA that generate high interfacial shear stress, which can only be dissipated by debonding, in addition to the lower bond characteristics of the tension face of sand-PLWAC slab. This behaviour is well agreed with the result obtained by Elsayed et al. [19], and Wu et al. [20]. It is observed that all strengthened OWS showed a brittle failure mode in comparison to the control un-strengthened slabs. Under static loads, the strengthened slabs showed about (38 to 131%) and (66.7 to 140.9%) higher visible cracking and ultimate loads respectively than comparable control un-strengthened slab. This may be attributed to the presence of CFRP strips that share tensile strains with the concrete and hence delay the stress that exceeding the modulus of rupture of concrete (i.e. the CFRP strips restrained the tensile stresses).

2. Effect of CFRP Amount and Layers

The CFRP amount is the CFRP ratio (the ratio of the CFRP area to the surface area of the bottom tensile face of the slab) [21, 22]. The first cracking and ultimate load increases with increasing the amount of CFRP strips. Firstly, the CFRP amount increased by increasing the total CFRP area bonded to the tension face of the slab as in the case of SS1CF5, SS1CF, compared to SS1CF4. The effect of the amount of CFRP area is presented in Table 10. Slab SS1CF5 showed (18.8% and 6%) higher first cracking and ultimate load respectively compared to slab SS1CF4. While slab SS1CF showed (35.5% and 15.5%) higher first cracking and ultimate load respectively compared to slab SS1CF4.

Secondly, the amount of CFRP strips was increased by increasing the number of CFRP layers (doubling the CFRP strips layer). Slabs with two layers of CFRP strips (had the same total surface area of CFRP strips, as shown in Table 10) showed a considerable increasing in the first cracking and ultimate load, as shown in Table 9 above. Slab SS2CF4 showed (46.3% and 38.9%) higher first cracking and ultimate load respectively compared to slab SS1CF4. At the same time, slab SS2CF5 showed (41.1% and 36.3%) higher first cracking and ultimate load respectively compared to slab SS1CF5.

Table (9): Static first visible cracking and ultimate loads for sand-PLWAC OWS.

Slab designation	P_{cr} (kN)	P_u (kN)	$(P_u-P_{uo})/P_{uo}$ %	P_{cr}/P_u %	Failure Mode
SS	5.8	15.9	-----	36.5	YS
SS1CF4	8.0	26.5	66.7	30.2	ROC
SS1CF5	9.5	28.1	76.7	33.8	ROC
SSCF	10.8	30.6	92.5	35.3	ROC
SS2CF4	11.7	36.8	131.4	31.8	DOC
SS2CF5	13.4	38.3	140.9	35.0	DOC
P_{cr} = Visible cracking load; P_u = Ultimate load;			YS= Yielding of Steel; ROC= Rupture of CFRP DOC=Debonding ofCFRP		

