EFFECT OF FIBERS TYPE ON FLEXURAL BEHAVIOR OF HIGH PERFORMANCE CONCRETE BEAMS UNDER REPEATED LOAD

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Received 29 September 2013; November 21 October 2013

ABSTRACT

The need of high performance concrete HPC is increasing in the recent years. This material becomes necessary, but it is brittle. So, fibers are used to enhance mechanical properties of HPC. The enhanced properties include tensile strength, compressive strength, elastic modulus, crack resistance, crack control, durability, fatigue life, resistance to impact and abrasion, shrinkage, expansion, thermal characteristic, and fire resistance of concrete. The main objective of this research is to study the effect of using Harex, polypropylene and glass fibers on flexural behavior of High performance concrete beams under static and repeated loads.

Keywords: high performance concrete, beams, harex fiber, polypropylene fiber, glass fiber, static loading, repeated loading

1. Introduction

Concrete being a brittle material has low tensile strength and low strain capacity, as a result, the mechanical behaviour of the concrete is critically influenced by crack propagation. Concrete in service may exhibit failure through cracks which are developed due to brittleness [K. komlos, B. Babal, and T. Nurnbergerova. 1995]. To improve properties of concrete like low tensile and low strain capacity, fiber reinforced concrete (FRC) has been developed which is defined as concrete containing dispersed randomly oriented fibers [Johnston C.D. 1974].

Fibers had been used to reinforce cementitious material since ancient times, sun-backed bricks were reinforced by using straw as fiber and masonry mortar and plaster were reinforced using horsehair. Experimental investigation involving the use of discontinuous fibers to improve the properties of concrete was started in 1910 [Naaman A. E. 1985]. During the early 1960, the first major investigation was made to evaluate the potential of steel fibers as reinforcement of the concrete [Romualdi, J. P. and Batson G. B. 1963].

The properties of concrete matrix and of the fibers greatly influence the character and performance of FRC. The properties of fibers which are of interest include fiber stiffness, bond between fiber and concrete matrix, fiber concentration, fiber geometry, fiber orientation, fiber distribution and fiber aspect ratio [John E. Bolander 2004].

The mixture-stiffening or workability effect is a major factor limiting the type, aspect ratio and amount of fibers that can be uniformly distributed throughout a particular cementitious matrix, which in turn determine the degree of improvement in the mechanical properties of composites in hardened state. Ideally the amount of fibers and aspect ratio

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should be as large as possible to maximise the improvements in the mechanical properties. On the other hand, both should be as small as possible (but compatible with aggregate size) to minimise the mixture-stiffenin effect of fibers and associated difficulties in fabricating components from FRC [Johnston C. D. 1996].

FRC has been used for numerous applications throughout the construction industry, such as in highways and airport runways, in shotcrete tunnel wall linings, as minimum shear and transverse reinforcement in precast bridge sections and decks, and in slabs-on-grade (Wang et al., 1987; Meda et al., 2005; Minelli, 2005). Steel fibres have also seen limited use in framed slabs and in other flexure-critical structural members (Meda et al., 2005). However, FRC has not been substantially utilized in more critical structural elements (Richardson and Landless, 2009). This is likely attributable to the limited development of rational design codes and standards needed to build the confidence of practitioners in the benefits and application of the material (Lee et al., 2013; Noghabai, 2000).

The main objective of this research is to predict the behavior of high performance R.C concrete beams under static and repeated loads taking the effect of adding different type of fibers on the flexural behavior of high performance R.C concrete beams.

2. Experimental Work

Eight beams were tested with main steel diameter 2#18mm having rectangular cross section equal to 12×30 cm as shown in fig(1). The considered span for all tested beams were 240cm as showen in fig (1). The study takes in to consideration the following parameters:

1. Type of loading (static and repeated).
2. Types of fibers (Harex, polypropylene and glass).

1. Group of beam without fibers under static load

group	fibers%	fiber type
B-S0	-	-

2. Group of beams with fibers under static load

group	fibers%	fiber type
B-Sh	3	harex fiber
B-S_p	3	polypropylene fiber
B-Sg	3	glass fiber

3. Group of beam without fibers under repeated load

group	fibers%	fiber type
B-R0	-	-

4. Group of beams with fibers under repeated load

group	fibers%	fiber type
B-Rh	3	harex fiber
B-R_p	3	polypropylene fiber
B-Rg	3	glass fiber

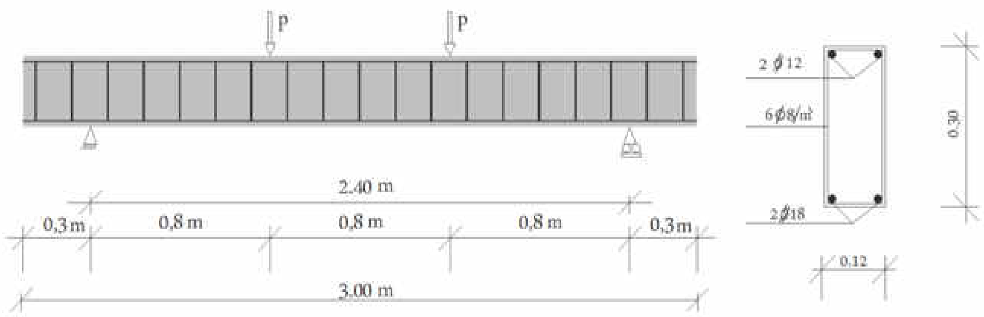

Fig. 1. Beam cross section and reinforcement

2.1 Materials

2.1.1 High performance concrete (H.P.C)

Concrete mix design was made to produce high performance concrete (H.P.C) with grade 600kg/cm^2 and its components are given in table (1).

Table1.
Concrete mix proportion.

concrete	**Cement** kg/m^3	**Silica-fum** kg/m^3	**Water** liter/m^3	**Superpl.** liter/m^3	**Fine aggregate** kg/m^3	**coarse aggregate** kg/m^3	**Vf** /m^3
C	500	110	160	17.5	531	1000	3%

2.1.2 Fiber types and its properties

The study concerned with metallic fibers (harex fiber) and non-metallic fibers (polypropylene and glass). The shape of fibers as shown in Fig. (2), typical properties of various types of the metallic and non-metallic fibers are given in Table (2).

