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Behavior of Reinforced Concrete Columns with (PVA) Under Fire

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HIGHLIGHTS

- Behavior of Concrete Columns Containing Poly Vinyl Alcohol fibers (PVA).
- Concrete columns exposed to variable periods of firing at 600^{0}C.
- ECC Columns exhibits an improvement in terms of ultimate loads, stiffness, and fire resistance.
- No signs of spalling were observed for ECC columns.

الملخص:

في هذا البحث نقدم اسلوب جديد لتحسين خواص الخرسانة في الشد والضغط ومقاومة الحريق وهذه التقنيه تعرف بالمركبات الاسمنتية الهندسية (ECC) وهي عباره عن خرسانة مكوناتها اقرب للخرسانة المعروفة ولكن مضاف اليها انواع من الالياف اهمها والاكثر توافق معها هي الياف تسمي (PVA) ويتميز هذا النوع من الخرسانة بتحسين خواص الضغط والشد ومقاومة الحريق وكذلك زيادة معدل امتصاص الطاقة ومقاومة العناصر الانشائية للتشوهات الجانبية وتحسين الممطولية وغيرها من الخواص التي تساعدنا علي انتاج عناصر خرسانيه انشائية بأفضل اداء وبتكلفة مناسبة.

ويهدف هذ البحث المعملي الي درسة سلوك الاعمدة الخرسانية المسلحة المحتوية علي الياف (PVA) والمعرضة لاحمال ضغط محورية وغير محورية مختلفة تحت تأثير مدد زمنية مختلفة من الحريق عند درجة حرارة 600 ^{0}م وتحديد تأثير هذه الالياف علي سلوك تلك الاعمده حيث اثبتت النتائج ان الاعمده المحتوية علي الياف (PVA) سلوكها افضل من تلك الغير محتوية علي الالياف وذلك في نواحي الشد والضغط ومقتومة الحريق بالاضافة الي مقاومة التشوهات الجانبية والقدرة علي امتصاص الطاقة.

ABSTRACT

Engineered cementitious composite (ECC) is a kind of high-performance material, it is featured by resistance to spalling, cracks, fire, and compressive stress of concrete. Polyvinyl Alcohol (PVA) fibers were considered as one of the most suitable polymeric fibers to be used as the reinforcement of engineered cementitious composites (ECC). So, an experimental research was carried out to study the behavior of concrete columns containing Poly Vinyl Alcohol fibers (PVA) under fire conditions and axial compression loads. In this research, a total of five reinforced concrete columns with constant longitudinal and transvers reinforcement, one of them had no fiber (control specimen) and the others containing constant ratio of polyvinyl Alcohol fibers (PVA)=0.75% of concrete volume as a main component of concrete mix subjected to variables periods of fire (0.0 min,30 min,60min,and 120 min) of firing at 600^{0}C were tested under concentric compression . The results proved that reinforced columns with (PVA) fiber gave higher results than concrete column without (PVA) fiber in terms of ultimate loads, stiffness, and fire resistance.

Keywords: Concrete Columns, ECC, PVA fiber, Fire, Concentric compression, axially loaded.

1. Introduction

The concrete material is unique as it is characterized by high resistance to compression but also has many disadvantages such as inability to tensile and fire resistance in addition to brittleness that lead to sudden collapse of concrete elements without warning, which poses great danger to the lives of humans. But must be said that the concrete like the stew by adding certain materials can avoid these disadvantages. It is also known that concrete structures consist of several elements of reinforced concrete especially, reinforced concrete column is a main carrier of loads in concrete structures when subjected to abnormal conditions that cause cracks and problems of concrete structures.

one of the main problems Affecting Reinforced concrete column is exposed to high compression concentric loads outweigh their resilience and also when exposed to elevated temperatures during fire that leads to total collapse and cracks overall concrete structure.in the last decades many methods and additions have been using with reinforced concrete columns in previous research to improve its resistance to fire, tensile and compressive strength. Hadi [1], tested seven circular reinforced concrete columns in the presence of variable ratios of polypropylene fibers (P.P) (0.00%,0.10%,0.30%) to study the effect of using (P.P) to increase compressive strength. The results showed that Increasing the fiber content from 0.1% to 0.3% results in higher strengths being reached before cover spalling takes place. Khalil et al.[2],tested fourteen (HPC) square columns containing variable ratios of steel fibers to study its behavior under axil compression load. The results showed that using fibers in NSC and HPC columns increases the maximum load. The percentage increase in maximum strength at constant steel fiber ratio is slightly decreased with the increase in fiber ratio.

