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PROPERTIES AND PERFORMANCE OF ENGINEERED CEMENTITIOUS COMPOSITES

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يهدف هذا البحث الي دراسة مفهوم مركبات المواد الاسمنتية من حيث متانتها وممطوليتها وكذلك دراسة سلوكها تحت تأثير احمال الانحناء حتي حدوث الانهيار ودراسة سلوكها تحت تأثير احمال الضغط ومقارنة نتائج العينات المختلفة فتم عمل مجموعتين في هذه الدراسة تحتوي كل مجموعة علي عدد ١٦ منشور و١٦ مكعب بابعاد (٣٠٠*١٠٠*٥٠ مم) و(٥٠*٥٠*٥٠مم) بنسبة رمل/ اسمنت = (٠,٥٠و ٠,٨٠)وبنسبة الياف (البولي بروبلين) متغيرة (١,٢,٣,٤%) من الحجم المطلق و بنسبة الرماد المتطاير/ الاسمنت متغيرة (٥٠,١٠٠,١٥٠,٢٠٠ %) وتم التأثير علي كلا المجموعتين باحمال الانحناء والضغط وتلخصت النتائج في ان الممطولية ومقاومة الانحناء ومقاومة الضغط تزيد كلما زادت نسبة الالياف حتي تصل الي ٣,٠٠% من الحجم المطلق وبعدها تقل وكذلك ايضا الممطولية ومقاومة الانحناء تزيد كلما زادت نسبة الرماد المتطاير/ الاسمنت حتي تصل الي ١٠٠(%) وبعدها تقل اما في حالة اجهاد الضغط فانه يقل بالكامل في حالة زيادة الرماد المتطاير

Abstract:

This paper reports new means to address engineered cementitious composites (ECC), which are designed based on micromechanics principles and exhibits higher tensile and ductility, as an alternative to the brittle concrete matrix. Two series of ECC mortar mixes with two ratios of sand/cement of 0.50 and 0.8, different fiber contents and fly ash/cement ratios were designed and tested. The results revealed that, ECC specimens exhibit significant increases in load-carrying capacity, ultimate deflection capacity and damage tolerance (such as crack width or spalling) in the mixes with sand/cement of 0.50. The extent of improvement strongly depended on the failure mode; that is, when the limit state was dominated by the matrix behavior, more significant improvement was observed. Moreover, ECC specimens showed improvement in the flexural performance in terms of ductility, deformability and compressive strength as the fiber content increased to 3.00%. Also, the experimental results revealed that the flexural behavior and ductility were improved at fly ash/ cement ratios of 100%, while the compressive strength decreased.

1. Introduction:

Conventional concrete is fundamentally a mixture of aggregates (sand and gravel or crushed stone) and paste (water and Portland cement). This type of conventional concrete may be strong, but it is very brittle and cracks easily [1]. On the other hand, the several environmental and mechanical conditions lack the required durability of the structures. So the maintenance costs of concrete structures are increased and the service life is decreased. Therefore, it is important to develop a cementitious material that can resist cracking and deform under tensile stress. The addition of small fibers is one improvement that has been used commercially since the 1900s. These fibers are usually made of steel or glass. This concrete mixture is called fiber reinforced concrete (FRC) [2]. Engineered Cementitious Composites (ECC) are prepared using water, cement, sand, fiber and some common chemical additives. Coarse aggregates are not used in ECC mixes as they tend to adversely affect the unique ductile behavior of the composite. ECC in general use 2% or less (by volume) discontinous fibers. Also, ECC has been generally reinforced with poly vinyl alcohol (PVA) fibers or high modulus polyethylene fibers [3]. ECC tensile strain hardening is a result of realizing and tailoring the synergistic interaction between fiber, matrix, and interface [4]. Micromechanics have been used as a tool to link material microstructures to ECC tensile strain hardening behavior [5]. Multiple cracking and tensile strain hardening in terms of the overall size of the compound ECC appears. Micromechanics model linking the parameters and scope of the partial component for bridging the constitutive behavior fibers in the medium range. Steady state crack connects fiber analysis of property tensile strain hardening in the overall level of the compound's. Compressive characteristics of ECC is not much different from the normal-to-high-strength concrete and ranges from 20 to 95 MPa. An elastic modulus of 15 to 34 GPa is usually less than that of normal concrete because of the absence of coarse aggregate. The compressive strain of ECC is slightly higher and ranges from 0.45 to 0.65 %. The flexural response of ECC reflect the softness in the tensile [6-7]. Under flextural, multiple micro -cracks formats in the beam base, allowing it to undergo for the development of large curvature. This results in what's called bendable concrete. 10 to 15 MPa easy to achieve for a flexural strength (modulus of rupture) and is accompanied by a significant deflection-hardening regim [8]. Also, engineered cementitious composites have significant improvements in fatigue response over normal concrete and FRC [9, 10]. There have been some applications of ECC in various countries. For example; use of ECC in precast RECC coupling beams in the core of two high-rise bulidings in Japan [11]. Another application include cast-in-place ECC link slabs on bridge decks in the United States and Italy; a composite ECC/steel bridge deck in Japan; sprayed ECC tunnel linings in South Korea, repair of the Mitaka Dam in Japan an irrigation channel repair in Japan (Kunieda and Rokugo, 2006b) [12], and prototype pipe extrusion in Australia. Several projects in the housing and energy industries employing ECC are in various planning stages. Despite the advanced stage of development of ECC and its application readiness, It remains a great deal of research and experimentation to be done.

2. Experimental program

To carry out the experemental work, thirty two mixes were prepared from ECC. Two series of ECC mortar mixes with two ratios of sand/cement of 0.50 and 0.8, different fiber contents and fly ash/cement ratios were designed and tested. Fly ash /cement ratios were 50, 100, 150 and 200%. Polypropylene fibers were used with different volume fractions of 1.00, 2.00, 3.00 and 4.00%.A total of 96 cubes50×50×50 mm were tested to determine the compressive strength of the mixes at 28 days. A total of 32 prisms 50×100×300 mm were tested to determine the flexural behavior of hardened concrete.

2.1 Materials

Ordinary Portland cement (CEM I 42.5 N) conformed to the requirements of E.S.S.**4765-1/2009** [13] with a specific gravity of 3.16 and Blain fineness of 3980 cm^2/gm. Well, graded siliceous sand conformed to the requirements of E.S.S.1109/2008 with a specific gravity of 2.60, absorption of 0.81%, and a fineness modulus of 2.55.Class (F) flay ash meeting the requirements of ASTM C618 [14] with a specific gravity of 2.1 was used. The cement content was 400 kg/m^3 in all mixes and the water per binder (flay ash+ cement) ratio (w/b) was 0.4. Tap water was used for mixing the concrete. A high range water reducer (HRWR) was used as a superplasticizer meeting the requirements of ASTM C494 (type A and F) [15]. The admixture is a brown liquid having a density of 1.18 kg/liter at room temperature. The amount of HRWR was 1.5% of the binder (flay ash + cement) weight. The polypropylene fibers were fibrillated with 15 mm length and 0.9 g/cm^3 density

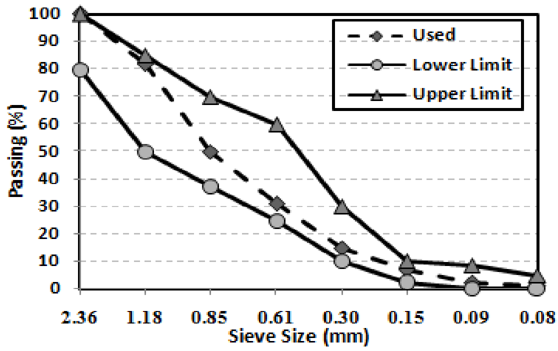
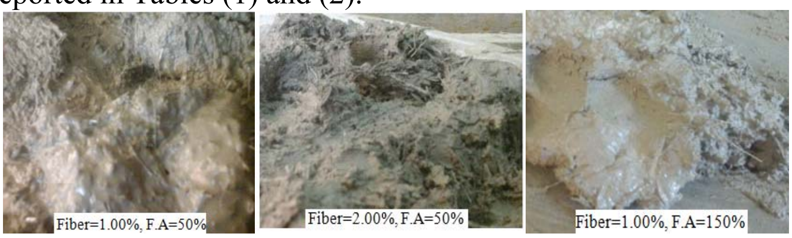


Fig. (2): Sieve analysis results for fine aggregate

2.2 Casting and testing procedures

Fine sand, cement and fly ash were mixed for approximately 1 minutes until the mixture becomes homogeneous then added the water and the HRWR were added and mixing contined for 3 mintes. Fibers were added slowly and mixed for 2 to 3 minutes to ensure that the fibers distributed. The mixes were poured in one layer then vibrated using table vibrating. The specimens were demouled after 24 hours and then cured unite the date of the testing Figs. (3) and (4) show different types of mixtures and the specimens. Mixes features are reported in Tables (1) and (2).