1. Harex steel fiber

2. Polypropylene

3. Glass fiber

Fig. 2. Fibers type used in beams.

Table 2.
Typical properties of fibers.

Type of fiber	**Diameter (µm)**	**Length (mm)**	**Density (gm/cm3)**	**Tensile Strength kg/cm2**	**Young's modulus kg/cm2**	**Elongation (%)**
Harex steel fiber	1000	32	7.8	$2*10^4$	$2*10^6$	3
Polypropylene fiber	2-20	18	0.91	$0.5*10^4$	$0.5*10^5$	8-10
Glass fiber (Cem-Fil)	2-20	12	2.7	$2.5*10^4$	$8*10^5$	3.6

2.2 Test procedure

2.2.1 Static loading

Four beams were tested at ages of 28 days under static loading; each of the tested beams was loaded by a minimum load with increment of 0.5 tons; This minimum load was kept constant between two successive increments for about five minutes. During this period, readings of the electrical strain gauges for concrete and steel strain, dial gauges for deflection, and the cracks propagation were recorded at the beginning and at the end of each increment of loading.

2.2.2 Repeated loading

The available testing machine (EMS 60 tons P_u) was used in repeated load. The testing machine gives a frequency changeable between 300 and 750 load cycle per minute. The stroke of the working piston is adjustable between zero and six mms.

During the fatigue tests the frequency was chosen to be 500 cycle per minute and the chosen stroke of the working piston was 0.2 mm. The selected testing machine is provided with heavy steel tare through which the applied load was transmitted to the tested beam. The own weight of the testing machine tare is 1.4 tons. This weight was released in the rest on time of tested beams.

The remaining four repeated loading beams were tasted under 60% of the ultimate static loading tests result. Beams loaded until 1 million cycles loading after that loaded with static load up to failure. Repeated test was summarized on Fig.(3) where the tested beam was firstly subjected to a static cycle , part 1-2 . After that strokes were began part 2-3 after 0.5 million cycle the load released gradually to zero load part 3-4. The statically loading again from zero to the level of load part 4-5, After that strokes were began part 5-6 and after another 0.5 million cycle. After complete 1 million cycle the loading case is to be static and increased to the end of beam life.

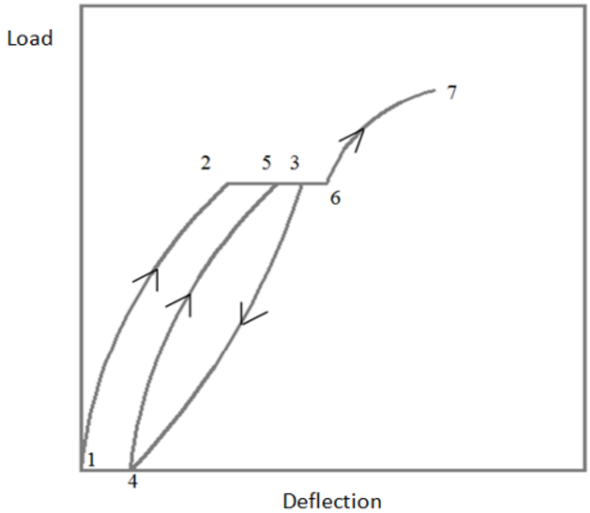

Fig 3. The repeated loading was summarized in this chart.

2.3 Measured strains of concrete and steel

Strains of concrete and steel were measured by means of electrical strain gauges at the shown positions in Fig (4).The gauge length was 52mm, and the 800mm resistance was 600 ohms and gauge factor (2 ± 0.75%) . Strain gauges were connected to strain indicator with its box résistance. The deflection was measured by dial gauge with accuracy of 0.01mm fixed at the position of maximum deflection for each beam as shown in fig (4).

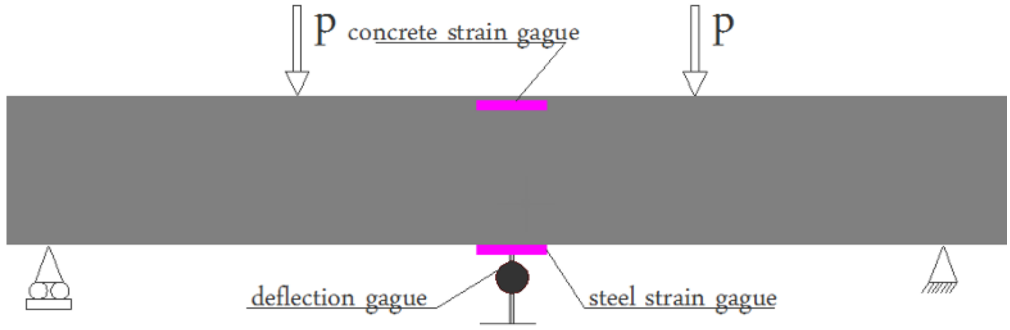

Fig. 4. Method of measuring deformation of beams

3. Test Result

3.1 Crack pattern and mode of failure

The crack pattern and mode of failure are explained for the tested reinforced high performance concrete (H.P.C) beams. Eight rectangular (H.P.C) reinforced concrete beams tested under static and repeated loading. The cracking and ultimate loads were summarized at table (3) and mode of failure was as follow:

1. <u>Group of Beams Without Fiber</u>

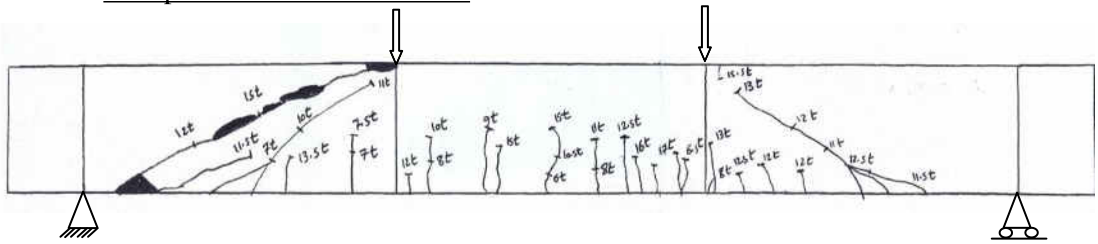

Fig. 5. Crack pattern of beam (Bs_0) [static load]