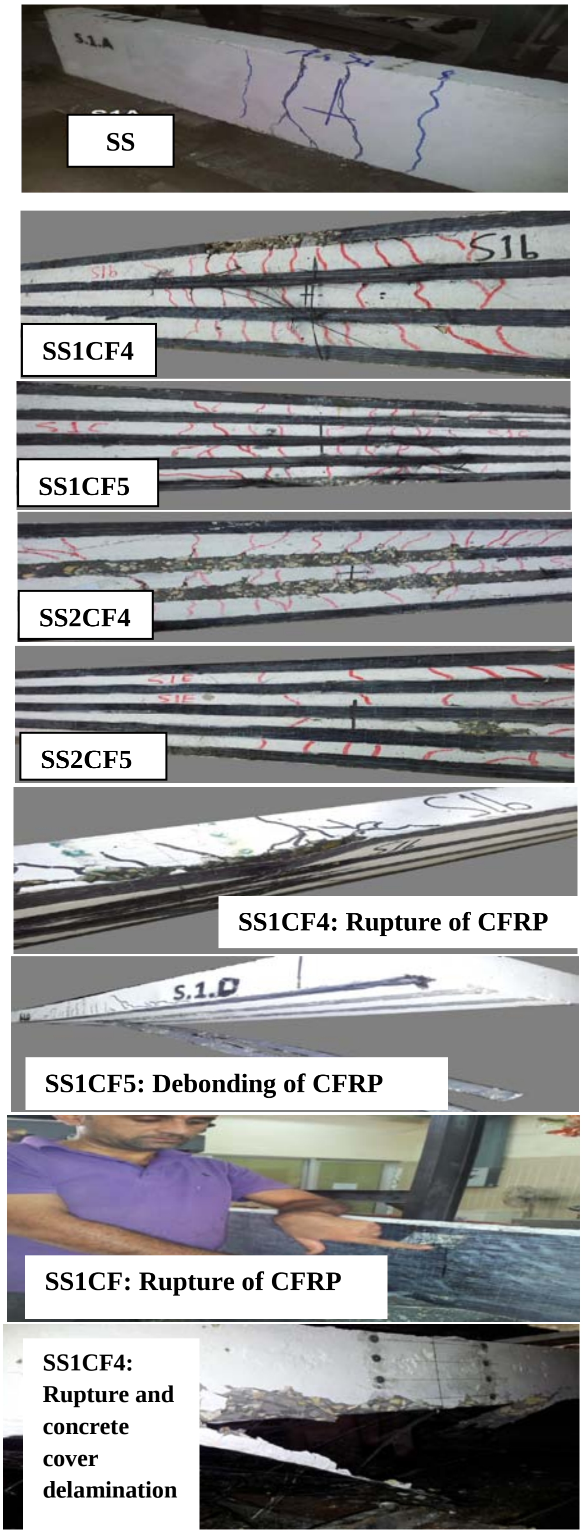


Fig. (7): Crack Patterns and Failure modes of strengthened sand-PLWAC OWS under static loading.

It can be seen that the most significant parameter on strengthening ratio is the number of layers of the external CFRP strips where the CFRP strain seems to decrease with increasing number of CFRP strip layers.

OWS Designation	A_T* mm^2 $\times 10^4$	A_{FRP}** mm^2 $\times 10^4$	A_{FRP} / A_T %	$(P_{cr}-P_{crs})/P_{crs}$ %	$(P_u-P_{us})/P_{us}$ %
SS1CF4	45	18	40	-	-
SS1CF5		22.5	50	18.8	6
SS1CF		45	100	35	15.5

A_T**= Surface area of tension face slab; *A_{FRP}**= Total surface area of CFRP strips; **P_{cr}**= First Cracking Load of the strengthened slab; **P_{crs}**= First Cracking Load of the control strengthened slab (SS1CF4); **P_u**= Ultimate Load of the strengthened slab; and **P_{us}**= Ultimate Load of the control strengthened slab (SS1CF4).

3. Deflection

Deflection was measured at mid span of the slabs at different loading stages. The maximum deflections at failure were not obtained to avoid dial gauge damage. From figure 8, and after the linear range, it can be noticed that the strengthened slabs exhibit less midspan deflection than control un-strengthened slab at all loading stages. This decrease in deflection for strengthened slabs is attributed to the bridging of the slab tension face provided by the bonded CFRP strips. The moment-deflection response for each slab is plotted in figure 9. It can be seen that the strength and stiffness of the strengthened slabs are increased with less ductility. The reduction in ductility increased with increasing CFRP amount. Also, the bridging effect in slabs SS2CF4 and SS2CF5 showed a considerable increase compared to slabs SS1CF4 and SS1CF5. Also, this implies that the increase of CFRP amount by increasing the number of CFRP strips layers is more effective in enhancing the flexural capacity.

4. Crack Patterns

Typical cracking patterns of sand-PLWAC OWS after failure are shown in figure 7. Figure 10 presents the crack width load relations for control and strengthened slabs. This figure shows that strengthened slabs have cracks width slightly less than control un-strengthened slabs. This may be attributed to the first crack load of strengthened slabs greater than that of control un-strengthened slabs.

