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The Production of Economical Precast Concrete Panels Reinforced by Waste Plastic Fibers

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Abstract This paper has discussed the effect of adding waste plastic fiber (PET) resulting from cutting the plastic beverage bottles by hand (which is used in Iraqi markets now) as a small fiber to the precast concrete panels. This research presents an experimental program for investigating rupture strength and impact resistance of precast concrete panels with different depths. Different volumes of fibers, i.e. 0%, 0.5%, 1.0% and 1.5% have been added as percentages of concrete by volume. The results show that the maximum volume of PET fiber for a desired rupture and impact resistance was 1.0%. The addition of waste PET fiber to the plain precast concrete panels has economical advantages .It tends to decrease the depth panel from (30 cm × 30 cm × 4 cm) to (30 cm × 30 cm × 3 cm) and the percentage of increase of rupture strength was 34.27% and the percentage of increase of impact resistance was 157.14% for reinforced concrete panels (30 cm × 30 cm × 3 cm) aged at 90-days compared with plain panels of (30 cm × 30 cm × 4 cm). In the impact test the visual observation is that the specimens of fiber reinforced precast concrete panel (FRPCP) have remained together in one piece though broken whilst plain concrete specimens have exhibited the total disintegration.

Keywords: *precast panel, waste plastic, impact resistance, PET fibers, rupture strength*

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1. Introduction

Concrete is one of the building materials widely used in the world. It has manufactured by mixing cement, sand, and gravel with water and it can easily cast at any size and shapes required. Concrete is one of the brittle building materials having good properties under compression but weak under tension and shear. Some bitter properties of concrete are due to micro-cracks at mortar aggregate interface. To overcome this, the fibers can be added as one of the ingredients of concrete. The fibers inclusion in cement base matrix acts as micro crack arrester. The prevention of prorogation of cracks under load can result in an improvement in static and dynamic properties of cement based matrix including tensile strength, toughness and wear resistance, while, at the same time, impair some other properties [1]. Different types of fibers such as steel, glass, natural cellulose, carbon, nylon, polypropylene etc. have been used in this application. The fiber reinforced concrete is usually used in industrial floors, tunneling, mining, security structures, heavy duty pavements, slab types members and runways of airport. As an alternative application for waste materials, with the objective of protection of environment, fibers made of some waste materials have also been used for reinforcing concrete [2].

Waste is the one of the challenge to dispose and manage. It has one of the major environmental, economic and social issues. Industrial activities are associated with significant amount of non-biodegradable solid waste. It is common to serve the mineral water in plastic bottles (polyethelene teraphthelne (PET) bottles) in every country. It has non-biodegradable properties. The polyethelene teraphthelne (PET) bottles are recycled and used in industry for different purposes [1].

Polyethylene terephthalate (PET) is one of the extensively used plastics in the world, 10 million tons of which is annually used for manufacturing 250 billion bottles worldwide. This numbers grows increasingly every year [3]. A large number of the plastic containers are thrown away after single usage, becoming a main cause of environmental pollution. It has been reported that, in 2007, 67% of waste bottles have been sent to landfill in Asia, while 8% of which has been recycled [4]. Recycling of PET waste needs additional expenses for processing. Therefore, the number of returned bottles is very low, making them the most abundant plastic in solid urban waste. Waste plastics, including PET, are considered as non-decaying waste materials, which are not decayed and circulated in the environment and may enter water resources and cause health problems for human and other animals. Thus, finding a low cost application for reusing the PET wastes is an effective measure for protecting the environment [2]. Many researchers in the civil engineering tend to use of waste PET as a fiber and granules to improve and enhance some properties of concrete.

Afroz et al. [3], found that the PET fiber reinforced concrete has a higher tensile and shear strength than the plain concrete.