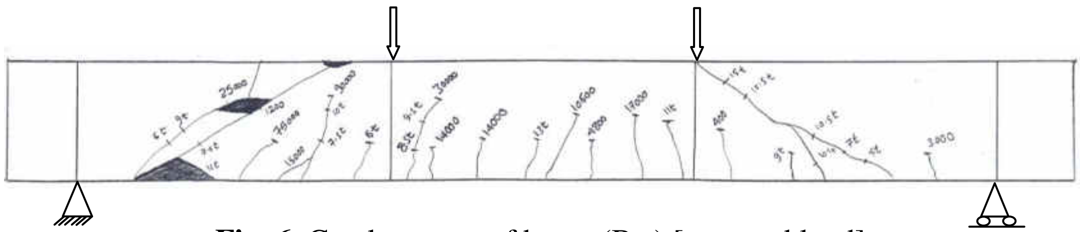

Fig. 6. Crack pattern of beam (Br_0) [repeated load]

2. Group of Beams with Harex Fibers

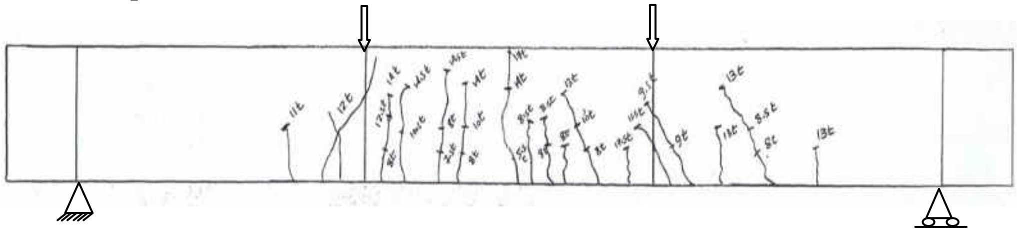

Fig. 7. Crack pattern of beam (Bsh) [static load]

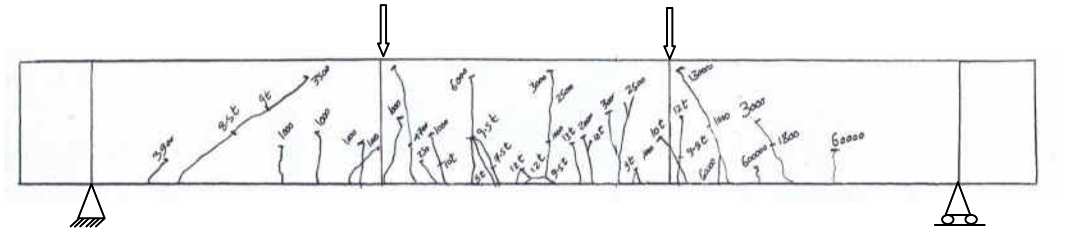

Fig. 8. Crack pattern of beam (Brh [repeated load])

3. Group of Beams with Polypropylene Fibers

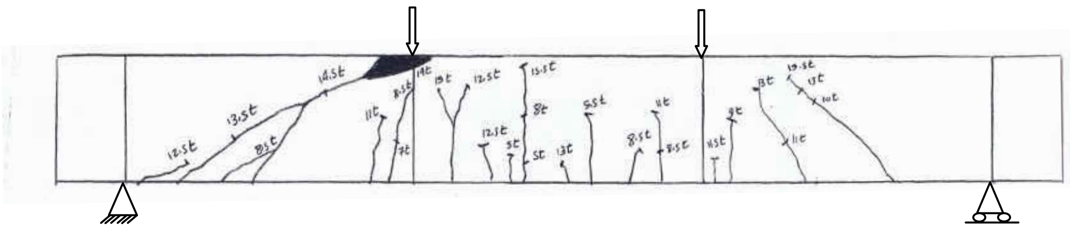

Fig. 9. Crack pattern of beam (Bsp [static load])

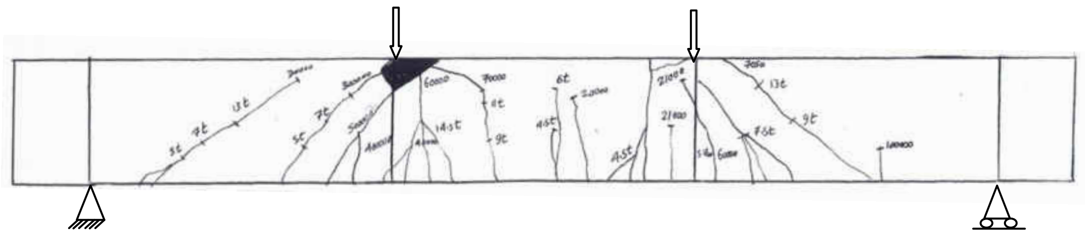

Fig. 10. Crack pattern of beam (Brp) [repeated load]

4. <u>Group of Beams with Glass Fibers</u>

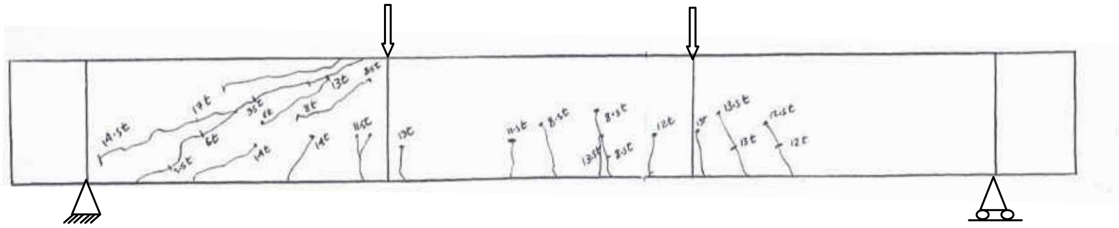

Fig. 11. Crack pattern of beam (Bsg) [static load]

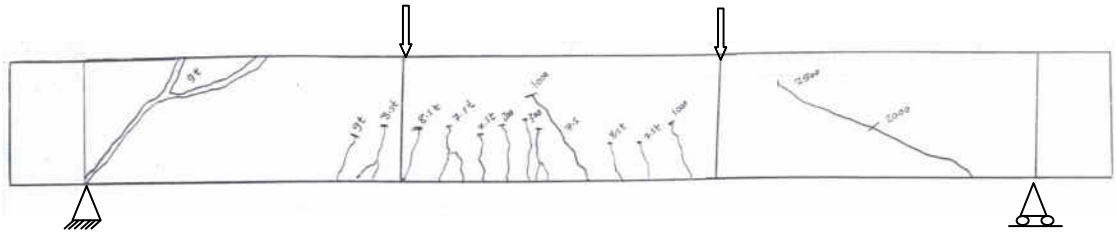

Fig. 12. Crack pattern of beam (Brg) [repeated load]

Table 3.
Cracking and ultimate loads for tested beams under static and repeated loads.

