ERJ
Engineering Research Journal
Faculty of Engineering
Minoufiya University

ASSESSING THE BEHAVIOUR OF CONCRETE REINFORCED WITH DIFFERENT POLYPROPYLENE FIBER TYPES

تقييم سلوك الخرسانة المسلحة بأنواع مختلفة من ألياف البولي بروبلين

Abu-Khashaba M. I.
Associate Professor, Construction Research Institute, Delta Barrages, Egypt

تم تنفيذ برنامج معملى لتقييم تأثير أنواع مختلفة من ألياف البولي بروبلين المتاحة التي يتم توريدها/إنتاجها بواسطة شـركات مختلفة على السلوك الميكانيكى للخرسانة، وذلك من خلال دراسة فعالية استخدام الألياف فـي تحـسين الـسلوك الميكـانيكى للخرسانة. وتتضمن هذه الدراسة استخدام خمسة أنواع مختلفة جميعها من الألياف المصنوعة من مادة البولي بروبيلين "PPF" لاختبارها وتقييمها. وخصص البحث الحالي لتحديد أنسب أنواع الألياف البولي بروبلين الموردة ليتم التوصية بتطبيقهـا مـع الخرسانة بعد تحديده واختياره من بين الألياف المختلفة الموردة من قبل الشركات المختلفة. تـم تـصميم خلطـة الخرسـانة المطلوبة لفحص الخصائص الميكانيكية المختلفة لها بعد إضافة أنواع الألياف المختلفة كلاً على حده. وقد تم اختبـار العينـات بعد معالجتها فى المياه لمدة 7 و 28 يوما. وقد تم إجراء وفحص اختبارات المتانة مثل البرى والانكماش (اللـدن / الجـاف).
وتشير النتائج إلى أن معظم عينات PPF البولي بروبلين فيبر المختبرة أثبتت كفاءتها في تحسين مقاومـة الخرسـانة للبـرى والتحكم فى انكماش الخرسانة سواء كلاً من الانكماش اللدن والجاف، وكذلك الحد من تكون الشقوق واتـساعها فـضلا عـن حسن توزيعها على طول السطح الخرسانى. وباستخدام PPF-2/ PPF-3 ، يمكن تحسين مقاومة الخرسانة للبـرى بنـسبة تصل إلى 35٪ مقارنة بقيمها الأصلية. وباستثناء PPF-1 ، تم خفض قيمة الانكماش اللدن باستخدام PPF في نطـاق 32 % - 61 % من القيم الأصلية المسجلة، وكذلك تم تقليل قيمة انكماش الجفاف عند عمر 28 يوما ليصل إلى حوالى 63 % من قيمته الأصلية باستخدام ألياف PPF ، ومن الممكن أيضا تحسين الخواص الميكانيكية المختلفـة باسـتخدام أليـاف PPF وخصوصا مقاومة الخرسانة للشد بدرجة ملموسة.

ABSTRACT

This research was initiated with the objective of evaluating the effect of different polypropylene fibers on the mechanical characteristics of the concrete, experimentally. This was achieved by examining the effectiveness of fiber addition in order to improve the concrete mechanical behavior. Five types of polypropylene fiber (PPF) were investigated to select an appropriate fiber to be added to the concrete mixture based on its purpose. A concrete mixture was designed and its different mechanical characteristics were examined. Specimens were tested after curing (i.e. after 7 and 28 days). Durability tests (i.e. abrasion, plastic/drying shrinkage and temperature differences exposure) were investigated. The results indicated that using PPF, randomly, helps to bridge and arrest the formed cracks in the concrete under different stresses such as that resulted from temperature differences exposure. Most of the tested PPF added to the concrete mixes proved its efficiency in improving the concrete abrasion resistance, controlling plastic so as drying shrinkage cracking as well as reducing it and enhancing its distribution along the concrete surface. Using PPF-1/PPF-2 could improve the abrasion resistance up to 35%. Also, the plastic shrinkage strain is minimized by 32% to 61% compared to its original value.

Keywords: Polypropylene Fibers (PPF); Inclusion; Durability; Abrasion; Plastic; Drying; Shrinkage; Resistance; Cracking; Tensile Properties.

1. INTRODUCTION

Historically, inclusion of fiber in construction is a very old process. For example: Ancient Egyptians used straw to reinforce mud bricks [1]. There is evidence that asbestos fiber was used to reinforce clay posts about 5000 years ago. The market for fiber reinforced concrete, FRC is still small compared to the overall production of concrete. FRC is concrete containing fibrous material that increases its structural integrity [2]. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers, each of which lends varying properties to the concrete. In addition, the characteristics of FRC changes with varying concretes, fiber materials, geometries, distribution, orientation, and densities [1-2]. Low inclusion volume of fibers, reduces shrinkage cracking. These fibers are used in slabs and pavements that have large exposed surface leading to high shrinkage crack. Using of discrete glass fibers with concrete mixes enhanced the ductility and deformability of R.C members. Experimental results indicated that the shear strength of tested beams was significantly increased as the percentage of fibers increased [3-6]. Since disperse fibers offer various advantages of steel bars and wire mesh to reduce shrinkage cracks:

- The fibers are uniformly distributed in three-dimensions making an efficient load distribution.

- The fibers are less sensitive to corrosion than the reinforcing steel bars and steel fibers.
- The fibers can reduce the labor cost of placing the bars and wire mesh. Moreover, incorporating fibers, could change the failure mode for concrete from a brittle, sudden and explosive failure to a ductile one.