Shihada and Nassar [3], tested 102 concrete columns reinforced with variable polypropylene fibers ratios (0, 0.45 and 0.67) kg/m3 which exposed to variable temperatures (400^0C , 600^0C and 800^0C) at different times (2 ,4 and 6 hours) under uni-axial compression to study the effect of using polypropylene fibers in improving fire resistance of reinforced concrete. The results showed that for unheated fibrous columns there was 5% gain in strength for ratio 0.45 g/m3 and 9% gain in strength for ratio 0.67 kg/m3 comparing with non-fibrous columns. For heated fibrous columns at 400^0C there was 20% gain in strength for ratio 0.67 kg/m3 and at (600^0C, 800^0C) there was 10% gain in strength for the same fiber ratio comparing with heated non-fibrous columns. Also, studies proved that using glass fiber improves fire resistance of concrete elements such that [4]tested eighteen reinforced concrete beams containing variable volume fractions of glass fibers (0.00%,0.50%,1.00%) to study the behavior of them when exposed to fire temp.(500^0C). The results proved that using 0.50 % of glass fiber increase residual stiffness and decrease deflection for heated beams which containing glass fiber comparing with heated control beam.

But in this paper, we will introduce a new technic to increase resistance to fire and consider a solution to the problem of ductility in concrete, it is known that the concrete is a brittle material and this leads to a sudden collapse of structure without warning specially with firing the columns collapsed dramatically when subjected to Low compression loads and this is one of the most important problems that must be studied to develop appropriate solutions and the best of these solutions is called Polyvinyl Alcohol Fiber Reinforced Engineered Cementitious Composites (PVA-ECC).

Polyvinyl Alcohol (PVA) fiber was created in japan for 50 years ago which produced by the polymerization of vinyl acetate to poly (vinyl acetate) (PVAc), followed by hydrolysis of PVAc to PVA. Also, (PVA) fibers had high mechanical properties comparing with other types of fibers which were used as a reinforcing material for cementitious composites [5]. Wang and Li [6], studied properties of Polyvinyl Alcohol fibers reinforced Engineered Cementitious Composites (PVA-ECC) in terms of tensile, flexure, compressive strength. the results showed that tensile stress was more than 5 MPa while the crack width still under 60 μm on the other hand flexure and compressive stress was more than 75 MPa and 15 MPa respectively. Noushini et al.[7],proved that air content, slump and density of concrete decreased by increasing (PVA) fiber ratio and length.

Yuan et al.[8],tested eight reinforced ECC columns which had a constant ratio of PVA=2% under eccentric compression load at 40mm and 120mm. the results proved that the ultimate strength of the ECC columns increased by 35.6%and 31.8% when the load eccentricity was 40 mm and120 mm respectively.

Shanour et al.[9], studied flexural performance of concrete beams containing engineered cementitious composites, they proved that the maximum load increases by 20% and 34% for 1.0% and 2.0% of PVA contents in total section respectively. The relative ductility factor increases by 30% and 45% for 1.0% and 2.0% of PVA content.

2. Materials and Concrete Mix Proportions

2.1. Materials

Materials used in this research were ordinary Portland cement as bonding material, basalt as coarse aggregate, pure sand as fine aggregate, polyvinyl Alcohol (PVA) fibers , tap water and two types of reinforcement the first type was high tensile deformed steel bars of diameter 12 mm with yield strength fy= 360 N/mm^2 were used as longitudinal reinforcement for columns and the second type was mild steel bars of diameter 8 mm with yield strength fy= 280 N/mm^2 were used as stirrups reinforcement for columns. Properties of used materials are shown in Tables 1,2, and 3. The shape of (PVA) fiber indicated in Fig.1.

Table 1: Properties of the used ordinary Portland cement.

Property	Test value
Initial Setting Time (min)	85
Final Setting Time (min)	230
Compressive strength at 3 days (MPa)	22
Compressive strength at 7 days (MPa)	30

Table 2: Properties of Coarse Aggregate (Basalt) and Fine Aggregate (Sand).

Property	Basalt	Sand
Specific Gravity	2.60	2.5
Bulk Density (t/m3)	1.70	1.60
Max Aggregate Size (mm)	22.4	---
Fineness modulus	---	2.65

Table 3: Properties of the Polyvinyl Alcohol (PVA) fiber.

Length (mm)	Diameter (mm)	Tensile strength (MPa)	Young's Modulus (GPa)	Density (g/cm3)	Elongation (%)
6	0.04	1600	37	1.30	6

Fig. 1. Shape of polyvinyl alcohol (PVA) fibers.