Group	series	Type of fibers	F_C	P_{cr} (ton)	Q_{cr} (ton)	P_u (ton)	Mode of failure
static	Bs0	Without fibers	534	4	5	15.2	shear failure
	Bsh	Harex fibers	721	5.1	8.5	17.5	flexural failure
	Bsp	Poly. fibers	618	4.6	7	16.4	shear flexural failure
	Bsg	Glass fibers	412	4.3	5	14.5	shear failure
repeated	Br0	Without fibers	534	4	5	15	shear failure
	Brh	Harex fibers	721	5.1	8.5	17.7	flexural failure
	Brp	Poly. fibers	618	4.6	7	16.5	shear flexural failure
	Brg	Glass fibers	412	4.3	5	8.7 at 0.25 million cycle	shear failure

3.2 Deflection characteristics

The measured values of maximum deflection are plotted versus the applied load from starting the loading up to failure as shown in Fig. (13),(14). All plotted values indicated that, the deflection increases as the applied load increases.

3.2.1 Beams tested under static loads

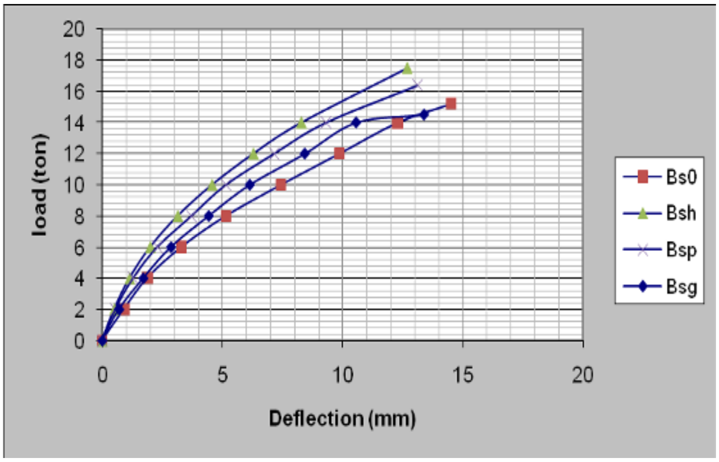

Fig. 13. Load - Mid Span Deflection relationship for beams tested under static loads.

3.2.2 Beams tested under repeated loads

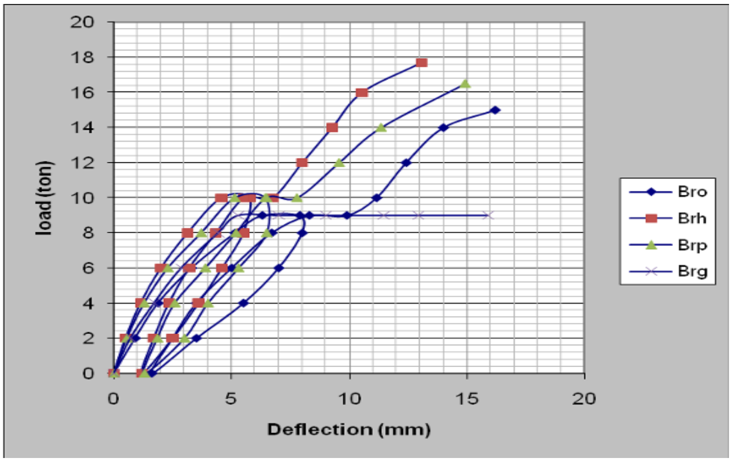

Fig. 14. Load - Mid Span Deflection relationship for beams tested under repeated loads.

3.3 Concrete Strain Distribution.

Figure (15),(16) shows the behavior of the concrete strain in compression for all beams. The results indicated that all specimens presented almost have the same trend where as the load increased, the strain also increased.

3.3.1 Beams tested under static loads

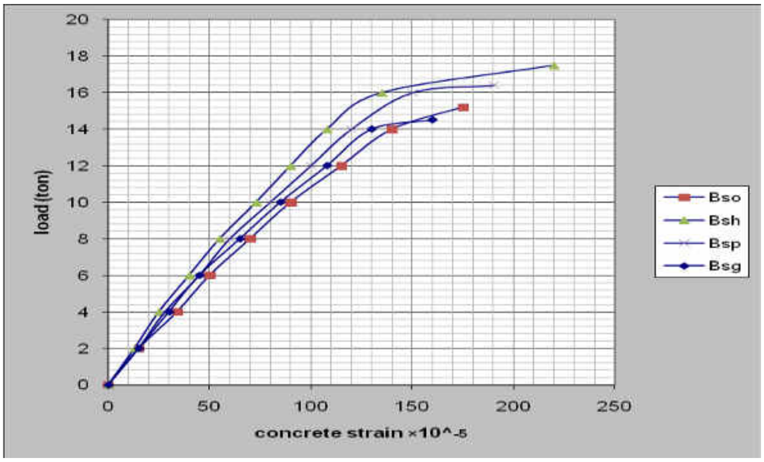

Fig. 15. Concrete Strain Distribution for beams tested under static loads.