10

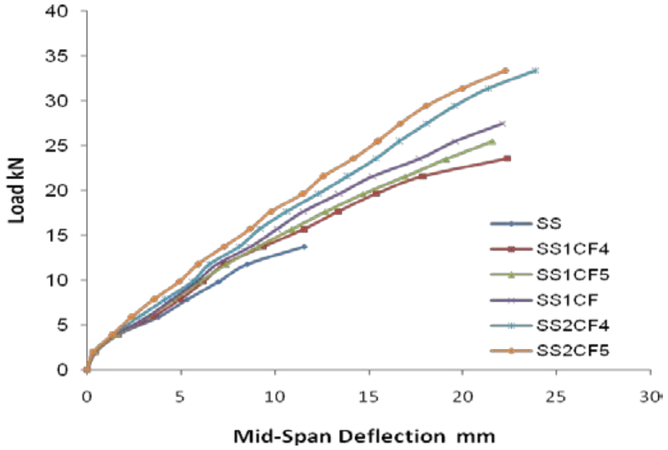


Fig. (8): Static Load – midspan deflection curves.

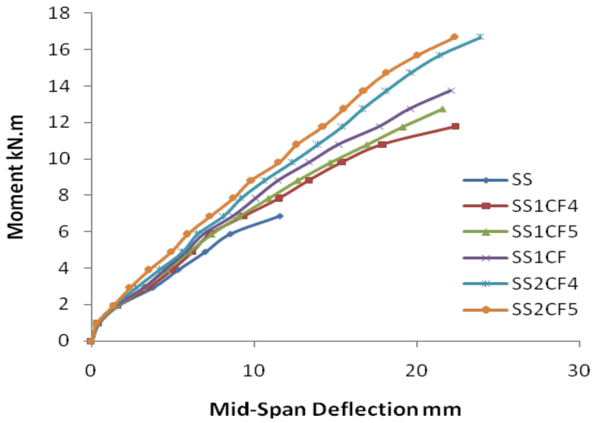


Fig. (9): Static Moment – midspan deflection curves.

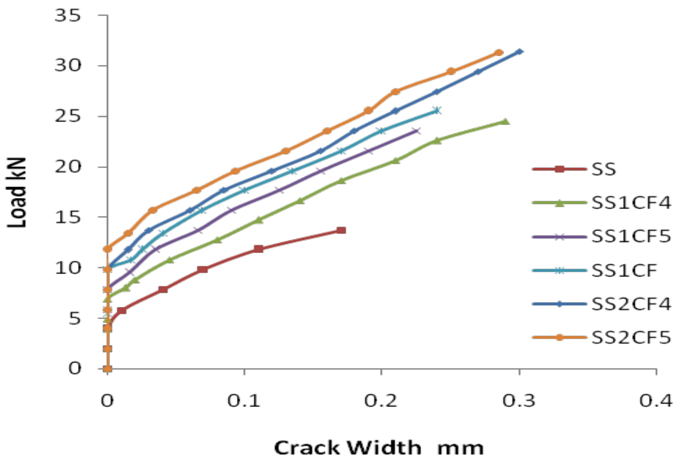


Fig. (10): Load-crack width curves for sand-PLWAC OWS under static loading.

Repeated Test Results

1. General Behviour

Three sand-PLWAC OWS were subjected to variable amplitude of repeated loading scheme. Table 11 shows the ultimate static and repeated loads with the failure modes, where P_{ur} is the repeated ultimate load of the strengthened slabs and P_{uro} is the repeated ultimate load of the control un-strengthened slab.

Table (11): Repeated ultimate loads and failure mode of sand-PLWAC OWS.

Slab Designa-tion	P_u (kN)	P_{ur} (kN)	$(P_{ur}-P_{uro}) / P_{uro}$ %	(P_{ur}/P_u) %	Failure Mode
SR	15.9	13.7	-----	86.2	Yielding of Steel
SR1CF4	26.5	23.4	70.8	88.3	Rupture of CFRP
SR1CF5	28.1	24.2	76.6	86.1	Rupture of CFRP

For all specimens, the loading and reloading was conducted for 20 load cycles, where failure occurred within the load cycle number 21. The control un-strengthened slab SR failed by yielding of steel followed by crushing of concrete (as in the static loading). The strengthened slabs failed by yielding of steel reinforcement followed by rupture of CFRP strips at the edge of the slab and debonding of interior CFRP strips. Under repeated loading, the ultimate load at which failure occurred in strengthened sand-PLWAC OWS was about 86.9% of the corresponding ultimate static loads. This indicates a good repeated loading performance for un-strengthened, strengthened sand-PLWAC OWS. The first visible flexural crack noticed at (22.6% to 32.2%) of failure load. In general, these ratios were less than those under static loading.