2.2 Concrete mix proportions

Two mixes were designed according to (PVA) fibers ratio to obtain compressive strength = 30 MPa after 28 days as shown in Table 4. Mix-1 expresses concrete without (PVA) fibers or reference mix. Mix-2 concrete with (PVA) fibers as a percentage of concrete volume (Vf_2= 0.75 %).

Table 4: Mix Proportions of Concrete mixes.

Mix	Water	Cement	Fine Agg.	Coarse Agg.	PVA	Fiber content (V_f) %
	(kg/m3)					
Mix-1	192	400	624	1122	0.00	0.00
Mix-2	192	400	624	1122	9.75	0.75

2.3 ECC Concrete mixing process.

Mixing was performed in a horizontal pan mixer. Firstly, (PVA) fiber were mixed manually by hand Until were separated from each other to ensure good distribution through the mix. Thereafter, cement and (PVA) fiber were also mixed manually. Then , sand and basalt were mixed together in a pan mixer for 3 minutes to provide a uniform distribution .And then, cement and (PVA) fiber were introduced and mixed in a pan mixer for a further 3 minutes to obtain ideal distribution. Finally, water was introduced and mixed with all the above components for a further 3 minutes to obtain a homogeneous mix .Then, six cubes, three cylinders and three beams were casted from each mix to carry out compression, tensile, and flexural test on them respectively as we will show in following section. Fig.2. illustrate mixing steps for each mix.

(1) (2)

(3)

Fig.2. steps of mixing process.

3. Hardness Properties of Concrete Mixes

To ensure access to the required strength in this research, must be study the properties of hardness concrete as compressive, tensile, Young's modules and flexural strength according to the Egyptian Code of concrete tests. So, six cubes with dim 100x100x100 mm, three cylinders with dim 100x200 mm, three cylinders with dim 150x300 mm and three beams with dim 100x100x500 mm were casted for each mix and tested to determine hardness properties of concrete mixes as compressive, tensile, and flexural strength respectively. The results of tests are shown in Table 5.

Mix No.	% Fibers	Compressive Strength at 7 days (MPa)	Compressive Strength at 28 days (MPa)	Splitting Tensile Strength at 28 days (MPa)	Flexural Strength at 28 days (MPa)
Mix-1	0.00	22.60	30.70	1.46	5.56
Mix-2	0.75	24.20	33.10	2.04	7.63

Table 5: Properties of hardened concrete mixes.

4. Test Program

4.1. Test specimens

Experimental program was carried out on five reinforced concrete columns with square section shape as indicated in Fig.3 to be exposed to axial compression with dimensions (120x120x1000) mm. A total of five columns were classified to a column had no fiber (control specimen) was tested at room temp. (0.0 min) and the others had fiber content=0.75% of concrete volume were exposed to variable periods (0.0 min,30 min, 60 min, and 120 min) of fire exposure at 600 ^{0}C .Table 6 clarifies the information of concrete dimensions and reinforcement of five tested columns in detail.

Table 6: Details of test columns.

Col No.	Col -dim mm.	Clear-Length mm.	Area mm^2.	µ%	RFT mm.	Stirrups mm.	Fiber content (PVA)%	Time of fire T (min)
C1	120x120	1000	14400	3.14%	4 Ø 12	Ø 8	0.00	0
C2	120x120	1000	14400	3.14%	4 Ø 12	Ø 8	0.75	0
C3	120x120	1000	14400	3.14%	4 Ø 12	Ø 8	0.75	30
C4	120x120	1000	14400	3.14%	4 Ø 12	Ø 8	0.75	60
C5	120x120	1000	14400	3.14%	4 Ø 12	Ø 8	0.75	120