3.3.2 Beams tested under repeated loads

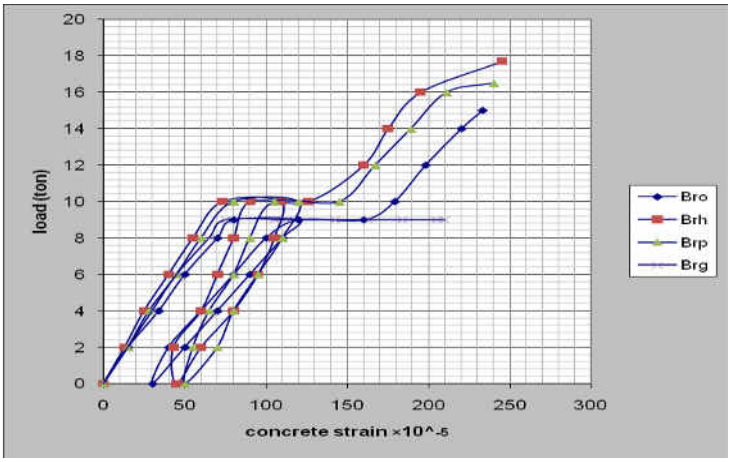

Fig. 16. Concrete Strain Distribution for beams tested under repeated loads.

3.4 Steel Strain Distribution

Figure (17),(18) shows the behavior of the steel strain in compression for all beams. The results indicated that all specimens presented almost have the same trend where as the load increased, the strain also increased.

3.4.1 Beams tested under static loads

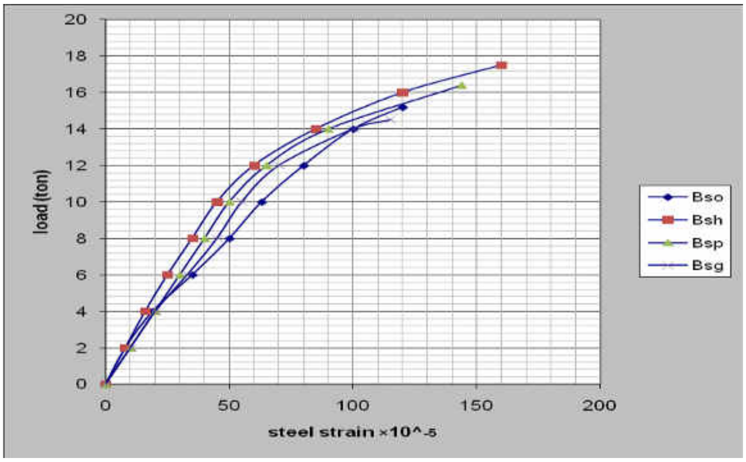

Fig. 17. Steel Strain Distribution for beams tested under static loads

3.4.2 Beams tested under repeated loads

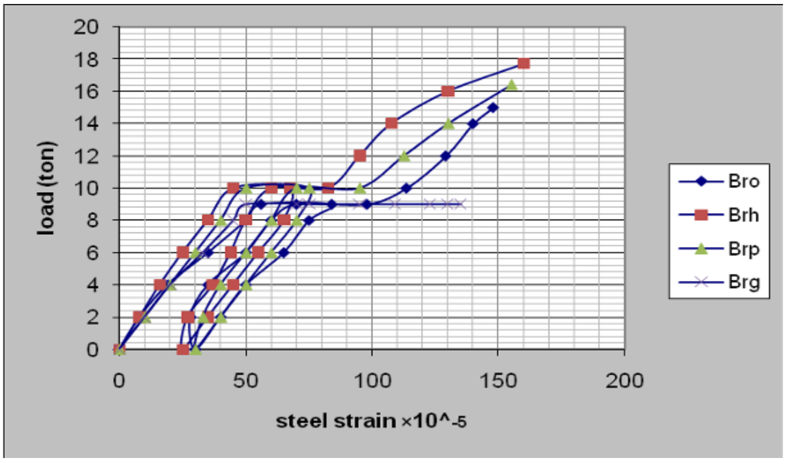

Fig. 18. Steel Strain Distribution for beams tested under repeated loads.

4. Discussion of Test Result

This item describes and interprets the analysis of the obtained test results of the HPC beams. The analysis includes the relationship between the value of cracking and ultimate loads, deflection, concrete strain and steel strain for tested beams. The characteristic of tested beams at cracking,*cracking shear load,* 0.6 ultimate load and ultimate load are given in table (4) to (7) the values of the experimental values of beams are in fig (19) to (24).

Table 4.
The characteristic of tested beams at cracking loads.

Group	series	Type of fiber	Pcr (ton)	Deflection δcr (mm)	Concrete Strain /10^{-5} ϵcr	Steel Strain /10^{-5} ϵcr
static	Bs0	without	4	1.87	30	19
	Bsh	harex	5	1.57	34	20.5
	Bsp	polypropylene	4.5	1.54	33	22.5
	Bsg	glass	4	1.73	32	20
repeated	Br0	without	4	1.87	30	19
	Brh	harex	5	1.57	34	20.5
	Brp	polypropylene	4.5	1.54	33	22.5
	Brg	glass	4	1.73	32	20

Table 5.
The characteristic of tested beams at cracking shear loads.

Group	series	Type of fiber	Qcr (ton)	Deflection δcr (mm)	Concrete Strain /10^{-5} ϵcr	Steel Strain /10^{-5} ϵcr
static	Bs0	without	5	2.58	46.5	27
	Bsh	harex	8.5	3.5	59.5	37.5
	Bsp	polypropylene	7	3	52.5	35
	Bsg	glass	5	2.29	37.5	26.5
repeated	Br0	without	5	2.58	46.5	27
	Brh	harex	8.5	3.5	59.5	37.5
	Brp	polypropylene	7	3	52.5	35
	Brg	glass	5	2.29	37.5	26.5

Table 6.
The characteristic of tested beams at 0.6 ultimate static loads.

Group	series	Type of fiber	Pr (ton)	Deflection δr (mm)	Concrete Strain /10^{-5} єr	Steel Strain /10^{-5} єr
static	Bs0	without	9.12	6.28	81.2	57.28
	Bsh	harex	10.5	4.57	77.25	48.75
	Bsp	polypropylene	9.84	5.14	78.5	49.2
	Bsg	glass	8.7	5.28	72	48.5
repeated	Br0	without	9.12	6.28	81.2	57.28
	Brh	harex	10.5	4.57	77.25	48.75
	Brp	polypropylene	9.84	5.14	78.5	49.2
	Brg	glass	8.7	5.28	72	48.5

Table 7.
The characteristic of tested beams at ultimate loads.