For control and strengthened slabs, the initiation and development of visible cracks under repeated loading, is very similar to that under static loading discussed before, except that the development and propagation of cracks under repeated loading occurred due to the increase in the number of load cycles. First visible cracking loads together with the ultimate loads are illustrated in Table 12. Based on repeated cyclic loading results, it is observed that with increasing the number of load cycles, the corresponding ultimate deflection, number of cracks and the width of these cracks increase. It is also noted that the magnitude of damage accumulated to the un-strengthened control slabs is higher than CFRP strengthened slabs. Repeated Crack pattern and failure modes for the strengthened OWS are presented in figure 11.

At ultimate repeated load, CFRP strengthened slabs (SR1CF4 and SR1CF5) failed by yielding of steel followed by rupture of CFRP strips at the edge of the slab and then by debonding of interior CFRP strips (that initiated near the center of the slab and propagates towards the end of the CFRP strip). It can be noted that the failure of these slabs under static loading was by yielding of steel followed by rupture of CFRP strips and there was no debonding. Slabs failure modes are presented in figure 11.

Table (12): Repeated first crack and ultimate loads of sand-PLWAC OWS.

One Way Slab designation	Visible Repeated Crack Load		Ultimate Repeated Load		P_{crr} / P_{ur} %
	N_{cr} *	P_{crr} ** (kN)	N_{ur} +	P_{ur} ++ (kN)	
SR	5	3.2	21	13.7	23.4
SR1CF4	5	5.3	21	23.4	22.6
SR1CF5	6	7.8	21	24.2	32.2

* $\mathbf{N_{cr}}$ = Number of Cycle at which the first visible crack was initiated;   ** $\mathbf{P_{crr}}$= First visible crack load under repeated loading;

+ $\mathbf{N_{ur}}$= Number of cycle at which failure occurred under repeated loading;   **++** $\mathbf{P_{ur}}$**=** Ultimate repeated load of the strengthened slabs.

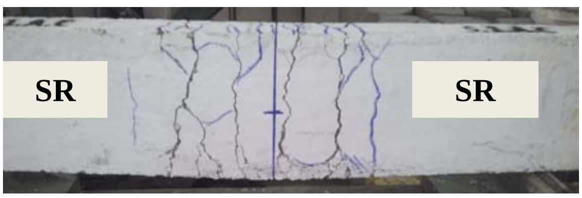


Fig. (11): Crack patterns and Failure modes of strengthened sand-PLWAC OWS under repeated loading.

Fig. (11): Continued.

Strengthened slabs showed (65.6% to 143.8%) and (70.8 to 76.6%) higher visible repeated cracking and ultimate loads than comparable control un-strengthened slab. This may be attributed to that with continuing and increasing the cyclic applied load, the stress in the whole slab redistributes and the CFRP shares more stress transferred from the slab to keep the force of the whole slab balanced [23].

2. Effect of CFRP Amount

The repeated first cracking and ultimate load increases with increasing the amount of CFRP strips. Slab SR1CF5 showed (47.2% and 3.4%) higher first visible cracking and ultimate load respectively compared to slab SR1CF4. It can be noticed that, the concrete still under repeated loading for a considerable period while it is cracked; this will lead to reduce its ultimate capacity compared to the static condition.

3. Deflection

The static and repeated load-midspan deflection curves in addition to the envelope were plotted in figure 12. The envelope is a curve joining the peak points of the repeated load- midspan deflection curve. The area within the cycle of the load-deflection curve is a critical parameter for repeated response because it is a measure of the energy dissipated through the repeated loading [24]. Figure 12 shows that under repeated loading, the strengthened OWS slabs exhibit less midspan deflection than control un-strengthened slabs at all loading stages due to the bridging effect of CFRP strips.