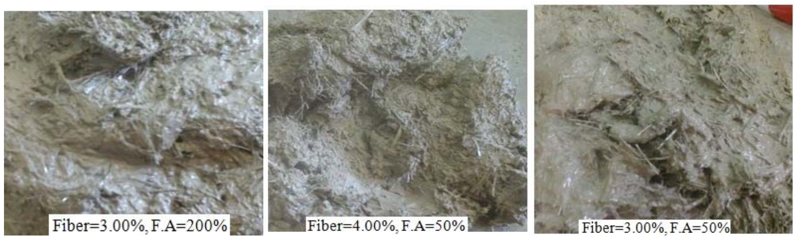


Fig. (3):mixing of concrete for (S/C=0.50)

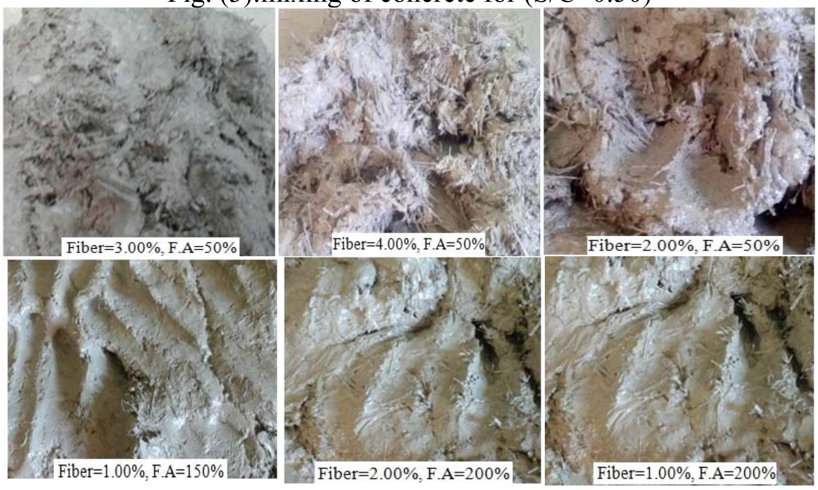


Fig. (4): mixing of concrete for (S/C=0.80))

Table(1): Constituents of concrete mixes (kg/m³) (Sand/Cement=0.80)

Mix	Cement	Fiber (Polypropylene)	Fly ash	Sand	Water	HRWRA
1	767	9.0 (1.0%)*	383.5(50%)**	614	345	11.5
2	656		656 (100%)**	525	295	9.80
3	576		864 (150%)**	461	259	8.60
4	508		1016(200%)**	406	229	7.60
5	760	18.0 (2.0%)*	380(50%)**	608	342	11.40
6	649		649(100%)**	519	292	9.75
7	567		851(150%)**	454	255	8.50
8	503		1006(200%)**	402	226	7.55
9	752	27.0 (3.0%)*	376(50%)**	602	338	11.28
10	642		642(100%)**	514	289	9.63
11	564		841.5(150%)**	449	252	8.50
12	497		994(200%)**	398	224	7.50
13	744	36.0 (4.0%)*	372(50%)**	595	335	11.16
14	636		636(100%)**	509	286	9.54
15	555		832.5(150%)**	444	250	8.30
16	492		984(200%)**	394	221	7.40
(*): Fiber volume fraction (**): Fly Ash /Cement (by weight)						

Table(2): Constituents of concrete mixes (kg/m^3) (Sand/Cement=0.50

Mix	Cement	Fiber (Polypropylene)	Fly ash	Sand	Water	HRWRA
1	839	9.0(1.0%)*	420(50%)**	420	378	12.6
2	707		707(100%)**	354	318	10.6
3	615		923(150%)**	308	277	9.22
4	541		1082(200%)**	271	243	8.11
5	831	18.0 (2.0%)*	416(50%)**	416	374	12.5
6	700		700(100%)**	350	315	10.5
7	609		914(150%)**	605	274	9.15
8	536		1072(200%)**	268	241	8.00
9	822	27.0 (3.0%)*	411(50%)**	411	370	12.5
10	693		693(100%)**	347	312	10.5
11	603		905(150%)**	302	271	9.00
12	530		1060(200%)**	265	239	8.00
13	814	36.0 (4.0%)*	407(50%)**	407	366	12.00
14	686		686(100%)**	643	309	10.50
15	596		894(150%)**	298	268	9.00
16	525		1050(200%)**	263	236	8.00
(*): Fiber volume fraction (**): Fly Ash /Cement (by weight)						

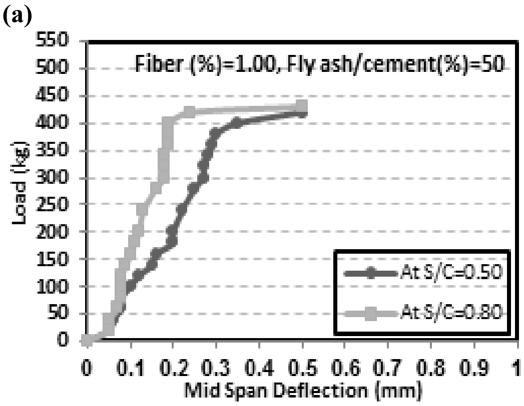
3. RESULTS AND DISCUSSIONS

Different parameters were used to study the properties of ECC. The results of the experimental program are detailed in the following sections.

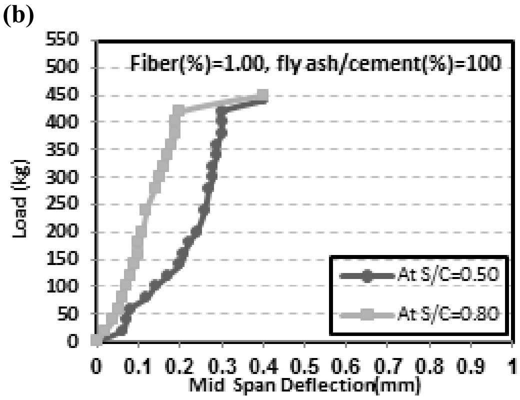
3.1 Effect of sand/cement ratio:

Fig. (1) illustrates the relation between mid-span deflection and load for the mixes containing different sand/cement ratio. The results illustrate that sand/cement ratio effects on the behavior of ECC. As the sand/cement ratio increase as the load increases. For example, Fig. (1-a) illustrates the relation between mid-span deflection and load for the mixes with sand/cement ratio of 0.50 and 0.80 for the mixes with V*f* of 1.00% of fiber and fly ash/cement of 50%. The figure shows that the load for mixes with S/C of 0.80 is more than that with S/C of 0.50. At mid-span deflection equal to 0.20 the loads were 200 and 400 kg for the mixes with S/C of 0.50 and 0.80, respectively. The ultimate loads were 420 and 430 kg for the mixes with S/C of 0.50 and 0.80, respectively. These measured increased by 45% for the mixes with S/C of 0.80 compared to the mixes with S/C of 0.50. On the other hand, the maximum mid-span deflection was the same for the two mixes. The ductility index of the mix with S/C of 0.80 was more than that of the mix with S/C of 0.50 by 37% as calculated in Tables [3] and [4]. The same trend was noticed for the different fiber volume fraction and fly ash/cement ratio as shown in Figs. (1-b) to (1-P). 62%, 26 % and 29% increasing in the ultimate load for the mixes with fly ash/cement ratio of 100, 150 and 200% at Vf of 1%. Also, the ductility index was increased by 33%, 49%, and 7%. Using 2% fiber volume fraction; the maximum load increased by 23%, 15%, 23% and 28% for the mixes with fly ash/cement ratio of 50, 100, 150 and 200 %, respectively. On the other hand 15, 41, 12 and 31% increasing in the ductility index for theses mixes. Using 3% fiber volume fraction; the ultimate load increased by 21%, 10%, 27% and 10% for the mixes with fly ash/cement ratio of 50, 100, 150 and 200 %, respectively. On the other hand, 28, 4, 15 and 43% increasing in the ductility index for theses mixes. Using 4% fiber volume fraction; the ultimate load increased by 22%, 0%, 22% and 10% for the mixes with fly ash/cement ratio of 50, 100, 150 and 200 %, respectively. On the other hand 26, 14, 23 and 21% increasing in the ductility index for theses mixes.

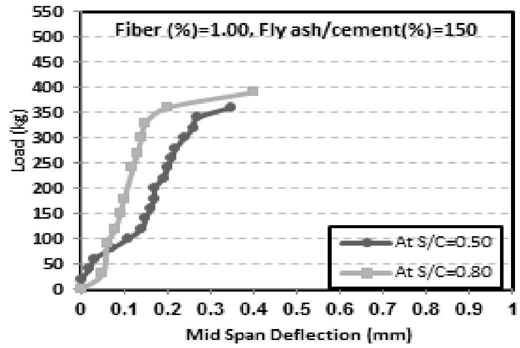
(a)



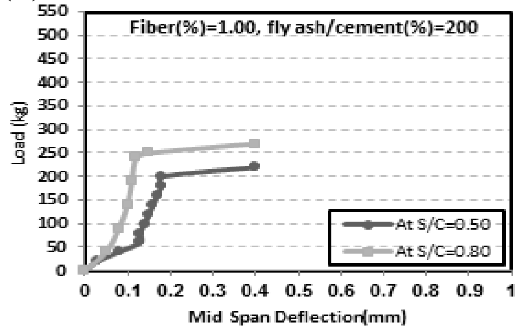
(b)



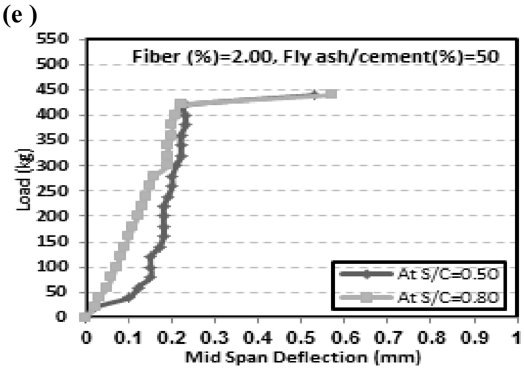
(C)



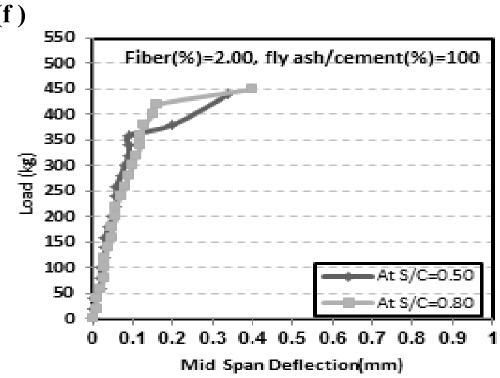
(d)



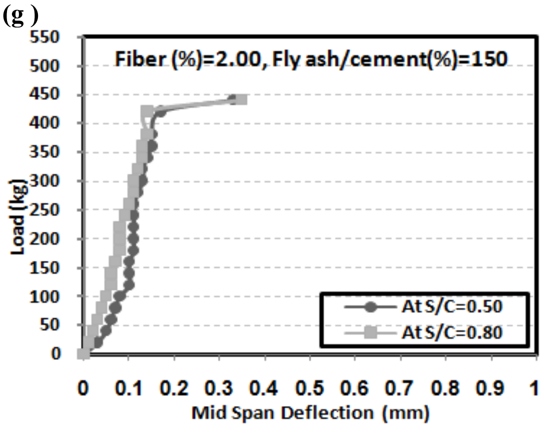
(e)



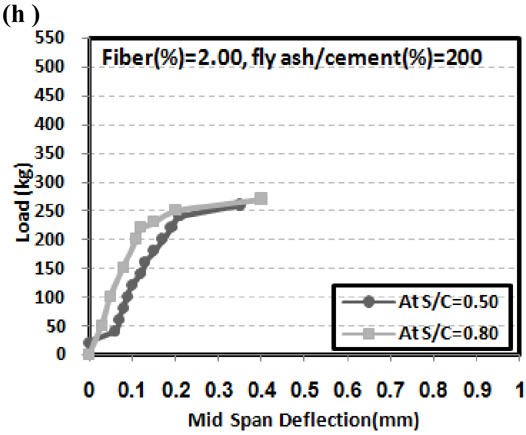
(f)



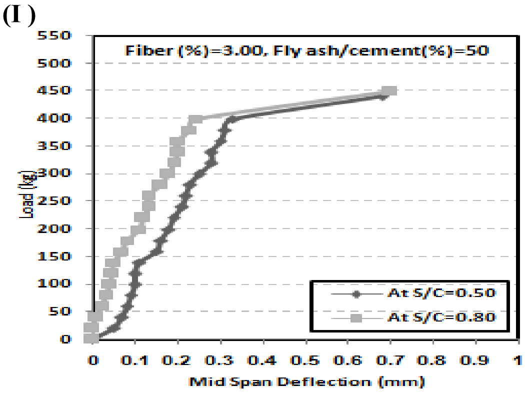
(g)


Fiber (%)=2.00, Fly ash/cement(%)=150
Load (kg)
Mid Span Deflection (mm)
At S/C=0.50
At S/C=0.80

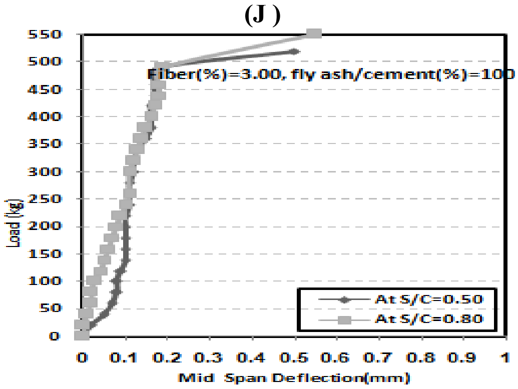
(h)


Fiber(%)=2.00, fly ash/cement(%)=200
Load (kg)
Mid Span Deflection(mm)
At S/C=0.50
At S/C=0.80

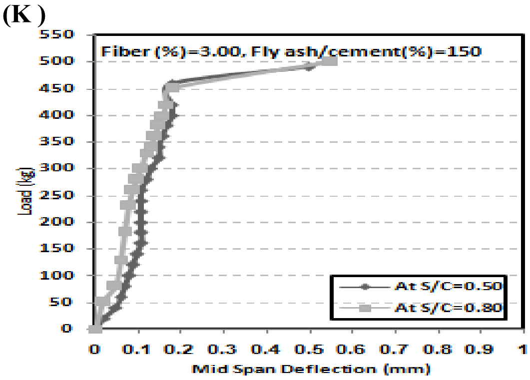
(I)


Fiber (%)=3.00, Fly ash/cement(%)=50
Load (kg)
Mid Span Deflection (mm)
At S/C=0.50
At S/C=0.80