Group	series	Type of fiber	Pu (ton)	Deflection δu (mm)	Concrete Strain /10^{-5} єu	Steel Strain /10^{-5} єu
static	Bs0	without	15.2	14.5	175	120
	Bsh	harex	17.5	12.7	220	160
	Bsp	polypropylene	16.4	13.1	190	144
	Bsg	glass	14.5	13.4	160	115
repeated	Br0	without	15	16.2	233	148
	Brh	harex	17.7	13.09	245	160
	Brp	polypropylene	16.5	14.95	240	155
	Brg	glass	8.7	15.89	210	135

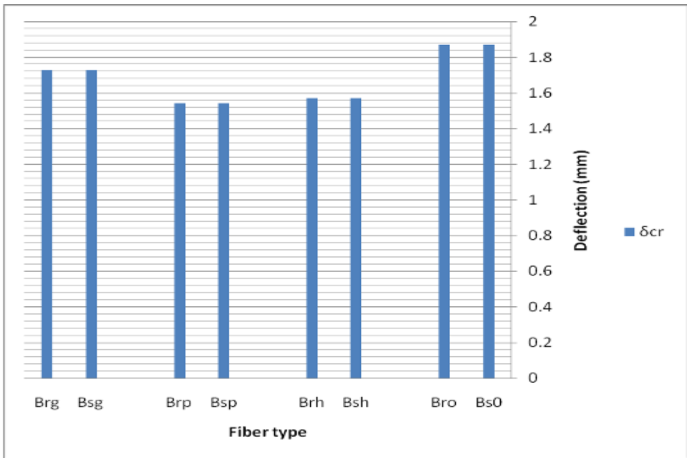

Fig. 19. The values of deflection of beams tested under static and repeated load at cracking load

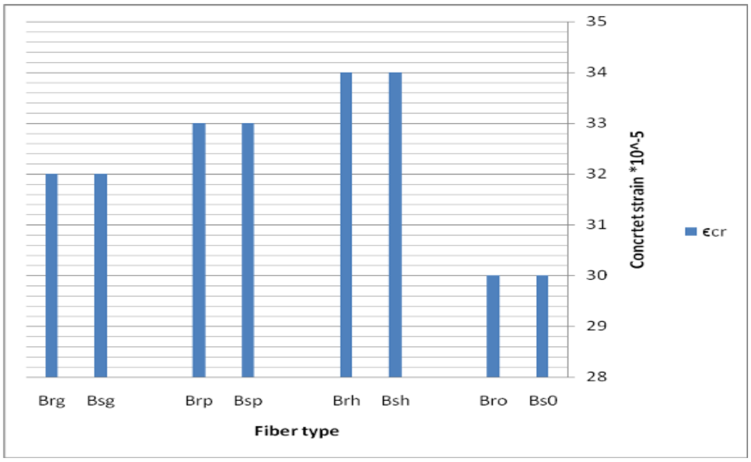

Fig. 20. The values of concrete strain of beams tested under static and repeated load at cracking load

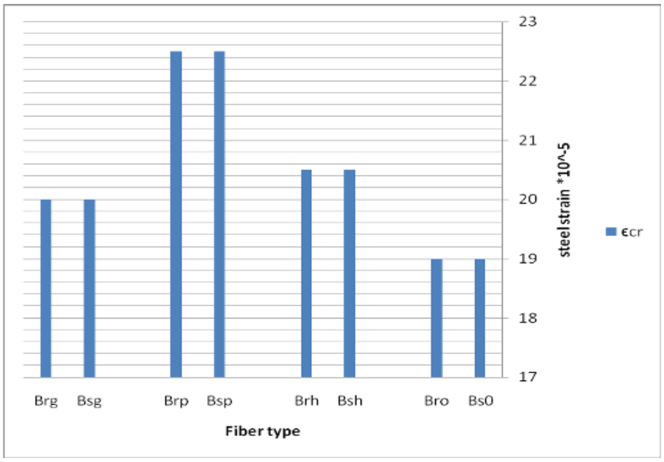

Fig. 21. The values of steel strain of beams tested under static and repeated load at cracking load

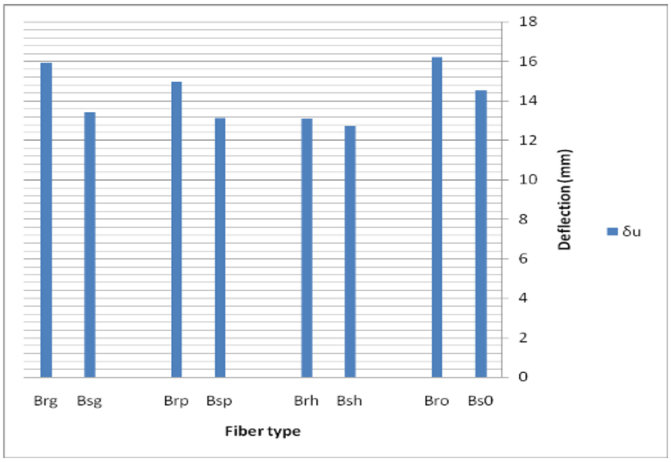

Fig. 22. The values of deflection at ultimate load of beams tested under static and repeated load

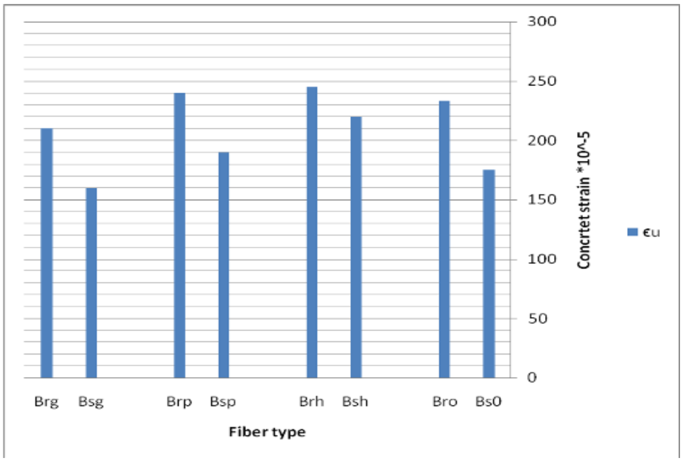

Fig. 23. The values of concrete strain at ultimate load of beams tested under static and repeated load