In terms of the importance of fiber inclusion into concrete, this research was thus initiated with the objective of evaluating the different polypropylene fibers, experimentally. Primarily, literature, in the field of FRC, was reviewed. Experimental work was carried out in order to examine the effectiveness of fiber addition to improve the concrete behavior. Five locally available types of polypropylene fiber, PPF, supplied by different companies were investigated. The effect of PPF on the different characteristics of concrete was evaluated. The above investigation steps are presented in the present paper under the following headlines:

- Reviewing the literature in the field of FRC
- Carrying out experimental work
- Executing computations
- Presenting the research results

2. LITERATURE REVIEW

Ronald, F.Z. [1] discussed the subject of fiber-reinforced concrete (FRC) and an overview of the types of commercially available FRCs and how they work were presented. As stated by [2], in North America there is a yearly growth rate of 20% of using FRC. It was also mentioned that, worldwide, the yearly consumption of fibers used in concrete is 300,000 tons. It is mentioned by [1-2] that the classification according to fiber volume fraction is:

- Low: the volume fraction, v_f, is <1%.
- Moderate: v_f is between 1 and 2%.
- High: v_f is greater than 2%.

The mechanical properties of FRC are influenced by the type, aspect ratio and amount of fiber; strength of the matrix; size, shape, and other properties of the aggregate (i.e. the size, shape, and method of preparation of the test specimen), [3-7]. Mostafa, A.E.M, [8] stated that incorporation of high strength fibers can improve the weakness and brittleness of concrete in tension. Incorporating the fiber reinforcement can achieve a remarkable improvement in concrete properties (i.e. cracking behavior, fracture toughness, fatigue/impact resistance, and flexural strength. The primary purpose of inclusion of fibers in conventionally R.C members is not for increasing strength. The strength can be increased more easily and economically by using steel bars placed along the direction of principal tensile stresses [7]. The deficiencies of ordinary R.C in the form of micro-cracks, which cannot be corrected by bar reinforcement, can be remedied to a significant extent by using fiber reinforcement. Addition of randomly oriented fibers in plain concrete mixes help to bridge and arrest the cracks formed in the brittle concrete under applied stresses, and enhances the ductility and energy absorption properties of the composite. Among the various produced fibers that are applied in concrete, steel fibers are superior in improving the engineering concrete properties and are used in wide range applications as outlined by [8-9]. However; corrosion is still the main obstacle for using it in extreme severe conditions. The potential of discontinues steel fibers (i.e. as reinforcement for concrete) was evaluated to improve its properties [10]. A cheap type of synthetic fibers, named as polypropylene, has excellent reinforcing characteristics for use in concrete products [11]. Since the early 1960s, PPF have been applied in ordinary concrete to improve the RC serviceability [12]. The effect of PPF on the plastic shrinkage cracks of HSC in concrete pavements and floor systems was investigated [13]. The cracking of FRC is more uniformly dispersed, and has smaller crack width than the unreinforced concrete [14]. Craig, R.J. [15] mentioned that the toughness and fracture energy for FRC concrete is higher than that of plain concrete. A noticeable enhancement in the concrete tensile strength was gained using low fiber content even it has little effect on density and thermal conductivity [16]. As mentioned by Lovata, N.L., et al [17], the compressive strength of the fiber composite could be improved by treating it chemically. Furthermore, the nominal stress at shear cracking and the ultimate shear strength increased with increasing the fiber volume, decreasing shear span-to-depth ratio, and also increasing the concrete compressive strength. The fiber content increases, the failure changes from shear to flexure mode [18]. Bazent Z.P., et al [19] mentioned that the diagonal shear failure of R.C beams is known to be a brittle failure. Therefore, a larger safety margin is provided by the capacity reduction factor in the codes. The present code formulas were calibrated to provide adequate safety against the initiation of diagonal shear cracks [20]. Ideally, the design should insure proper safety margins against failure and crack initiation. Zararis, P.D., et al [21] outlined that the shear failure of R.C beams is brittle and occurs suddenly. The fiber concrete is designed to carry the full shear capacity. The number of cracks increased by using discrete fibers and became finer. Moreover, the crack propagation and modes of failure may be changed by using discrete fibers. The discrete fibers increase ductility and failure loads of the tested beams [22].

3. EXPERIMENTAL WORK

An experimental program was conducted. It included physical and chemicals tests carried out on polypropylene fibers, PPFs in order to determine its properties. A concrete mix was designed. The absolute volume method was implemented to define the different proportions appropriate for the common concrete grade of about 30 MPa. (i.e. after adjusting both the used sand and gravel content with the required w/c ratio).

Different tests were carried out to examine the effect of various PPF on the mechanical properties of the concrete. Five PPF were selected to be examined in this research, therefore concrete mix proportions was determined. Table (1) lists these proportions.

3.1. Concrete Mix Proportions

A concrete mix was designed with an approximate compressive strength of 30 N/mm^2. Ordinary Portland cement (CEM I 42.5 N) produced according to the Egyptian standards 4756 was used. High range water reducing agent conforming to ASTM C444, "MC43-Type G" was added to all concrete mixes for improving concrete workability with dose of 1.85 kg/m^3. Polypropylene fibers, PPF, of length 19 mm were used for all mixes. The designed mix was applied for all tested specimens. PPF, produced/supplied locally by different companies was basically used with content of 0.9 Kg/m^3 as recommended by the producer. Five supplied PPF had the same length of 19 mm, were examined. A reference control specimen without PPF and five types of PPF were investigated. All supplied five various PPF are sampled in order to determine their physical and chemical properties. Figure (1) shows the photo of one of the tested PPFs, while the results of physical and chemical properties of PPF are listed in Table (2).