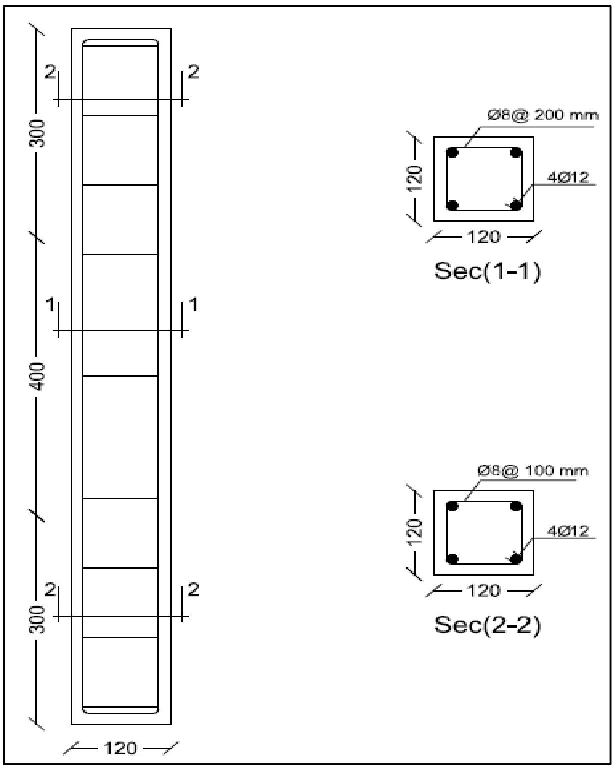

Fig. 3. Geometry and details for tested column.

4.2. Test setup

The column specimens were tested under framing load with capacity (1000 KN) to identify the ultimate failure load of columns. A horizontal linear variable displacement transformers (LVDT) with stroke was +/- 100 mm with 0.1 sensitively was placed in the mid-height of column during loading by loading jack (1000 KN capacity) as indicated in Figs.5 and 6 to determine the lateral deflection which occurs during and after loading. Four columns were subjected to fire at 600 ^{0}C by using electrical furnace consists of eight electrical heaters with capacity (1200 ^{0}C).

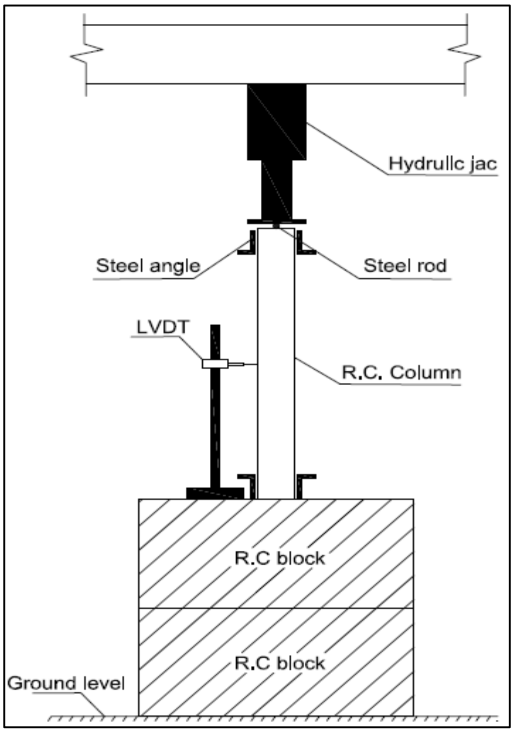

Fig. 5. setup for tested column.

Fig. 6. Typical column during testing.

5. Experimental results and discussion

5.1. Test results

The results of test are mentioned in Table 7. The table shows the values of ultimate failure load, ultimate deflection, stiffness, energy absorption and ductility for all tested columns.

Table 7: Test results.

Col No.	Fiber content (PVA)%	Time of fire T (min)	Ultimate load Pu (KN)	Ultimate deflection (mm)	Stiffness K (KN/mm)	Energy absorption (KN.mm)	Ductility factor
C1	0.00	0	575	2.75	213.30	976.50	1.38
C2	0.75	0	600	3.00	222.90	1290.30	1.56
C3	0.75	30	473	3.25	139.50	1205.30	1.46
C4	0.75	60	382	4.25	97.90	1020.10	1.35
C5	0.75	120	234	5.00	49.00	839.40	1.24

5.2 Discussion of results

After analyzing the results in general, it is clear that the presence of PVA fiber enhance behavior of concrete columns in terms of ultimate load failure, fire resistance, stiffness, energy absorption, crack control, and ductility.

5.2.1 Effect of PVA fiber on ultimate load at variable fire periods

One of the most significant properties of PVA fiber as previous research have mentioned was high resistance to fire[10-11].The results of ultimate loads of all tested columns were mentioned in Table 7. Noteworthy, no signs of spalling occurred in ECC columns and the reason for this known as fiber bridging effect such that when concrete subjected to elevated temperatures leads to capture water vapor in concrete but the existence of ECC materials form ways to escape water vapor through it which leads to enhance fire resistance of concrete. For column C2 at room temp. (0.0 min) with fiber content 0.75% the percentage increase in ultimate load was 4.50%compared to C1. Additionally, for columns C3, C4, and C5 which subjected to periods (30min,60min, and 120 min) of fire at 600^{0}C the ultimate load decreased because of firing exposure by 27.00%,57.00, and 156.00% respectively compared to C2.