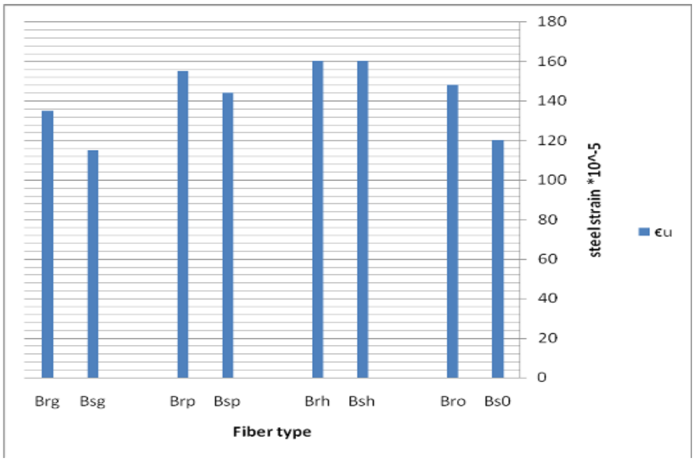

Fig. 24. The values of steel strain at ultimate load of beams tested under static and repeated load

5. Effect of number of cycles (N) for beams tested under repeated loading.

The values of deflection , concrete and steel strains are measured at mid span of the beam with fibers and without fibers. The values of the measured deflection , concrete and steel strains due to (N) cycles shown in Table (8) to (10). The comparison between beam without fibers (Br0) for repeated loading with beams have fibrous content Harex, polypropylene and glass fibers are included in Figs. (25) to (27).

Table 8.
Values of experimental deflection at (N) cycles for beams tested under repeated load.

Group	series	Def. at (N)=0	Def. at (N)=0.25 million	Def. at (N)=0.5 million	Def. at (N)=0.75 million	Def. at (N)=1 million	δ_u
repeated loads	Br0	6.28	7.1	7.9	9.1	9.9	16.2
	Brh	4.57	5.17	5.77	6.14	6.74	13.09
	Brp	5.14	5.79	6.44	7.14	7.79	14.45
	Brg	5.28	15.89	-	-	-	15.89

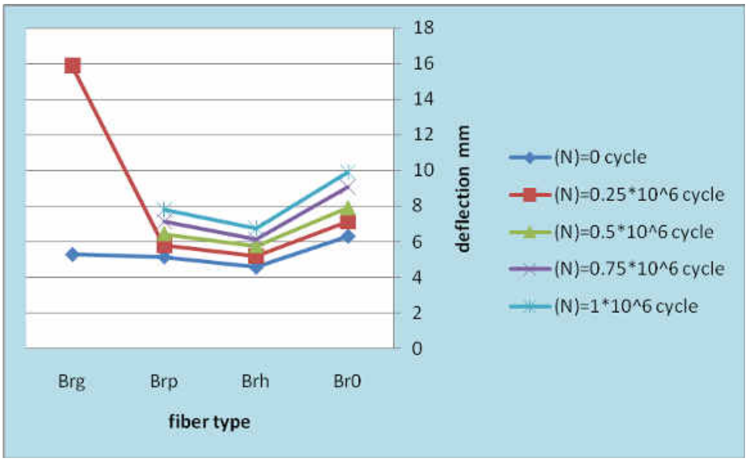

Fig. 25. The values of the deflection due to(N) cycles of tested beams under repeated load.

Table 9.
Values of experimental concrete strain at (N) cycles for beams tested under repeated load.

Group	series	Concrete strain at (N)=0 ×10^-5	Concrete strain at (N)=0.25 million ×10^-5	Concrete strain at (N)=0.5 million ×10^-5	Concrete strain at (N)=0.75 million ×10^-5	Concrete strain at (N)=1 million ×10^-5	ϵ_{cu}×10^-5
repeated loads	Br0	86	100	120	140	160	233
	Brh	77.25	91	109	108	126	245
	Brp	78.5	100	120	125	145	240
	Brg	72	210	-	-	-	210

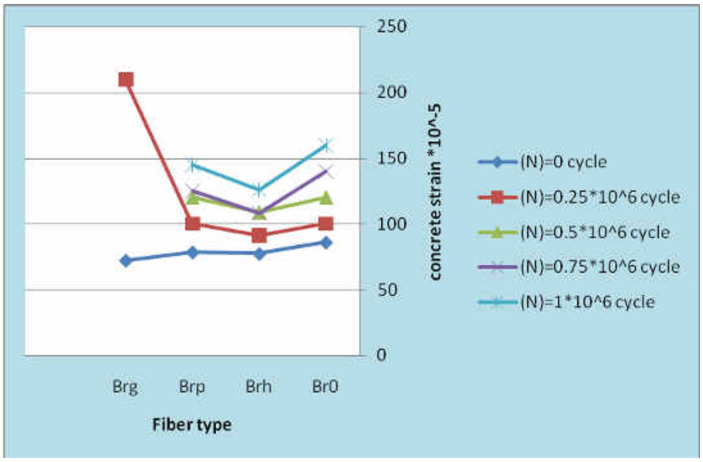

Fig. 26. The values of the concrete strain due to(N) cycles of tested beams under repeated load.

Table 10.
Values of experimental steel strain at (N) cycles for beams tested under repeated load.