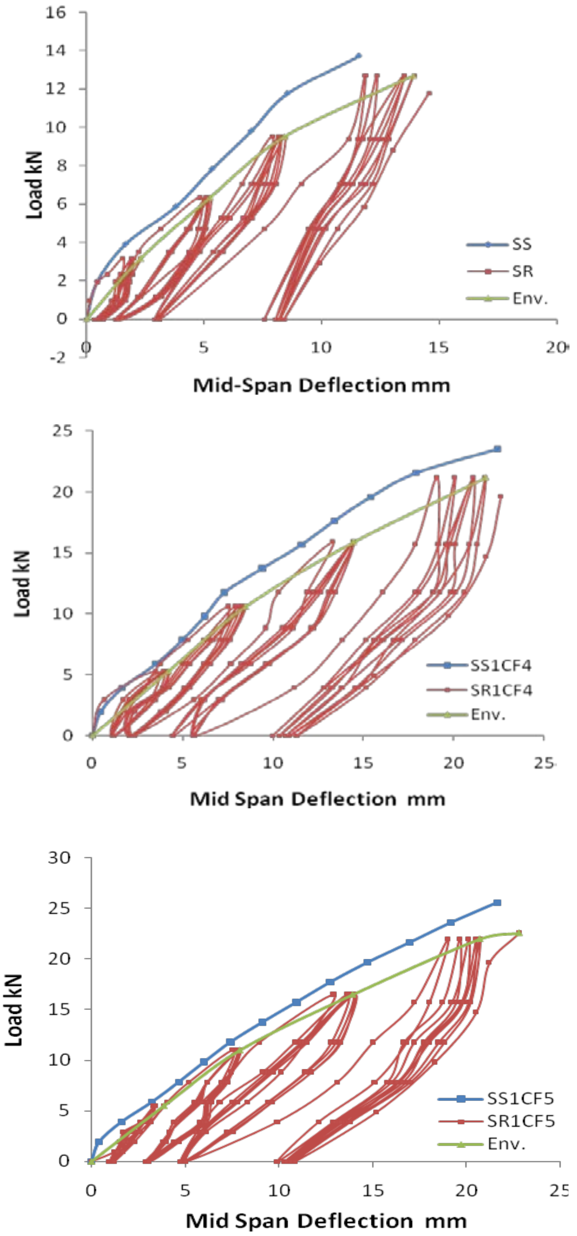


Fig. (12): Load-midspan deflection curves for sand-PLWAC OWS under repeated loading.

4. Crack Patterns

Crack patterns of sand-PLWAC OWS at ultimate repeated load are shown in figure 11. Figure 13 presents crack width repeated load relations in addition to the envelope. In the same loading stage, the strengthened slabs have cracks width less than control un-strengthened slabs and the cracks width of the un-strengthened and strengthened slabs under repeated loading were greater than those of the corresponding slabs under static loading. Also, the increasing of CFRP amount decrease the cracks width.