Soroushian et al. [5] drew attention to the good impact strength of a cylindrical concrete specimen reinforced with PET fibers uniformly dispersed in the concrete matrix, while the effects on compressive and flexural strength were small. Prabhu et al. [6] found that PET fibers increased both ductility and energy absorption of the axially compressed concrete samples. The highest ductility belonged to the specimens with fiber percentage 1.5%.

The main objectives of this study are to evaluate the possibility of using waste plastic fiber as a reinforcement material in concrete. The following objectives are also proposed:-

1. Investigate the effect of the addition of different volume fractions of fibers on the workability of concrete.
2. Investigate the effect of addition of waste plastic fiber on rupture and impact performance of precast concrete panels.
3. Study the effect of thickness reduction on the rupture and impact performance of plastic fiber reinforced precast concrete panels.
4. To determine the percentage of plastic fiber which gives more rupture and impact resistance when compared to control concrete.

2. Experimental Program

2.1. Materials Used

2.1.1. Cement

Ordinary Portland cement (OPC) manufactured by Tassloja factory in north of Iraq was used in all concrete mixes. The quantity of cement has been brought to the laboratory and stored in a dry place. The chemical composition of OPC cement is shown in Table 1, and the physical properties are shown in Table 2.

Table 1. Chemical compositions and main compounds of portland cement

Oxide	% by Weight
CaO	62.13
MgO	2.7
SiO_2	22.01
SO_3	2.4
Fe_2O_3	3.3
Al_2O_3	5.26
Loss on ignition	1.45
C_3S	32.5
C_2S	38.7
C_3A	8.3
C_4AF	10.4

Table 2. Physical properties of Portland cement

Physical properties	Test result
Specific surface area (Blain) cm^2/g	290
Initial setting (Vicat Method) min.	92
Final setting (Vicat Method) hr.	3:30
Compressive strength (MPa)	
3-days	16.5
7-days	25.7

2.1.2. Fine Aggregate

The used fine aggregate is brought from Gorashin region, and tested to determine grading. Table 3 shows the sieve analysis of fine aggregate used.

Table 3. Sieve analysis of fine aggregate

Sieve size(mm)	Percentage passing
4.75	100
2.36	92.24
1.18	84.89
0.6	70.18
0.3	33.31
0.15	0.71

2.1.3. Coarse Aggregate

The natural river with irregular shape gravel used as a coarse aggregate has been obtained from Gorashin region, with a maximum size of 12.5 mm for all mixes. The selection of this size is based on the consideration of getting acceptable workability. Table 4 shows the used grading of coarse aggregates.

Table 4. Grading of coarse aggregate

Sieve size(mm)	Percentage passing
12.5	100
10	96.5
4.75	15.1
2.36	0.5

2.1.4. Water

Water used for mixing concrete should be free from impurities that could adversely affect the process of hydration and, consequently, the properties of concrete. Drinking water is suitable, and it is usually easy to obtain from local water utility.

2.1.5. Plastic Fibers

The waste plastic fiber (polyethylene terephalate PET) mineral water bottles of a single brand are collected from local consumers. The waste plastic bottle is sliced to a small uniformed piece with an average length of (40 mm) and width equal to about (2- 2.5 mm) and with a corrugated surface that is expected to enhance the adherence with concrete. The hand cutting technique consists of removing the neck and the base of the bottle and longitudinally cutting a 40mm-wide strip. Then, there must be a cut of each strip to width equal (2-2.5mm) as shown in Figure 1. The fibers should be washed by tap water for several times in order to remove residues at their surfaces. The physical and mechanical properties of the used plastic fibers are illustrated in Table 5.

Figure 1. Waste plastic fibers

Table 5. Physical and mechanical properties of the plastic fibers [7]

Density (g/cm^3)	1.38
Tensile strength at break (MPa)	79.3
Tensile modulus (MPa)	2758
Elongation at break (%)	70
Flexural strength (MPa)	103.42
Flexural modulus (MPa)	2758
Water absorption, 24 hours (%)	0.10

2.2. Preparation of Specimens

The aim of this experimental work is to study the effect the addition of plastic fibers on the properties of plain concrete panels. The details of the mixes used throughout the study are given in Table 6.