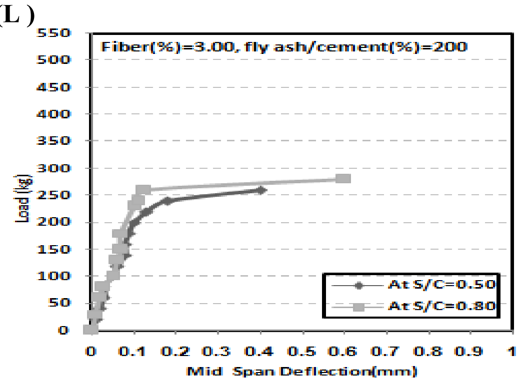
(J)


Fiber(%)=3.00, fly ash/cement(%)=100
Load (kg)
Mid Span Deflection(mm)
At S/C=0.50
At S/C=0.80

(K)


Fiber (%)=3.00, Fly ash/cement(%)=150
Load (kg)
Mid Span Deflection (mm)
At S/C=0.50
At S/C=0.80

(L)


Fiber(%)=3.00, fly ash/cement(%)=200
Load (kg)
Mid Span Deflection(mm)
At S/C=0.50
At S/C=0.80

(M)

(N)

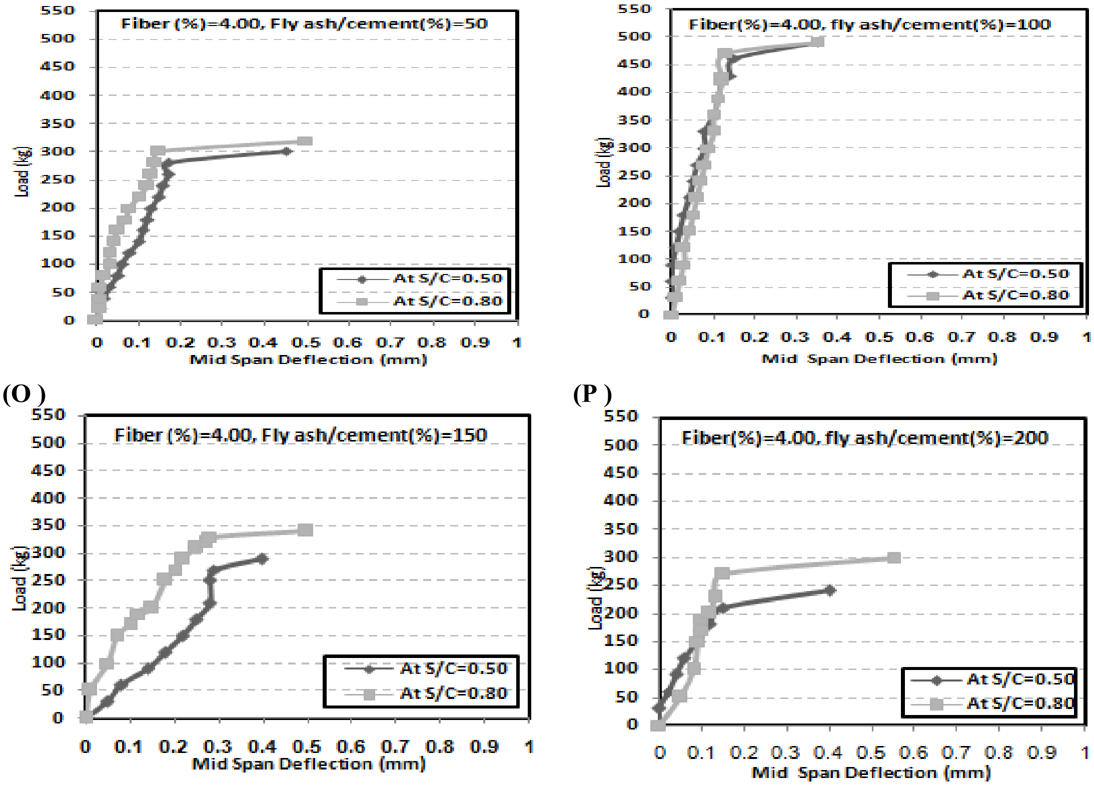


Fig 1:The relation between mid span deflection and load for different sand/cemnt ratio.

Table [3] Flexural strength of mixtures ECC and max deflection at ultimate load at (Sand/Cement) =0.50

Mix	Fiber (%)	F.A/C (%)	ff (kg/cm²)	Δu	Ultimate def/span(%)	Δy	μd
1	1.00%	50%	63	0.50	0.25	0.3	1.67
2		100%	66	0.40	0.20	0.3	1.33
3		150%	54	0.35	0.175	0.26	1.35
4		200%	33	0.40	0.20	0.18	2.22
5	2.00%	50%	66	0.53	0.265	0.23	2.3
6		100%	66	0.34	0.17	0.09	3.77
7		150%	66	0.33	0.165	0.15	2.2
8		200%	39	0.35	0.175	0.19	1.84
9	3.00%	50%	66	0.68	0.34	0.31	2.19
10		100%	78	0.50	0.25	0.17	2.94
11		150%	73.5	0.50	0.25	0.18	2.77
12		200%	39	0.40	0.20	0.13	3.08
13	4.00%	50%	45	0.45	0.225	0.17	2.64
14		100%	73.5	0.35	0.175	0.14	2.5
15		150%	43.5	0.40	0.20	0.28	1.43
16		200%	36	0.40	0.20	0.12	3.33

F.A = Fly Ash, C = Cement, *f* = Flexural Strength, μd is deflection ductility index.
Δu is the final deflection corresponding to max load.
Δy is the member deflection at first yielding of the tension reinforcement

Table [4] Flexural strength of mixtures ECC and max deflection at ultimate load at (Sand/Cement) =0.80

Mix	Fiber (%)	F.A/C (%)	f*f* (kg/cm^2)	Δu	Ultimate def/span(%)	Δy	μd
1	1.00%	50%	64.5	0.50	0.25	0.19	2.63
2		100%	67.5	0.40	0.20	0.20	2.00
3		150%	58.5	0.40	0.20	0.15	2.67
4		200%	40.5	0.25	0.125	0.12	2.08
5	2.00%	50%	66	0.57	0.285	0.21	2.71
6		100%	67.5	0.40	0.20	0.15	2.67
7		150%	60	0.35	0.175	0.14	2.50
8		200%	40.5	0.40	0.20	0.15	2.67
9	3.00%	50%	67.5	0.70	0.35	0.23	3.04
10		100%	82.5	0.55	0.275	0.18	3.06
11		150%	75	0.55	0.275	0.17	3.24
12		200%	42	0.6	0.3	0.11	5.45
13	4.00%	50%	48	0.50	0.25	0.14	3.57
14		100%	66	0.35	0.175	0.12	2.91
15		150%	51	0.50	0.25	0.27	1.85
16		200%	45	0.55	0.275	0.13	4.23

F.A = Fly Ash, C = Cement, *f* = Flexural Strength, μd is deflection ductility index.
Δu is the final deflection corresponding to max load.
Δy is the member deflection at first yielding of the tension reinforcement