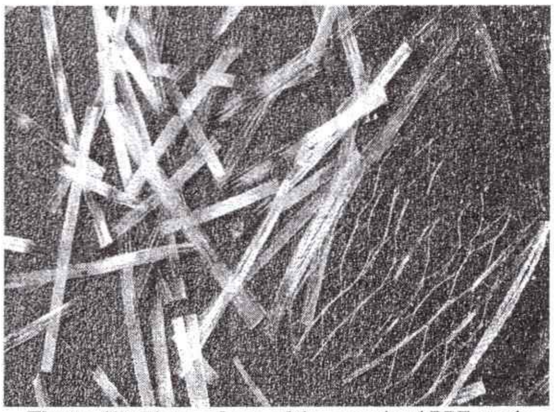

Figure (1): Photo of one of the examined PPF mesh

3.2. Experimental Procedure

The followed mixing procedure can be summarized in the following steps:

1. The various components of the mixture are weighted.
2. The coarse aggregates "gravel" were added in the mixer followed by cement and sand. The grain size distribution of the fine and coarse aggregates are shown in Figs. 2-3. The natural siliceous gravel with a nominal maximum size of 20 mm and specific gravity of 2.50 was used as coarse aggregate. The grain size distribution of coarse aggregate confirming to the ECP is shown in Fig. 2 and the test, was performed in accordance with the ASTM-D422 test method for particle size analysis of soils.
3. These components are flipped in dry blender for 30 seconds with the distribution of the amount of fiber in the mixture during that period.
4. The amount of water is added during the continuous mixing of different components for a period of 60 seconds.

Table (1): Used concrete mix proportions

Mix Code	Proportions Content, Kg/m^3					
	Gravel	Sand	Water	Cement	Admixture	Fiber
Control	1210	640	163	350	1.85	-
PPFC	1210	640	163	350		0.90

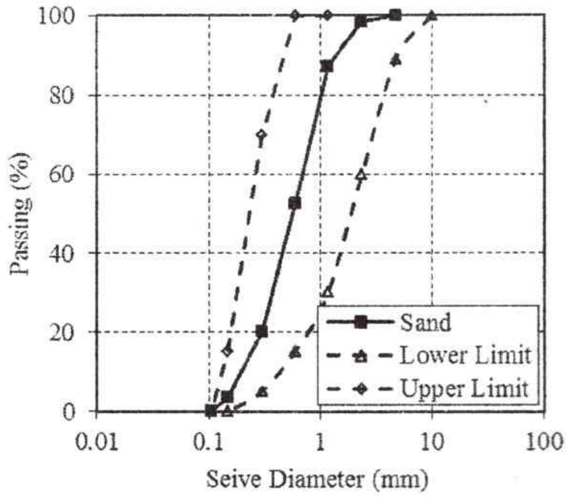

Figure (2): Grain size distribution of fine aggregate

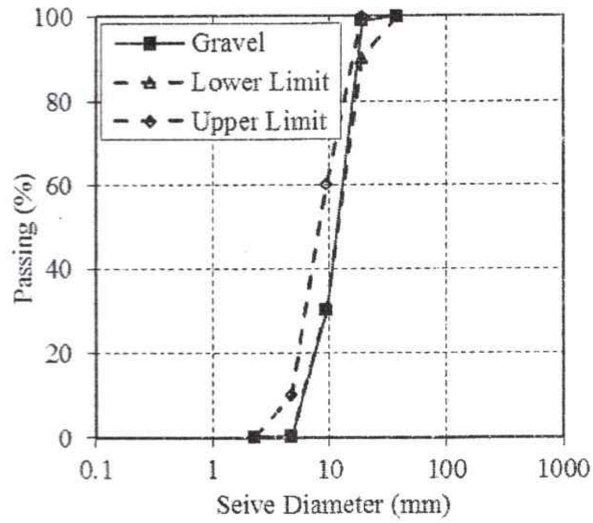

Figure (3): Grain size distribution of coarse aggregate

Table (2): Physical and chemical properties of PPF

Fiber Type	PPF-1	PPF-2	PPF-3	PPF-4	PPF-5
Length, mm	19	19	16-21	19	19
Nominal Diameter of fiber, µm	75	60	52	64	95
Danner value of fiber	7200	7600	7100	7640	11640
Water absorption, %	0	0	0	0	0
Specific weight, gm/cm^3	0.90	091	0.90	0.92	0.92
Melting degree	162°C	165°C	161°C	-	163°C
Combustibility degree	600°C	610°C	600°C	-	600°C
Acids, alkaline & salts resistance	100%	100%	100%	100%	100%

5. The mixer was stopped and mortar was downloaded and fiber that stuck on the blades of the mixer was removed using an iron bar.
6. Mixing continued for another 60 seconds to reach total mixing time of2.5 minutes "150 seconds".
7. Concrete was poured in the oiled steel moulds for the preparation of samples and the necessary work of mechanical compaction using vibrator.
8. Samples were extracted from the moulds in the next day and were put in the treatment basin until the time of testing.
9. Specimens were prepared and tested according to ASTM standards. The test results for the different categorizes of every mix were determined and then tabulated and plotted.

3.3. Type of Tests

The laboratory program that was conducted to evaluate the behavior of different types of fiber supplied by various companies is conducted as follows:

3.3.1 Fresh properties tests

Penetration resistance test was carried out to determine initial and final setting time, IST, FST according to ASTM C403 and slump was also determined based on ASTM C143 for fresh concrete properties.

3.3.2 Hardened properties tests

- Concrete cubes with dimensions of 150 x 150 x 150 mm were poured and tested to determine the compressive strength of these samples after 7 days and 28 days.
- Cylinders of 100 mm diameter and 200 mm height were poured and tested to determine the indirect tensile strength of the concrete after 7 days and 28 days.
- Concrete beams of dimensions 100x100x500 mm were poured and tested to determine the concrete flexure strength after 7 days, 28 days and shrinkage.
- Specimens of 73 mm length, 70 mm width, and 40 mm thickness for abrasion test after 28 days.
- Cubes 100 x 100 x 100 mm were cast for the test of exposure to temperature differences.

The supplied PPF was evaluated in terms of IST, FST, slump, compression test, split tensile test and flexure test, as well as some durability tests such as abrasion, exposure to temperature differences and both plastic and drying shrinkage.