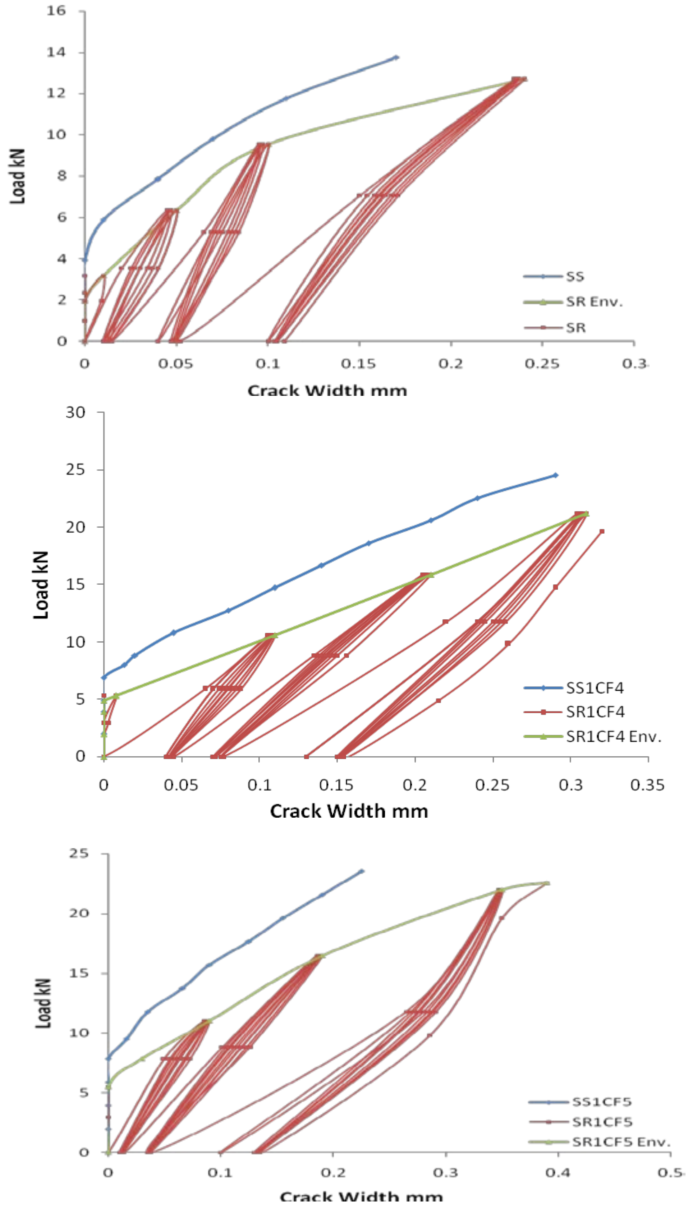


Fig. (13): Repeated load-crack width curves for sand-PLWAC OWS.

Conclusions

The following conclusions can be drawn as follows**:**

1. In general higher ultimate loads were achieved for sand-PLWAC one way slabs strengthened with CFRP strips as compared with control un-strengthened slab under monotonic and repeated loading. Under monotonic loading, the strengthened sand-PLWAC OWS showed an increase in the ultimate load of about 78.0% for the single CFRP layers specimens and about 130.0% for the double CFRP layers slabs, both compared to the control un strengthened slab. Under repeated loading, the enhancement of the flexural strength of the strengthened sand-PLWAC OWS was about 71.0% , compared to un strengthened control slab.
2. Under repeated loading, the sand-PLWAC OWS showed a good performance compared to static loading. The average repeated failure load of one way slabs was about 84.5% of the corresponding ultimate static load.
3. The failure of sand-PLWAC OWS under static and repeated loading was by rupture or debonding of CFRP strips.
4. The ultimate static and repeated failure load of the strengthened sand-PLWAC OWS increased with the increasing of the amount of CFRP strips. At the same time, the increasing of CFRP strips layers was more effective in enhancing the monotonic flexural capacity compared to the increasing of total CFRP surface area.
5. A decrease in the cracks width due to presence of CFRP strips is occurred under static and repeated loading for sand-PLWAC one way slabs. This reduction was about 50% and 43% under static and repeated loading respectively. A stiffer static and repeated load-deflection response is observed for sand-PLWAC one way slabs strengthened with CFRP strips as compared with response of control un-strengthened slab.

References

1. Rahman, M. M., and Jumaat, M. Z., 2013, " The Effect of CFRP Laminate Length for Strengthening the Tension Zone of the Reinforcement Concrete T-Beam", Journal of Scientific Research & Reports, Article no. 2013.012, pp. 626-640.
2. Irwin, R., and Rahman, A., 2002, " FRP Strengthening of Concrete Structures-Design Constraints and Practical Effects on Construction Details", Construction Techniques Group Ltd, Zurich, Research Report 2002-9, pp. 8-32.
3. Zadeh, B., and Azmirad, H., 2005, " Structural Lightweight Concrete Production Using Eskandan Region Pumice", CI-Premier PTE LTD, 30th Conference on our World in Concrete & Structures: 23-24 August 2005, Singapore, Article no. ld:100030024, pp. 152-157
4. NRMCA , 2006, “Concrete in Practice: What, Why and How?”, CIP 36, Structural Lightweight Concrete, pp. 84.
5. ACI Committee-318, 2011, “Building Code Requirements for Structural Concrete (ACI 318M-11) and Commentary”, American Concrete Institute, Farmington Hills, MI 48331, USA, pp. 30.
6. American Specifications for Testing Materials, ASTM C330-2004.
7. AL-Musawi, J.M., 2004, “Flexural Behavior of Porcelinite Reinforced concrete Beams”, Ph.D. Thesis, University of Technology, Baghdad, Iraq.
8. SCGSM Laboratory Sheet, “Chemical Properties of Porcelinite Rock”, the State Company of Geological Survey and Mining, Baghdad, Iraq.
9. Sivagamasundari, R. and Kumaran, G., 2008, “A Comparative Study on the Flexural Behavior of One Way Concrete Slabs Reinforced with GFRP Reinforcement and Conventional Reinforcement when Subjected to Monotonic and Repeated Loading”, The Open Civil Engineering Journal, Vol. 2, Bentham Science Publishers Ltd., India, pp. 24-34.