3.2 Effect of fiber volume fraction:

Fig. (2) shows the relation between the mid-span deflection and the load for the mixes containing different fiber percentages (V*f* %) at sand/cement ratio equal to 0.5. The results clear that, the use of fiber increased the toughness and ductility index of the mixes. Further increase of polypropylene fibers content did not increase the ultimate load, but it provided much more ductile behavior. It is noticed that; use polypropylene fibers in the mixes prevent the propagation of the fine cracks in the direction of the load. This leads to delay of the formation of the main crack that causes failure. On the other hand, polypropylene fibers can reduce stress concentration around the cracks and therefore the strength increased. Fig. (2-a) shows the relation between the mid-span deflection and load for the mix with sand/cement ratio of 0.50 and fly ash/cement ratio of 50% at different fiber percentages (V*f*%). This figure shows that the load increases until V*f* of 3% then decreases. The ultimate load was 440 kg for the mix with V*f* of 2.00 and 3.00%. The maximum mid-span deflection was 0.68 mm for the mix with V*f* of 3.00%. The ductility index was increased by increased the percentage of volume fraction until 2.00% then decreased. The ductility indexes were 1.67, 2.30, 2.19 and 2.65 for the mixes with V*f* of 1.00%, 2.00%, 3.00% and 4.00%, respectively as calculated in Table [1]. The same trends were shown in Figs. (2-b) to (2-d). At 100% fly ash/cement ratio; the ultimate load was 520 kg for the mix with V*f* of 3.00%. The ductility indexes were 1.33, 3.78 , 2.94 and 2.5 for the mixes with V*f* of 1.00%, 2.00%, 3.00% and 4.00%, respectively. At fly ash/cement ratio of 150%, the ultimate load was 490 kg for the mix with V*f* of 3.00%. The ductility indexes were 1.35, 2.2, 2.78 and 1.43 for the mixes with V*f* of 1.00%, 2.00%, 3.00% and 4.00%, respectively. At fly ash/cement ratio of 200%, the ultimate load was 260 kg for the mixes with V*f* of 2.00% and 3.00%. The ductility indeces were 2.22, 1.84, 3.08 and 3.33 for the mixes with V*f* of 1.00%, 2.00%, 3.00% and 4.00%, respectively.

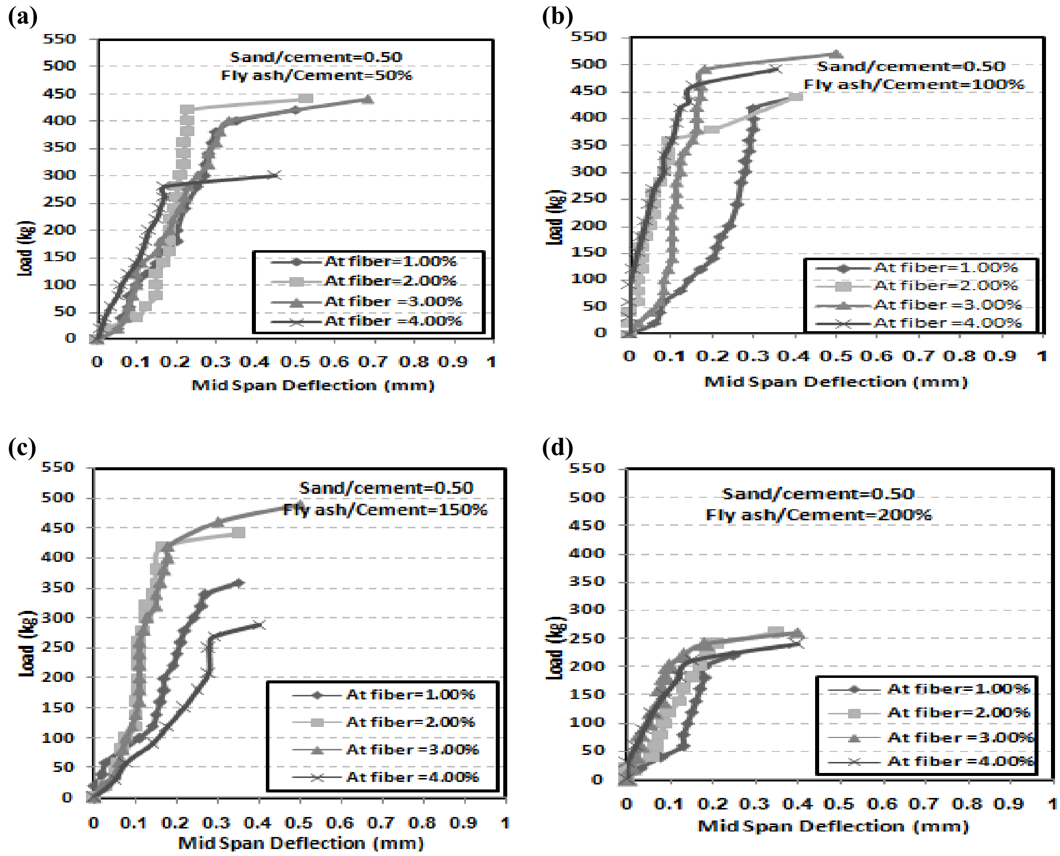


Fig 2:The relation between mid span deflection and load for different fiber content at s/c=0.50

Fig. (3) shows the relation between the mid-span deflection and the load for the mixes containing different fiber percentages (V*f* %) at sand/cement ratio equal to 0.5. At 50% fly ash/cement ratio, the ultimate load recorded was 450 kg for the mix with V*f* of 3.00%. The maximum mid span deflection was 0.70 mm for the mix with V*f* of 3.00%. The ductility indexes were 2.63, 2.71, 3.04 and 3.57 for the mix with V*f* of 1.00%, 2.00%, 3.00% and 4.00%, respectively as calculated in Table [2]. The same trends were shown in Figs. (3-b) to (3-d). At 100% fly ash/cement ratio; The ultimate load recorded was 550 kg for the mix with V*f* of 3.00%. The ductility indexes were 2.00, 2.67, 3.06 and 2.91 for the mix with V*f* of 1.00%, 2.00%, 3.00% and 4.00%, respectively. At 150% fly ash/cement ratio, the ultimate load recorded was 500 kg for the mix with V*f* of 3.00%. The ductility indexes were 2.67, 2.5, 3.24 and 1.85 for the mix with V*f* of 1.00%, 2.00%, 3.00% and 4.00%, respectively. At fly ash/cement ratio 200% the ultimate load recorded was 300 kg for the mix with V*f* of 4.00%. The ductility indexes were 2.08, 2.67, 5.45 and 4.23 for the mix with V*f* of 1.00%, 2.00%, 3.00% and 4.00%, respectively.

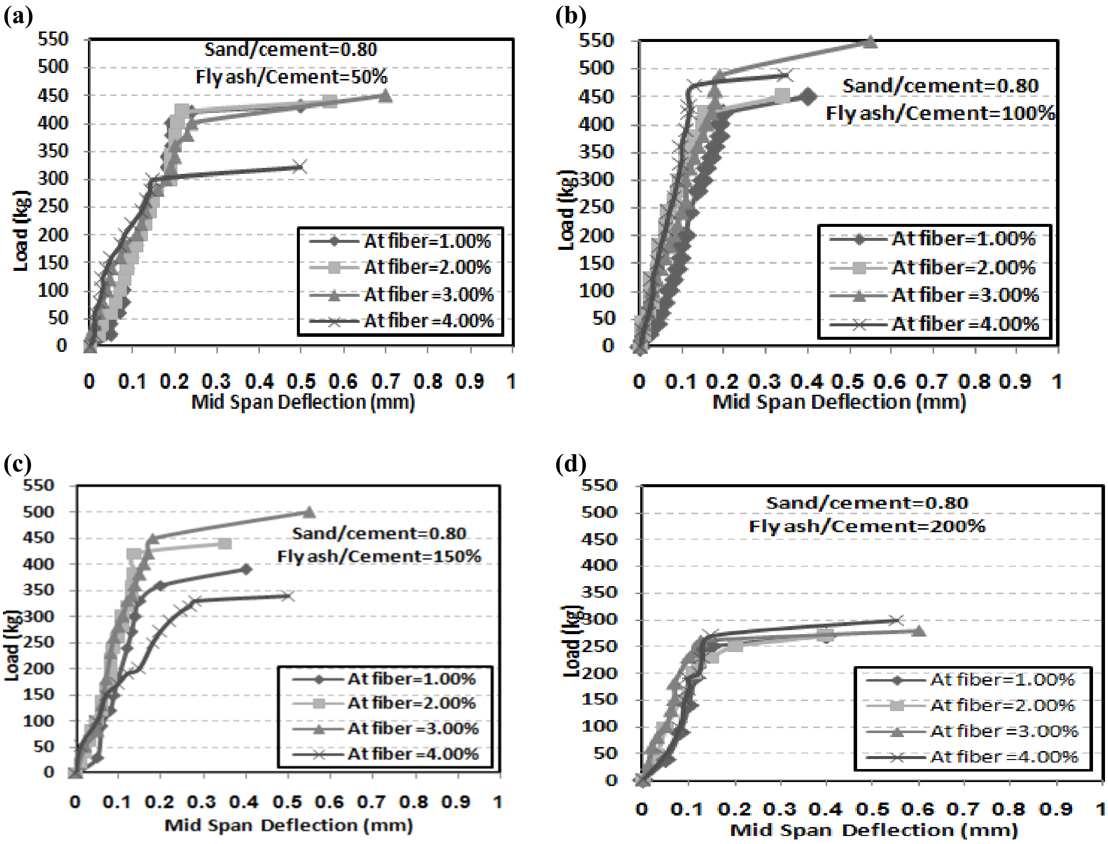


Fig 3:The relation between mid span deflection and load for different fiber content at s/c=0.80