4. EXECUTING COMPUTATIONS

The strength of the fiber reinforced concrete can be measured in terms of its maximum resistance when subjected to either compressive, tensile, and flexure loads as well as abrasion and shrinkage. Compressive strength (f_c) for the tested specimens was calculated according to Egyptian Standard Specifications. Split tensile test is an indirect test to determine the tensile strength of concrete. Split tensile strength (f_{spl}) was calculated according to ASTM C496:

$$f_{spl} = 2P/\pi ld \qquad (1)$$

Where: P = maximum applied load, l = specimen length, *and* d = specimen diameter.

The flexural strength under 4-point loading was calculated according ASTM C78 as the modulus of rupture and can be denoted by (f_{flex}):

$$f_{flex} = Pl/bd^2 \qquad (2)$$

Where: P=maximum applied load, l=span length, b=average specimen width, and d=average specimen depth.

5. PRESENTING THE RESEARCH RESULTS

The performance of polypropylene fiber reinforced concrete, PPFRC was evaluated based on the examinations of 6 concrete specimens that were casted with the same concrete proportions to examine the effect of various PPF on the properties of fresh and hardened concrete as follows:

5.1. Effect of PPF, on Concrete Slump and Setting Time

Table (3) shows the results of slump test conducted for the tested specimens and the effect of the various examined PPF on both initial setting time (IST) and final setting time (FST) of the concrete.

Table (3): Effect of the examined PPF on slump and setting time of concrete

Mix with PPF Type	Slump, (mm)	I.S.T, (min)	F.S.T, (min)
Control	65	181	252
PPF-1	50	169	235
PPF-2	45	168	230
PPF-3	30	170	235
PPF-4	40	164	238
PPF-5	30	165	242

The examination of the results, listed in Table (3) for various PPF specimens, indicated that the PPF has a significant negative effect on the concrete consistency since they decrease slump with 23% for PPF-1 to 54% for both PPF-5 and PPF-3. This indicates that using the consistency improvement agent with FRC is highly recommended.

Furthermore, the test results illustrated in Table (3) indicated that using PPF in the concrete mix leads to a decrease in the concrete setting time, both IST and FST. A decrease in setting time ranged between 5 and 10 minutes for both IST and FST. A minimum reduction is gained when PPF-5 was used, while a highly reduction was obtained for PPF-2.

5.2. Effect of PPF on Concrete Mechanical Properties

The effect of the used PPF on the concrete compressive strength, and tensile strength in terms of both splitting and flexural strength were investigated. Table (4) shows the effect of the examined various PPF on the mechanical properties of concrete.

Table (4): Effect of the examined PPF on the mechanical properties of concrete

Mix with PPF Type	Compressive strength, (N/mm^2)			Splitting tensile strength, (N/mm^2)			Flexure strength, (N/mm^2)		
	7-D	28-D	Norm.*	7-D	28-D	Norm.	7-D	28-D	Norm.
Control	28.40	33.70	1.00	2.81	3.37	1.00	4.80	6.60	1.00
PPF-1	24.40	31.10	0.92	2.97	3.50	1.04	6.27	6.99	1.06
PPF-2	23.80	31.60	0.94	2.76	3.45	1.02	5.46	6.90	1.05
PPF-3	26.60	33.40	0.99	3.21	3.50	1.04	5.93	7.38	1.12
PPF-4	26.50	34.10	1.01	3.13	3.65	1.08	5.91	7.77	1.18
PPF-5	24.60	34.60	1.03	3.21	3.74	1.11	6.06	7.48	1.13

**Normalization is carried out by dividing the obtained PPF specimen value by control specimen value.*

5.2.1. Effect of Various PPF on Concrete Compressive Strength

The compressive strength, after 28 days for control PC specimen without PPF was found to be 33.70 MPa. The compressive strength value was slightly decreased by 8%, 6%., 1% after adding the PPF-1, 2, and 3 to the concrete mix, respectively. Moreover, these strength values are increased by 1% and 3% when reinforcing the plain concrete mixes with PPF-4 and PPF-5, respectively. The obtained results confirmed the fact that by using PPF, no significant effect on the concrete compressive strength was observed. Figure (4) shows a comparison between compressive strength of PC and PPFRC specimens.

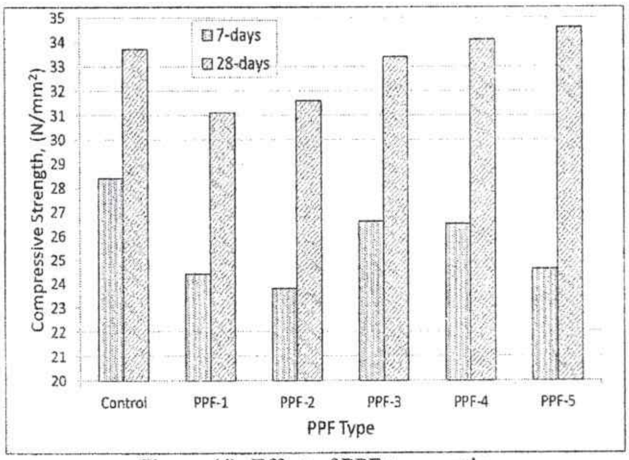

Figure (4): Effect of PPF type on the concrete compressive strength.

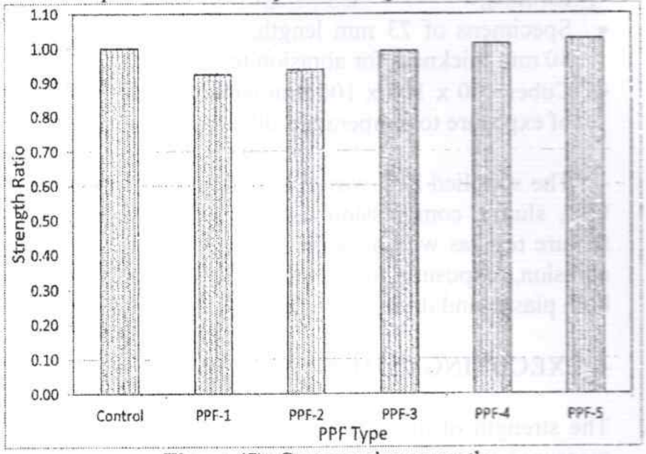

Figure (5): Compressive strength normalization of various tested PPF

Moreover, results of the compressive strength normalization for all PPF specimens in terms of that of specimen without PPF are plotted on Figure (5).