10. Dimitrios, D., 1980, “Punching Shear Strength of Steel Fiber Reinforced Lightweight Concrete Slabs”, Ph.D. Thesis, Department of Civil and Structural Engineering, Faculty of Engineering, University of Sheffield.

11. Zhang, J., Li, V.C., and Stang, H., 2001, “Size Effect on Fatigue in Bending of Concrete”, Journal of Materials in Civil Engineering, Vol. 13, No. 6, pp. 446-453.

12. Papakonstantinou, C. G., Petrou, M. F. and Harries, K. A., Papakonstantinou, C. G., Petrou, M. F. and Harries, K. A., 2001, “fatigue Behavior of RC Beams Strengthened with GFRP Sheets”, Journal of Composites for Construction, Vol. 5, No. 4, pp. 246-253.

13. ASTM A615/A615M-04b, “Standard Specification for Deformed and Plain carbon Steel Bars for Concrete Reinforcement”, 2004, pp. 1-6.

14. Iraqi Standards No. 5/1984, “Ordinary Portland Cement”, Ministry of Housing and Constructions, Baghdad, 2004.

15. Iraqi Standards No. 45/1984, “Aggregate from Natural Sources for Concrete and Construction”, Ministry of Housing and Constructions, Baghdad, 2004.

16. Products Catalog, Innovation and Consistency, Product Data Sheet, Edition 6, 2010, Version No. 08. 06, pp.65.

17. Manos, G.C., Stavroy, D.S., Dimosthenous, M.A., and kourtides, B., 2044, “Expermental and Analytical Investigation of Repaired and Strengthened Reinforced Concrete Structural Elements Utilizing CFRP”, 1^{3th} World Conference on Earthquake Engineering , Vancouver, B. C., Canada, pp. 91.

18. Bonaldo, E., Barros, J.A., and Lourenco, P.B., 2007, “Influence of the Spacing Between NSM-CFRP Lamenates on the Flexural Strengthening Efficacy of RC Slabs”, FRPRCS-8, University of Patras, Patras, Greece, pp. 1-11.

19. Elsayed, W., Ebead, U.A., and Neale., 2007, “Interfacial Behavior and Debonding Failures in FRP-Strengthened Concrete Slabs”, Journal of Composites for Construction, Vol. 11, No. 6, pp. 619-628.

20. Wu, C.H., Kan, Y.C., Huang, C.H., Yen, T., and Chen, L.H., 2011, “Flexural Behavior and Size Effect of Full Scale Reinforced Lightweight Concrete Beam”, Journal of Marine Science and Technology, Vol. 19, No. 2, pp. 132-140.

21. Nanni, A., and Gold, W., 1998, “Strengthening of RC Flexural Members with FRP Composites”, Repaired and Rehabilitation of Reinforced Concrete Structures: The State of the Art, ASCE, LCCC No. 97-31657, ISBN 0-7844-0299-X, USA, pp 144-154.

22. Arduini, M., Nanni, A., and Romagnolo, M., 2004, “Performance of One-Way Reinforced Concrete Slabs with Externally Bonded Fiber-Reinforced Polymer Strengthening”, Technical Paper, ACI Structural Journal, Title No. 101-S19, pp. 193-201.

23. Shfigh, P., et. al., 2011, “An Investigation of the Flexural Behavior of Reinforced Lightweight Concrete Beams”, International Journal of the Physical Sciences, Vol. 6(10), pp. 2414-2421.

24. Anwar, A.K.G., 2008, “Behavior of Fiber Reinforced Ferrocement Slabs Under Static and Cyclic Loading”, Ph.D. Thesis, Building and Construction Engineering Department, University of Technology, Baghdad, Iraq.

View publication stats