Fig. (4) and Fig. (5) illustrate the relation between the fiber percentage (V*f*%) and the flexural strength using sand/cement ratio of 0.50 and 0.80 at different fly ash percentages. It can be seen; the use of fibers increased the flexural strength of the mixes. Further increase of polypropylene fibers more than V*f* of 3% did not increase the ultimate load strength, but it provided much more ductile bond behavior. Fig. (4) shows the effect of fiber percentage on the flexural strength at sand/cement ratio of 0.50. For example; the corresponding flexural strength was 63, 66, 54 and 33 kg/cm² at fly ash/cement ratio of 50%, for the mixes with V*f* of 1.00%, 2.00%, 3.00 and 4.00%, respectively. On the other hand, the maximum flexural strength was noticed for the mix with V*f* of 3.00% at 100% fly ash/cement ratio where the flexural strength was 78 kg/cm^2. Fig. (5) shows the effect of fiber percentage on the flexural strength at sand/cement ratio of 0.80. the same trend was recorded. For example; the corresponding flexural strength was 58.5, 60, 75 and 51 at fly ash/cement ratio of 150%, for the mixes with V*f* of 1.00%, 2.00%, 3.00 and 4.00%, respectively. On the other hand; the maximum flexural strength was noticed for the mix with V*f* of 3.00% at 100% fly ash/cement ratio where the flexural strength was 82.5 kg/cm^2.

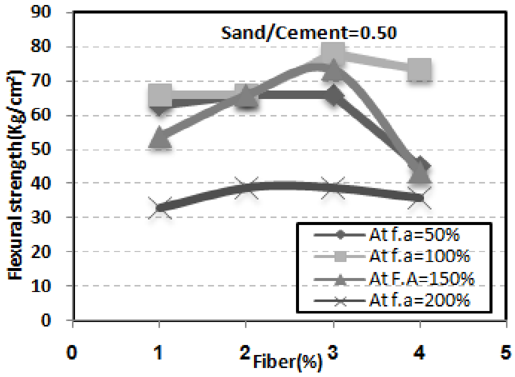


Fig. 4: The relation between fiber and flexural strength

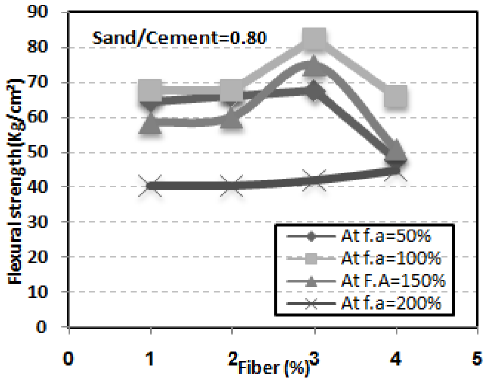


Fig. 5: The relation between fiber and flexural strength

Fig. (6) and Fig. (7) illustrat the relation between the fiber percentage (V*f*%) and the compressive strength using sand/cement ratio of 0.50 and 0.80 at different fly ash percentages. It can be seen; the use of fiber increased the compressive strength of the mixes. Further increase of polypropylene fibers more than V*f* of 3.00 % did not increase the ultimate compressive strength. Fig. (6) shows the effect of fiber percentage on the compressive strength at sand/cement ratio of 0.50. For example; the corresponding compressive strength was 153, 306, 326 and 316 kg/cm^2 at fly ash/cement ratio of 50%, for the mixes with V*f* of 1.00%, 2.00%, 3.00 and 4.00%, respectively. On the other hand, the maximum compressive strength was recorded at V*f* of 3.00% at 50% fly ash/cement ratio where the compressive strength was 326 kg/cm^2. Fig. (7) shows the effect of fiber percentage on the compressive strength at sand/cement ratio of 0.80. The same trend was recorded. For example; the corresponding compressive strength was 143, 159, 159 and 153 kg/cm^2 at fly ash/cement ratio of 150%, for the mixes with V*f* of 1.00%, 2.00%, 3.00 and 4.00%, respectively. On the other hand; the maximum compressive strength was recorded for the mixes with V*f* of 3.00% at 50% fly ash/cement ratio where the compressive strength was 235 kg/cm^2.