5.2.2. Effect of Various PPF on Concrete Splitting Strength

The splitting tensile strength, after 28 days for control PC specimen without PPF, was estimated to be 3.37 MPa. The splitting strength value increased after using PPF. The gain in splitting strength was found to be 4%, 2%, 4%, 8%, and 8% using PPF-1, 2, 3, 4, and 5 respectively. The splitting strength of PPFRC specimens are given in Figure (6).

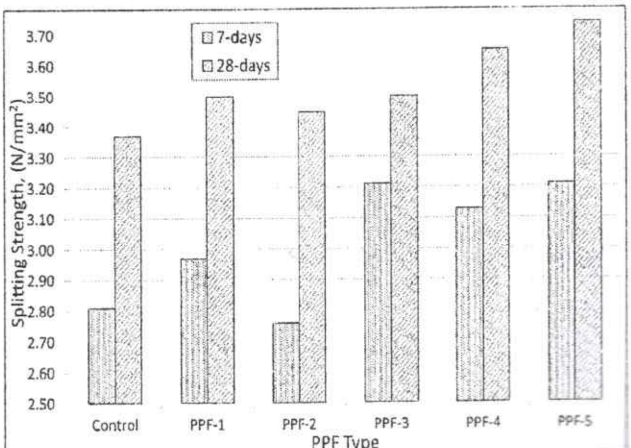

Figure (6): Splitting strength of various PPF in FRC concrete mix

5.2.3. Effect of Various PPF on Concrete Flexure Strength

The flexural strength, after 28 days for control PC specimen without PPF, was found to be 6.60 MPa. The flexure strength value was improved by using PPF. The flexural strength enhancement was found to be 6%, 5%, 12%, 18%, and 13% using PPF-1, 2, 3, 4, and 5 respectively. Comparison among the flexure strength of various PPFRC specimens was plotted in Figure (7). The obtained results confirmed the fact that was proven before (i.e. efficiency of the applied PPF improved the concrete tensile strength).

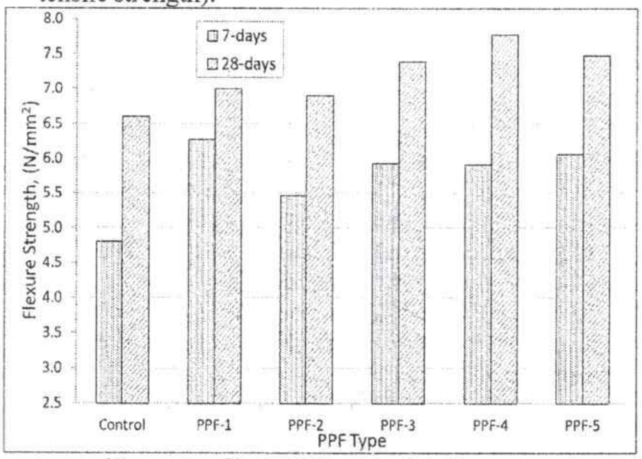

Figure (7): Flexural strength of various PPF used in FRC concrete mix

5.3. Results of Durability Tests

Some durability aspects for both concrete with/without various supplied PPF such as abrasion, shrinkage, and temperature exposure tests were investigated. Figure (8) describes photo of shrinkage specimen while Figure (9) illustrates strain gauge device used for measuring shrinkage-strain.

5.3.1. Effect of PPF on the Concrete Abrasion Resistance

The abrasion strength test was conducted according to the Egyptian Standard Specifications on 4 samples of PC and PPF concrete. PPF was added by 0.90 kg/m^3. Results of abrasion test of concrete after 28 days in terms of both weight and thickness loss are listed in Table (5).

As illustrated in Table (5), the average loss in the specimen thickness was found to be 2.80%, 2.56%, 1.82%, 2.31%, 3.03%, and 2.75% for PC and PPF-1, 2, 3, 4, and 5 respectively. This indicates that, except for PPF-4, using the other various PPF, improves the abrasion resistance in the range of 2% for PPF-5 to 35% for PPF-3. However, only Abaco PPF has a negative effect on the abrasion resistance leading to an increase in the thickness loss by about 8%.

Table (5): Effect of the examined various PPF on the concrete abrasion resistance

Fiber Type	Unit Weight	Thick-orig.	Thick. Loss		Wt.-orig	Wt.-final	Wt. Loss
	(t/m^3)	mm	mm	%	gm	gm	%
None	2.28	41.4	1.161	2.80	477.2	463.8	2.81
PPF-1	2.21	40.4	1.035	2.56	453.8	442.2	2.56
PPF-2	2.36	43.4	0.790	1.82	539.4	529.8	1.78
PPF-3	2.24	42.2	0.975	2.31	503.2	492	2.23
PPF-4	2.40	39.4	1.194	3.03	491.8	477.4	2.93
PPF-5	2.30	41.40	1.140	2.75	469.23	451.24	3.83

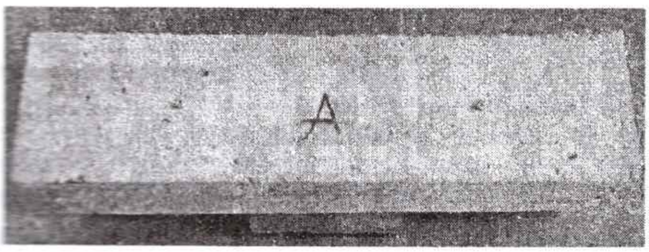

Figure (8): Shrinkage specimen with 2 demic points.