Group	series	steel strain at (N)=0 ×10^-5	steel strain at (N)=0.25 million ×10^-5	steel strain at (N)=0.5 million ×10^-5	steel strain at (N)=0.75 million ×10^-5	steel strain at (N)=1 million ×10^-5	$\epsilon_u \times 10^{-5}$
repeated loads	Br0	60.4	70	84	84	98	148
	Brh	48.75	56	67.5	65.5	82.5	160
	Brp	49.2	62.5	75	82.5	95	155
	Brg	48.5	135	-	-	-	135

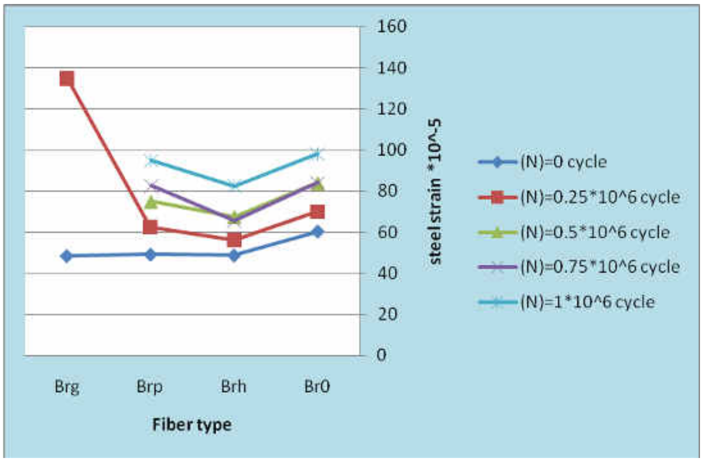

Fig. 27. The values of the steel strain due to(N) cycles of tested beams under repeated load.

6. Conclusions

This work presents an experimental study on the behavior of high performance reinforced concrete beams (H.P.C) with and without fibers subjected to static and repeated loading. From the test result and their analysis, the following conclusions are obtained:

1- For static load test

a) Harex fibers beam has an increase in the ultimate load by 15.1%, decrease in deflection by 12.4% and increase in ultimate concrete and steel strain by 25.7%, 33.3% respectively.
b) Polypropylene fibers beam has an increase in the ultimate load by 7.9%, decrease in deflection by 9.7% and increase in ultimate concrete and steel strain by 8.6%, 20% respectively.
c) Glass fibers beam has decrease in the ultimate load by 4.6%, decrease in deflection by 7.6% and decrease in ultimate concrete and steel strain by 8.6%, 4.2% respectively.

2- For repeated load test

a) Harex fibers beam has an increase in the ultimate load by 18%, decrease in deflection by 19.2% and increase in ultimate concrete and steel strain by 5.2%,8.1% respectively.
b) Polypropylene fibers beam has an increase in the ultimate load by 10%, decrease in deflection by 7.7% and increase in ultimate concrete and steel strain by 3%, 4.7% respectively.
c) Glass fibers beam has decrease in the ultimate load by 42%, decrease in deflection by 1.9% and decrease in ultimate concrete and steel strain by 9.9%, 8.8% respectively.
d) Harex steel fiber improved the shear and flexural capacity for beams under static and repeated loading, The mode of failure changed from shear to flexural failure.
e) Both fiber reinforced concrete beams with Harex and polypropylene has mode of failure flexural and shear flexural failure because of the fiber addition enhanced shear strength for fiber concrete beams.
f) The addition of Harex and polypropylene fibers to reinforced concrete beams increases the fatigue life and decreases the crack number and its width under fatigue loading.
g) Flexure strength of beams with harex steel fiber is substantially greater than beams without fibers in tension or compression because ductile behavior of the FRC on the tension side of a beam alters the normally elastic distribution of stress and strain over the member depth.
h) Additional of the fibers in the concrete mixture confine the cracking behavior of the HPC beam.
i) Fiber reinforced concrete has substantial enhancement of the load carrying capacity of the FRC beams with harex and polypropylene.

j) The first-crack tensile strength and the ultimate tensile strength of the concrete increased by harex and polypropylene fibers.
k) It is not recommended to use reinforced concrete beams with glass fibers under the effect of repeated loading resulting unability to resist this kind of loading.

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تأثير نوع الألياف على سلوك الانحناء للكمرات الخرسانية عالية المقاومة تحت تأثير الأحمال المتكررة

الملخص العربي

تعد الخرسانة واحدة من اكثر المواد قصافة التي لها مقاومة ضعيفة للشد. تم تطوير الخرسانة ذات محتوى الالياف لتحسين الخواص الميكانيكية حتى تعطي الخرسانة تحت تأثير أحمال الشد سلوك تشكل مرن. و الاستجابة المرنة المصحوبة بشروخ مجهرية و حتى الانهيار.

إضافة الالياف الى الخرسانة يحسن مقاومة الشد التي تتغير من مقاومة مبدئية الى مقاومة جوهرية يعتمد على مجموعة عوامل مثل نوع الالياف ، معامل مرونة الالياف ، نسبة الطول إلى العرض للالياف ، مقاومة الالياف ، قوة التماسك بين الالياف و الخرسانة ، اتجاة الالياف داخل الخرسانة .

أصبح واضحا ان من اهم فوائد استخدام خرسانة الالياف هو زيادة عمر الخدمة للمنشأ الخرساني. عمر الخدمة هو عبارة عن قدرة المنشأ او جزء منة للحصول على المقاومة المرجوة منة و تحقيق السلامة و الهدف المرجو من تصميم المنشأ على مدار عمر الخدمة الخاص بة.

واحدة من اهم جوانب تحسين عمر الخدمة للخرسانة ذات الالياف هو الحد من تكون الشروخ و اتساعها. الالياف تمنع من تكون شروخ كبيرة الاتساع ، تلك الشروخ التي تسمح للمياة بالدخول مكونة صدأ الحديد أو التدهور المحتمل للخرسانة.

و بدراسة سلوك الخرسانة تحت الأحمال الاستاتيكية و الأحمال المتكررة وجد أن:

1. الكمرات ذات محتوى الياف الهاركس لها مقاومة اعلي في منطقة العزوم و القص تحت تأثير الأحمال الاستاتيكية و الديناميكية , طراز الانهيار تغير الى انهيار في منطقة العزوم بدلا من النهيار في منطقة القص.
2. الكمرات ذات محتوى ألياف البولي بروبيلين لها مقاومة اعلي في حالة العزم و القص تحت تأثير الأحمال الاستاتيكية و الديناميكية .
3. إضافة كلا من ألياف الهاركس و البولي بروبيلين حسن من تحمل الكمرات للأحمال المتكررة و قلل من عدد الشروخ و اتساعها.
4. هناك زيادة في حمل الشرخ الاول في الكمرات ذات محتوى الألياف الهاركس و البولي بروبلين .
5. لا ينصح باستخدام الكمرات ذات محتوى الألياف الزجاجية تحت الأحمال المتكررة .