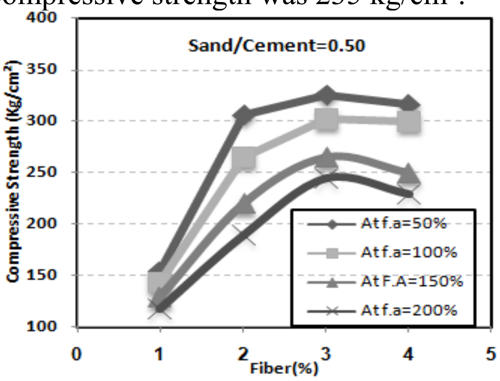


Fig. 6: The relation between fiber and compressive strength

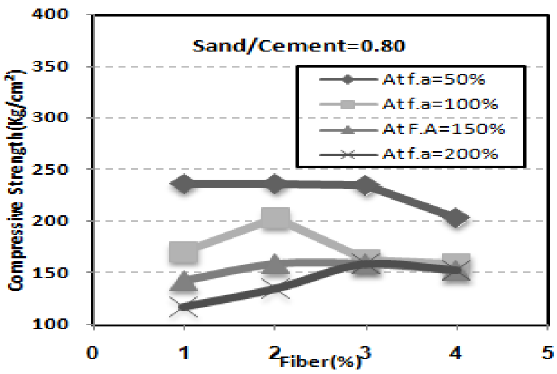


Fig. 7: The relation between fiber and compressive strength

3.3 Effect of fly ash/cement ratio:

Figs. (8) and (9) show the relation between the mid-span deflection and load for the mixes containing different fly ash percentages at sand/cement ratio equal to 0.5 or 0.8. Most fly ash particles are spherical with smooth surface and it acts as balls to lubricate mixtures. Because of this, fly ash is benefit to workability of concrete. Fly ash has both pozzolanic and physical properties that enhance the performance of concrete. When Portland cement hydrates, it produces quantities of alkali calcium hydroxide (lime). Pozzolans react with this lime to form stable calcium silicate hydrates (C-S-H) and aluminates hydrates. These hydrates fill the voids within the concrete, removing some of the lime and thus reducing the permeability. This process improves the strength and durability of the concrete. The pozzolanic reaction occurs relatively slowly at normal temperatures enhancing strength in the longer term relative to normal Portland cement concrete. The results clear that, the use of fly ash/cement ratio increased the strength and ductility index of the mixes at the same fiber volume fraction percentage. Further increase of fly ash/cement ratio didn't increase the ultimate load but it provided much more ductile behavior. Fig. (8-a) shows the relation between the mid-span deflection and load for the mixes with sand/cement ratio of 0.5 containing different fly ash percentages at Vf of 1.00%. This figure shows that the load increases until fly ash/cement of 100% after that the load decrease. The ultimate load was 440 kg for the mix with fly ash/cement ratio of 100%. On the other hand, the ultimate load decreases by 20 and 50% for the mix with fly ash/cement ratio of 150 and 200%, respectively. The ductility indexes were 1.67, 1.33, 1.35 and 2.22 for the mixes with fly ash/cement ratio of 50, 100, 150 and 200%, respectively. The same trends were recorded in Figs. (8-b) to (8-d). At 2% fiber volume fraction; the ultimate load was 440 kg for the mix with fly ash/cement ratio of 100%. On the other hand, the ultimate load decreased by and 1.00 and 40% for the mixes with fly ash/cement ratio of 150 and 200%, respectively. The ductility indexes were 2.30, 3.78, 2.20 and 1.84 for the mixes with fly ash/cement ratio of 50, 100, 150 and 200 %, respectively. At 3% fiber volume fraction. The ultimate load was 520 kg for the mix with fly ash/cement ratio of 100%. On the other hand, the ultimate load decreased by 6 and 50% for the mixes with fly ash/cement ratio of 150 and 200%, respectively. The ductility indexes were 2.19, 2.94, 2.78 and 3.08 for the mixes with fly ash/cement ratio of 50, 100, 150 and 200 %, respectively. At 4% fiber volume fraction; the ultimate load was 490 kg. On the other hand, the ultimate load decreased by 39, 40 and 51% for the mixes with fly ash/cement ratio of 50, 150 and 200%, respectively. The ductility indexes were 2.65, 2.50, 1.43 and 3.33 for the mix with fly ash/cement ratio of 50, 100, 150 and 200 %, respectively.

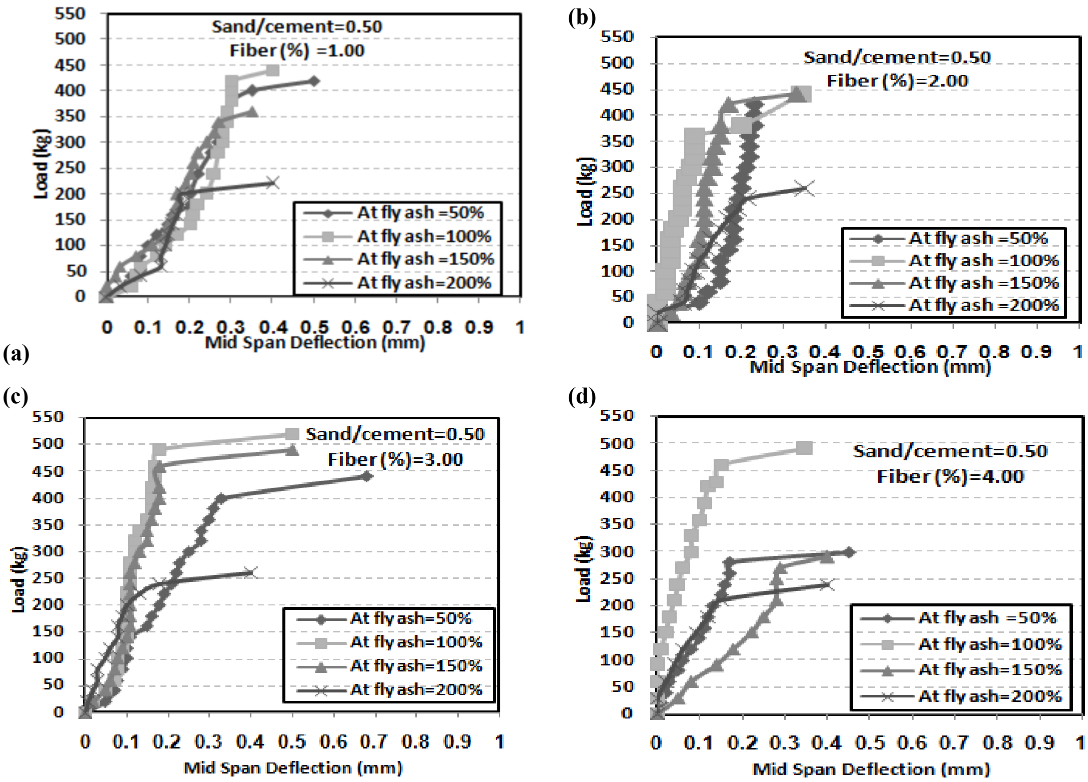


Fig 8: The relation between mid span deflection and load for different fly ash content at S/C=0.50

Fig. (9) shows the relation between the mid-span deflection and load for the mixes with sand/cement ratio of 0.8 containing different fly ash percentages. This figure shows that the load increases up to a ratio 100% fly ash/cement content after that the load was decreased. Fig. (9-a) clear that, The ultimate load was 450 kg for the mixes with Fly ash /cement ratio of 100 % at Vf of 1%. On the other hand, the ultimate load decreased by 13 and 40% at fly ash/cement ratio of 150 and 200%. The ductility index was 2.65, 2.50, 1.43 and 3.33 for the mixes with Fly ash /cement ratio of 50, 100, 150 and 200 %, respectively. The same trends were noticed in figs. (9-b) to (9-d). At 2% fiber volume fraction; the ultimate load was 450 kg for the mixes with Fly ash /cement ratio of 100%. On the other hand, the ultimate load decreased by 3%and 40% at fly ash/cement ratio of 150 and 200%. The ductility index was 2.71, 2.67, 2.50 and 2.67 for the mixes with Fly ash /cement ratio of 50, 100, 150 and 200 %, respectively. At 3% fiber volume fraction; the ultimate load was 550 kg for the mix with fly ash/cement ratio of 100%. On the other hand, the ultimate decreased by 10 and 49% at fly ash/cement ratio of 150 and 200%, respectively. The ductility index was 3.04, 3.06, 3.24 and 5.55 for the mixes with Fly ash /cement ratio of 50, 100, 150 and 200 %, respectively. At 4% fiber volume fraction; the ultimate load was 490 kg for the mixes with Fly ash /cement ratio of 100 %. On the other hand, the ultimate load decreased by 30 and 39% at fly ash/cement ratio of 150 and 200%, respectively. The ductility index was 3.57, 2.91, 1.85 and 4.23 for the mixes with Fly ash /cement ratio of 50, 100, 150 and 200 %, respectively.