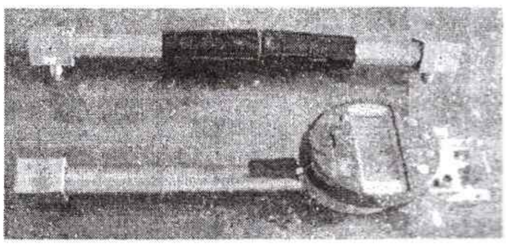

Figure (9): Strain gauge device.

Moreover, the average loss in the specimen weight was found to be 2.81%, 2.56%, 1.78%, 2.23%, 2.93%, and 3.83% for PC and PPF-1, 2, 3, 4, and 5 respectively. The results clarified that, except for both PPF-4 and PPF-5, using the other various PPF improved the abrasion resistance in the range of 9% for PPF-1 to 36.5% for PPF-2. However, both PPF-4 and PPF-5 have a negative effect on the abrasion resistance leading to an increase in the thickness loss by about 4% and 36%, respectively. The effect of the supplied PPF used in FRC concrete mix on abrasion resistance is drawn in Figure (10).

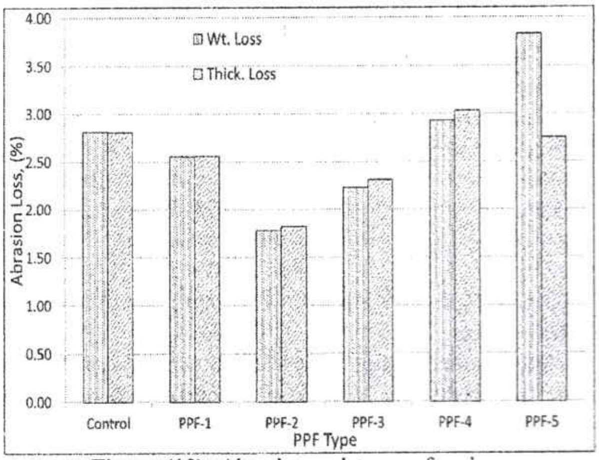

Figure (10): Abrasion resistance of various PPF used in FRC concrete mix

5.3.2. Effect of PPF on the Concrete Plastic Shrinkage

The effect of adding various types of PPF on the plastic shrinkage strain, induced in the concrete, was investigated. Concrete specimens, were prepared with/without PPF of 0.90 kg/m^3 and tested for measuring the plastic shrinkage strain according to ASTM C827. The observations, during the plastic shrinkage test, indicated the efficiency of PPF in controlling the plastic shrinkage and showed the most beneficial advantages of using PPF in arresting the cracks propagation, as well as enhancing the crack distribution and reducing crack width, compared to the control concrete mix without fiber. The average measured plastic shrinkage strain value was minimized for PPFRC specimen in the range 32%-61%, since the reduction percent was found to be 34%, 42%, 32%, 42%, and 61% for MC, PPF-1, 2, 3, 4, and 5 respectively when compared to the control PC specimen without PPF. Figure (11) shows a comparison between plastic shrinkage of various supplied PPF investigated in this study.

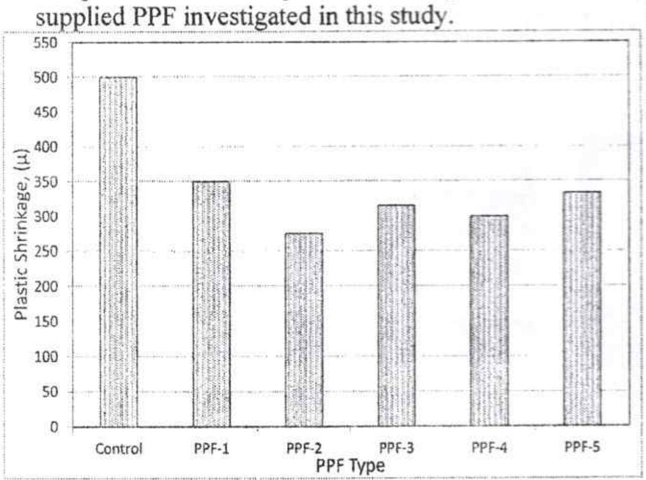

Figure (11): Plastic shrinkage of various PPF used in FRC concrete mix

5.3.3. Effect of PPF on the Concrete Drying Shrinkage

The effect of adding various types of PPF on the drying shrinkage strain induced in the concrete was investigated and plotted in Figure (12). Concrete specimens were prepared with/without PPF of 0.90 kg/m^3 and tested for measuring the plastic shrinkage strain according to ASTM C157. All specimens were cured in water for 7 days. The measured drying shrinkage strains plotted in Figure (12) indicated the importance of using the PPF in concrete for the purpose of controlling the drying strains especially at the latest ages (i.e. 21 days and 28 days) in spite of its bad effect during the early ages (i.e. 10 days and 14 days). The test results showed that the negative effect of PPF-1 on the drying shrinkage strain along all ages, Figure (12). At the end, using PPF in concrete proved its efficiency in reducing the plastic shrinkage in comparison with the concrete without PPF. Except for PPF-1, the average measured drying shrinkage strain value was reduced after 28 days for PPFRC specimen in the range 19%-63.3%. The reduction percent was found to be -22.5%, 19%, 27.9%, 63.3%, and 46.8% for PPF-1, 2, 3, 4, and 5 respectively, when compared to the control PC specimen without PPF.