5.2.2. Modes of failure

Previous research have proved the ability of ECC materials to control the width of crack up to 60µm to 100µm [12]. Generally, it was noted that the behavior of ECC columns was higher than non-fibrous columns such that for ECC columns micro cracks appeared during loading which spread out by increasing the load till reach to its ultimate load then load started to decrease while concrete has to maintain consistency during failure. Noteworthy, for all columns, local failure occurred before top and bottom ends of the columns. Failure modes are shown in Figs.7,8,9,10, and 11.

Fig. 7. Failure mode of Specimen C1

Fig. 8. Failure mode of Specimen C2

Fig. 9. Failure mode of Specimen C3

Fig. 10. Failure mode of Specimen C4

Fig. 11. Failure mode of Specimen C5

5.2.3. Load-deflection curves

The results of loads versus lateral deflections for all columns were recorded by using Laboratory instrument then a relationship has been plotted between them. Load-deflection curves for all tested columns are shown in Fig.12. Generally, it was noted that the behavior C2 (ECC column) was better than C1 (column without PVA fibers) such that stiffness increase and lateral deflection decrease while load increase in the existence of PVA fiber. So, the existence of PVA enhance the ability of the columns to resist lateral deflections and also enhance its ability to carry higher loads.

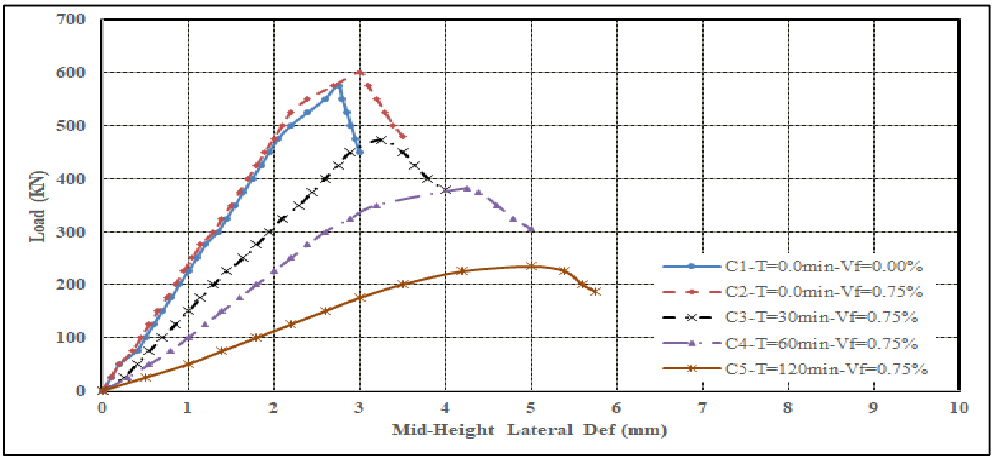

Fig.12. Load–mid-height deflection curves of tested columns.

5.2.4. Stiffness (K)

Stiffness is defined as the slope of load deflection curve till maximum load. Stiffness was calculated by approximate method[13] and its values were mentioned in Table 7. It was noted that stiffens increase in the presence of PVA fiber. For C2 column at room temp. (0.0 min) fire exposure with fiber content 0.75%, the percentage increase in stiffness was 5.00% compared to C1. For C3, C4, andC5 columns at 600^{0}C fire exposure for (30min, 60 min, and 120 min) with fiber content 0.75% the stiffness decreased by 59.00%,127.00%, and 354.00% respectively compared to C2.

6. Conclusions

This paper studied the behavior of concrete columns containing Engineered Cementitious Composites (ECC) under fire. Depending on the results presented in this study, the main necessary conclusions are as the follows:

- Generally, the results proved that ECC columns gave better behavior than non-fibrous columns in terms of ultimate loads, stiffness, and fire resistance.
- Using of fiber content =0.75% increase results in terms of ultimate load and stiffens by 4.50% and 5.00% respectively.
- Using of fiber content =0.75% increase results in terms of energy absorption and ductility by 32.00% and 13.00% respectively.
- For columns which containing PVA fiber micro cracks occured during loading which spread out by increasing the load till reach to its ultimate load then load started to decrease while concrete has to maintain consistency during failure. On the other hand, for columns without PVA a brittle local failure occurred directly after reach to its ultimate failure load which leads to sudden collapse.

- No signs of spalling appeared on ECC columns and the main reason for this called fiber bridging effect such that when concrete subjected to elevated temperatures leads to capture water vapor in concrete but the existence of PVA form ways to escape water vapor through it which leads to increase fire resistance of concrete.

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