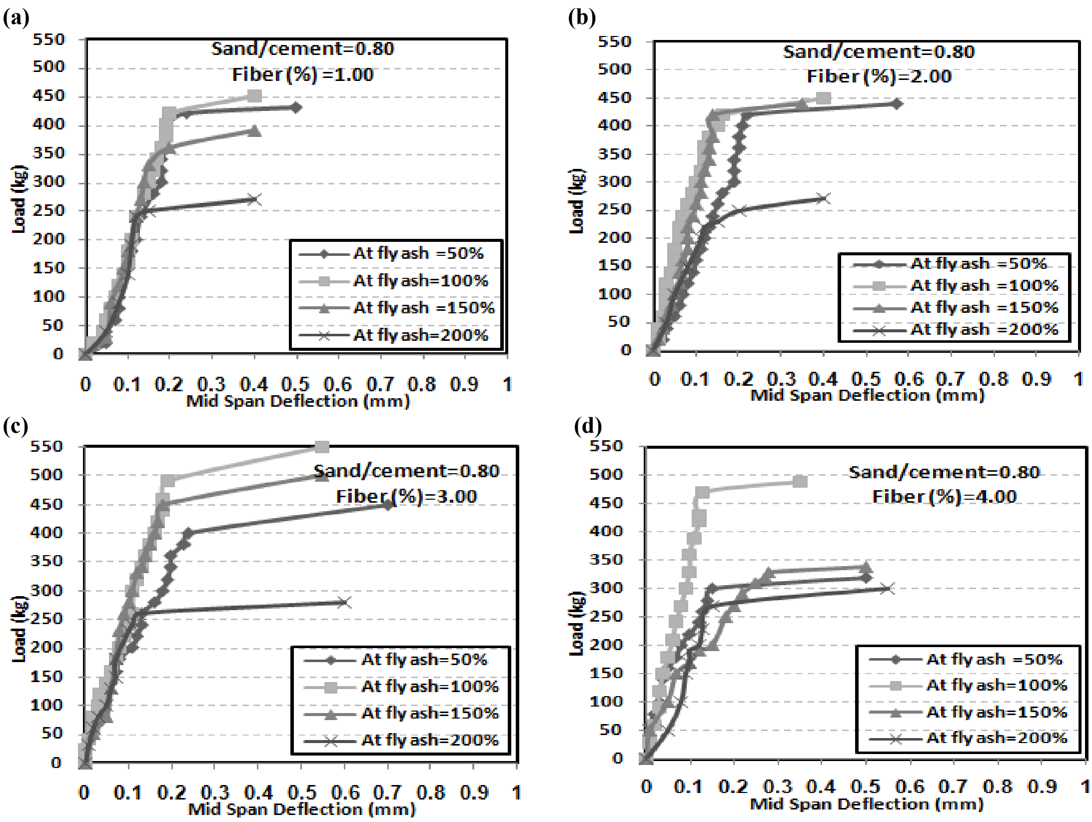


Fig 9: The relation between mid span deflection and load for different fly ash content at S/C=0.80

Fig. (10) and Fig. (11) illustrate the relation between the fly ash/cement ratio and the flexural strength using sand/cement ratio of 0.50 and 0.80 at different fiber percentage. It can be seen; the use of fly ash increased the flexural strength of the mixes. Further increase of fly ash cement ratio more than 100 % did not increase the ultimate flextural strength. Fig. (10) shows the effect of fly ash percentage on the flexural strength at sand/cement ratio of 0.50. For example; the corresponding flexural strength was 63, 66, 54 and 33 kg/cm² at V*f* of 1% for the mixes with fly ash/ cement ratio of 50, 100, 150 and 200 %, respectively. On the other hand, the maximum flexural strength was noticed for the mix with fly ash/cement ratio of 100% at V*f* of 3% fiber volume fraction where the flexural strength was 78 kg/cm². Fig. (11) Shows the effect of fly ash percentage on the flexural strength at sand/cement ratio of 0.80. The same trend was recorded. For example; at 4% fiber volume fraction, the corresponding flexural strength was 48, 66, 51 and 45 kg/cm² for the mixes with fly ash/ cement ratio of 50, 100, 150 and 200 %, respectively. On the other hand; the maximum flexural strength was noticed at V*f* of 3.00% for the mix with fly ash/cement ratio of 100% where the flexural strength was 82.5 kg/cm².

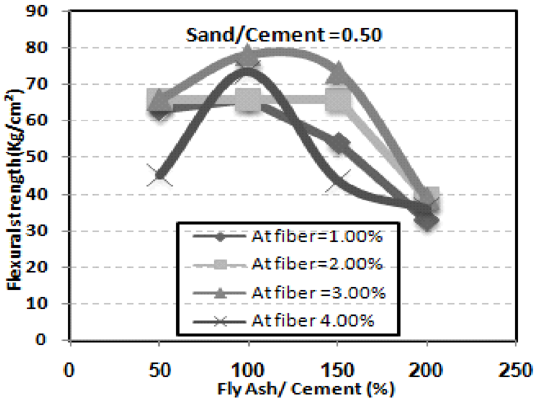


Fig. 10: The relation between (fly ash/cement) and flexural strength

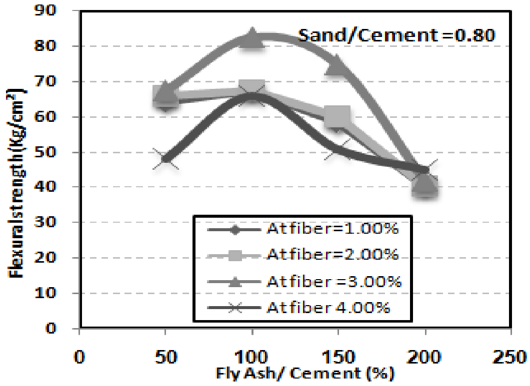


Fig. 11: The relation between(fly ash/cement) and flexural strength

Fig. (12) and Fig. (13) illustrate the relation between the fly ash/cement ratio and the compressive strength using sand/cement ratio of 0.50 and 0.80 at different fiber percentages. It can be seen; as fly ash increased as the compressive strength decreased. Fig. (12) shows the effect of fly ash/cement ratio on the compressive strength at sand/cement ratio of 0.50. For example; the corresponding compressive strength was 153, 143, 129 and 118 kg/cm² at Vf of 1% for the mixes with fly ash/cement ratio of 50, 100, 150 and 200 %, respectively. On the other hand, the maximum compressive strength was noticed fly ash/cement ratio of 50% at Vf of 3% where the compressive strength was 326 kg/cm^2. Fig. (13) Shows the effect of fly ash percentage on the compressive strength at sand/cement ratio of 0.80. The same trend was recorded. For example; at 4% fiber volume fraction, the corresponding compressive strength was 204, 159, 153 and 153 kg/cm² for the mixes with fly ash/cement ratio of 50, 100, 150 and 200 %, respectively. On the other hand; the maximum compressive strength was noticed at Vf of 1.00% and 2.00% for the mix with fly ash/cement ratio of 50% where the compressive strength was 237 kg/cm^2.

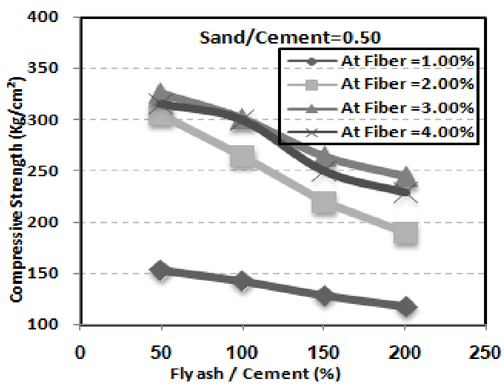


Fig 12:The relation between (fly ash/ cement) and compressive strength

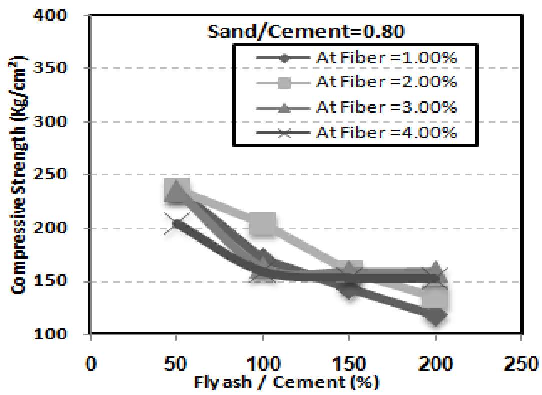


Fig 13:The relation between (fly ash/ cement) and compressive strength

4. Conclusions:

The following conclusions could be drawn from the results of the research carried out to determine the behavior of ECC:

- The mixes with Sand/Cement of 0.80 have larger load carrying capacity by an averages of 25% more than that of similar mixes with sand/cement of 0.50.
- The ductility index of the mixes with sand/cement of 0.80 was more than that of the mixes with sand/cement of 0.50 by an averages of 25%.
- The ductility index was increased by increasing the percentage of fiber volume fraction up to a ratio of 3.00%, after which the ductilty index was reduced.
- The flexural strength increased by increasing the percentage of fiber volume fraction up to a ratio of 3.00%, after which the flextural strength was reduced.
- The compressive strength increased by increasing the percentage of fiber volume fraction up to a ratio of 3.00%, after which the compressive strength was reduced.
- The ductility index was increased as the fly ash / cement ratio increased.
- The flexural strength increased by increasing the percentage of fly ash / cement ratio up to a ratio of 100% fly ash/cement ratio, after which the flexural strength was reduced.
- The compressive strength decreased by increasing the percentage of fly ash / cement .

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