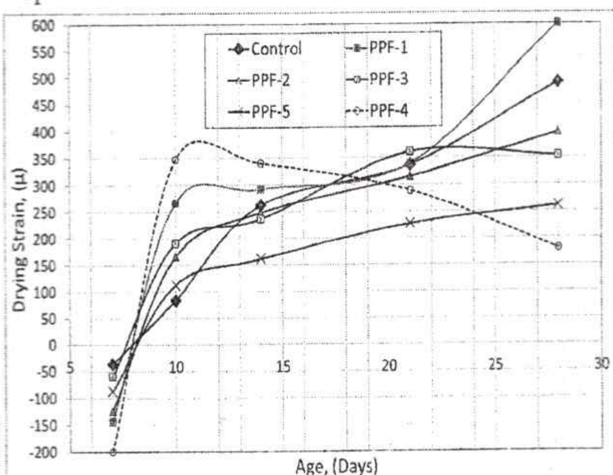

Figure (10): Effect of PPF type used in FRC concrete mix on its drying shrinkage

5.3.4 Effect of PPF on Cracks due to Exposure to Temperature Differences

Cubes 100 x 100 x 100 mm with/without PPF were exposed to cycles of temperature differences ranging from (23°C ±2) as room temperature to (75°C ±2) and relative humidity (50% ±5). Exposure results indicate that there is no increase in number and length of cracks for PPF specimens. Furthermore, the length of cracks for PPF specimens was not only shortened but also the cracks number was also minimized compared to specimens without PPF. On the other hand, both surface and deep cracks were observed for concrete cubes without PPF especially at the fifth cycle of cool-heat at which the surface cracks increased to be deeper. However, these cracks were decreased as a result of PPF inclusion especially for cubes stayed under water for 28 days. It was observed that cubes with PPF, (4 and 5) had the smallest surface cracks amongst all.

5.4. Comparison among Different Measured PPF-Concrete Characteristics

The outcome of some results of different tests, carried out on concrete samples containing the five PPF, could be summarized in Table (6).

A comparison between all the obtained results was conducted so that one can assess the performance of the PPF and its impact on the different characteristics of the concrete from which the following were deduced:

- The PPF sample type "PPF-5" was found to be the best species as they contain fiber with good regularity and clarity in fiber mesh, distribution, the fiber diameter and danner value were appreciated about 95 microns, 11640, respectively. This complies with the limits of specifications that are identified by ≥90 microns, ≥10000, respectively. In addition, it improved all the other mechanical properties of concrete "compressive, splitting, and flexure strength" with satisfactory percent.
- The PPF sample type "PPF-4" comes in the second degree as it has the same above advantages, and it enhances the compressive, splitting, and flexure strengths. However, the fiber diameter and danner value were estimated by 64 microns, 7640, respectively. This doesn't meet the specifications limits, in addition to its negative effect on the abrasion resistance.
- Both PPF samples type "PPF-2 & PPF-3" are considered the best among the tested PPF in improving the abrasion resistance. However, they have negative effect on the compressive concrete strength at variable rates with 6% and 1%, respectively. Moreover; their fiber diameter and danner value were found small to be less than the specifications limits.
- The results clarified that the PPF-1 sample type comes at the end in the last level as it is considered the only sample that increases the drying shrinkage with 22.5% and it decreases the compressive concrete strength by 8% in addition to the declined values of both fiber diameter and danner.

Table (6): Comparison among the different characteristics of the PPF

PPF Fiber Type	PPF-1	PPF-2	PPF-3	PPF-4	PPF-5
PPF Code	MC	G-UL	G-DL	Abaco	Econo-net
Nominal Diameter of fiber, μm	75	60	52	64	95
Danner value of fiber	7200	7600	7100	7640	11640
Effect on Initial Setting Time, IST	Decrease by 8 mint.	Decrease by 10 mint.	Decrease by 5 mint.	Decrease by 6 mint.	Decrease by 5 mint.
Effect on Final Setting Time, FST	Decrease by 8 mint.	Decrease by 10 mint.	Decrease by 7 mint.	Decrease by 7 mint.	Decrease by 5 mint.
Effect on preventing cracks resulting from IST, FST, Temp. differences	Minimize	Minimize	Minimize	Minimize & shorten Crack length	Minimize & shorten Crack length
Compressive Strength, 28 days	Decrease by 8.0%	Decrease by 6.0%	Decrease by 1.0%	Increase by 1.0%	Increase by 3.0%
Splitting Strength, 28 days	Increase by 4.0%	Increase by 2.0%	Increase by 4.0%	Increase by 8.0%	Increase by 11.0%
Flexure Strength, 28 days	Increase by 6.0%	Increase by 5.0%	Increase by 12.0%	Increase by 18.0%	Increase by 13.0%
Abrasion Resistance, 28 days	Decrease by 8.6%	Decrease by 35%	Decrease by 17.5%	Increase by 8.2%	Decrease by 9.6%
Plastic Shrinkage	Decrease by 31.9%	Decrease by 43.8%	Decrease by 34.8%	Decrease by 41.3%	Decrease by 46.9%
Drying Shrinkage, 28 days	Increase by 22.5%	Decrease by 19%	Decrease by 27.9%	Decrease by 63.3%	Decrease by 46.8%

6. CONCLUSIOINS

The main conclusions obtained from the test results are summarized in the following:

1. PPF has a negative effect on the concrete workability that was described by slump test results since they decrease slump by 23% for PPF-1 to 54% for both PPF-5 and PPF-3. This indicated that using the workability improvement agent with FRC is highly recommended.
2. The compressive strength of concrete is slightly affected according the type of PPF used, while the tensile concrete strength for both splitting and flexural strength is noticeably enhanced in the range of 2%-8% and 5%-18% for both splitting tensile and flexural tensile strength, respectively. The results indicated that the enhancement percent in the flexural strength was found to be the highest among all the tested cases.
3. PPF has a positive remarkable effect on both plastic and drying shrinkage since it suppresses the propagation of cracks, enhances the crack distribution and reduces crack width. The plastic shrinkage strain is reduced in the range of 32%-61% for PPFRC specimens compared to a concrete specimen without fiber. Furthermore, Except for PPF-1, the average measured drying shrinkage strain value was reduced after 28 days for PPFRC specimen in the range 19%-63.3%.
4. The PPF sample type "PPF-5" was found to be the best species as they contain fiber with good regularity and clarity in fiber mesh and distribution, and the fiber diameter and danner value were appreciated about 95 microns, 11640, respectively. This complied with the limits of specifications that identified with $\geq$90 microns, $\geq$10000, respectively. In addition, it improved all the other mechanical properties of concrete "compressive, splitting, and flexure strength" with satisfactory percent.
5. The PPF sample type "PPF-4" came in the second degree as it has the same above advantages, and it enhances the different concrete strengths. However, it has a negative effect on the abrasion resistance.
6. Both PPF samples type "PPF-2 and PPF-3", are considered the best among the tested PPF in improving the abrasion resistance.
7. The results indicated that the PPF sample type "PPF-1" comes at the end in the last level as it is considered the only sample that increases the drying shrinkage by 22.5% and it decreases the compressive strength by 8%.

REFERENCES

1. ***Ronald, F. Z.,*** "Fiber-Reinforced Concrete: An Overview after 30 Years of Development", Cement and Concrete Composites, V.19, I. 2, pp. 107-122, 1997.
2. ***Mehta, P.K., and Monteiro P.J.M.,*** "Concrete: Microstructure, Properties, and Materials, Fibers in Concrete", 1-32 slides, 2012. http://www.ce.berkeley.edu/~paulmont/241/fibers.pdf.
3. ***Abu-Khashaba, M.I.,*** "Factors Affecting Performance of Fiber Reinforced Concrete, FRC", Water Science, The NWRC J., I.No. (39 & 40), pp. 78–90, 2006.
4. ***Brian B., Denzil S., and Barry H.,*** "Concrete Fibers", Abcpolymer, http://www.abcpolymerindustries.com.
5. ***Kamran, M.N.,*** "Fiber-Reinforced Concrete", Concrete Technology, CM425, Washington Univ., Spring Qurtar, 2012.
6. ***Abdel-Motaleb, M.***, "Analysis of Flexural Strength and Energy Absorption of Fiber Reinforced Concrete", M.Sc. Thesis, Colorado State University, 1989.
7. ***Shah Fellow R.H., and Mishra, S.V.,*** "Crack and deformation characteristics of SFRC deep beams", IE (I) J CV, 85, pp. 44–48, 2004.
8. ***Mostafa, A.E.M,*** "Practical Evaluation of Flexural Behavior of Fiber Reinforced Concrete Beams", M.Sc. Thesis, Tanta University, 2004.
9. ***Balaguru, P., and Ramakrishnan, V.,*** "Mechanical Properties of Superplasticized Fiber Reinforced Concrete Developed for Bridge Decks and Highway Pavements", SP-93, Concrete in Transportation, ACI, Detroit, Michigan, pp. 563-584, 1986.
10. ***Allam, M.L., & Kukacka, L.E.,*** "Strength and Durability of Polypropylene Fiber Reinforced Grouts", Concrete and Concrete Research, V.25, No.3, pp. 511-521, 1995.
11. ***State-of-the-art Report on Fiber Reinforced Concrete,*** SP-44, Fiber Reinforced Concrete: International Symposium, American Concrete Institute, Detroit, Michigan, pp. 535-549, 1974.
12. ***Committee 544 of ACI,*** "Fiber Reinforced Concrete", ACI Committee Report 544. 1R-96, American Concrete Institute, Farmington Hills, MI, May, 1997.
13. ***Egyptian Code for Design and Construction of Concrete Structures,"ECDCCS",*** 7-th ed., 2-nd Renewal, 2001.
14. ***Swailem, M. K., & Badr, A.,*** "Controlling Plastic Shrinkage Cracking of High Strength Concrete Using Polypropylene Fibers", AICSGE5, MT-401-410, 2003.
15. ***Craig, R. J.,*** "Flexural Behavior and Design of Reinforced Fiber Concrete Members." SP-105,

Fiber Reinforced Concrete: Properties and Applications, American Concrete Institute, Detroit, Michigan, pp. 517-561, 1987.

16. ***Mohamed O.M.,*** "Influence of polypropylene on the Properties of Non-Autoclaved Aerated Concrete", AICSGE6, Alexandria Univ., 5-17, 2007.
17. ***Lovata, N.L., and Fahmy, M.F.,*** "Interfacial Bond Study of a Chemically Treated Polypropylene Fiber-Reinforced Concrete", Constructing & Building Material, June, V.1, No.2, pp. 83-87, 1987.
18. ***Zararis P.D., and Zararis I.P.,*** "Shear strength of reinforced concrete beams under uniformly distributed loads", ACI Struct. J, 6 (105), pp. 711–719, 2008.
19. ***Bazent Z.P., and Kim J.,*** "Size effect on diagonal shear failure of beams without stirrups", ACI Struct J, 3 (88) pp. 268–276, 1991.
20. ***Yoon-Keun, K., Eberhard, M.O., Woo-suk K., and Jubum K.,*** "Shear strength of steel fiber reinforced concrete beams without stirrups", ACI Struct J, 4 (99), pp. 530–538, 2002.
21. ***Zararis, P.D., and Zararis, I.P.,*** "Shear strength of reinforced concrete beams under uniformly distributed loads", ACI Struct J, 6 (105), pp. 711–719, 2008.
22. ***El-kareim, Ata, Soliman, S., and Abdel-megied, M.O.,*** "Efficiency of Using Discrete Fibers on the Shear Behavior of R.C. Beams", Ain shams Univ, J., 2012.
23. ***Construction Research Institute,*** "Technical Report on Evaluation of Polypropylene Fiber samples to be Used for Lining of the Old Elsaf Canal", Egypt, 2004.

ACKNOLEDGMENTS

The author appreciates the support introduced by all the four companies (Master chemicals, Geos, Alexandria, and finally Golden Trade Company) that provide us with sufficient free quantities of the five PPF types that investigated in the current st