Table 6. Mix proportions of precast concrete panels

Mix	Vf %	C (kg)	S (kg)	G (kg)	W (kg)	PF (kg)
Precast concrete panel (30 cm × 30 cm × 4 cm)						
R	0	12	24	28.2	6.24	-
PF0.5	0.5	12	24	28.2	6.24	0.184
PF1.0	0.1	12	24	28.2	6.24	0.368
PF1.5	1.5	12	24	28.2	6.24	0.552
Precast concrete panel (30 cm × 30 cm × 3 cm)						
PE0.5	0.5	9	18	21.15	4.68	0.138
PE1.0	0.1	9	18	21.15	4.68	0.276
PE1.5	1.5	9	18	21.15	4.68	0.414

VF=Volume Fraction, C=Cement, S=Sand, G=Gravel, PF=Plastic Fiber.

Many tests are required to be assessed in this work such as: workability, rupture strength and impact resistance. The concrete mix is designed according to the building research establishment method. All mixes were designed to have a 28-days compressive strength of 30 MPa, after many trials one mix proportion was used in this study (1:2:2.35) by weight Cement content was 330 kg/m^3 and w/c ratio was 0.52.

Precast involves a mould shaped to the required form, the essential feature is that the same mould is used many times without any modification. Steel moulds are used in this study with two types according to their dimensions (30 cm × 30 cm × 4 cm) for the plain concrete panels and (30 cm × 30 cm × 4 cm) and (30 cm × 30 cm × 3 cm) for plastic fiber reinforced concrete panels, economical purposes is taken into account in designing the second type. The precast concrete slabs mixes can be summarized in two groups, which are described as follows:-

1. **Group A:** this group represents a mix of plain concrete, and designated as (R).

2. **Group B:** this group represent a mix of fiber reinforced concrete, in which three volume fractions of waste plastic fiber were used (0.5,1.0 and 1.5)% and designated as (PF0.5, PF1.0 and PF1.5) respectively for (30 cm × 30 cm × 4 cm) precast concrete panels, and (PE0.5, PE1.0 and PE1.5) respectively for (30 cm × 30 cm × 3 cm) precast concrete panels.

A rotary mixer of 0.05 m^3 capacity is used in the mixing process. The dry constituents are initially mixed for one minute, then the required amount of water is added gradually and the whole mix constituents are mixed for another minute. The fibers are then added and the whole constituents mixed for proper tune until a uniform dispersion of fibers is achieved, over mixing is avoided because the fiber will suffer damage and loss of strength. To obtain a fair face casting and facilitate demoulding, the moulds are thoroughly oiled before casting.

Care is taken during mixing process to avoid segregation and to achieve uniform distribution of the fibers in the concrete which lead to distribute stresses and improve microcracking. The precast panels are cast in two layers and compacted by vibrating table the mould for half minute for each layer then covered with nylon sheets until demoulding after 24 hours, and finally cured in tap water until the test time of 28-day and 90-days.

2.3. Test Methods

2.3.1. Slump Test

The workability of the fresh concrete is measured by using the standard slump test apparatus Figure 2. The slump test was carried out according to B.S.1881:1952. The internal surface of the mold was thoroughly cleaned and freed from superfluous moisture before conducting the test. The mold was placed on a smooth, horizontal, rigid and nonabsorbent surface metal plate and then filled with four layers. Each layer is one-fourth the mold height and was tamped with 25 strokes of the rounded end of a tamping rod. The strokes were distributed in a uniform manner over the cross-section of the mold and for the subsequent layers, penetrated into the underlying layer. The mould is removed from the concrete by raising it in a vertical manner and then allowing the concrete to subside. The slump was then measured immediately by determining the difference between the height of the mould and the highest point of the specimen.

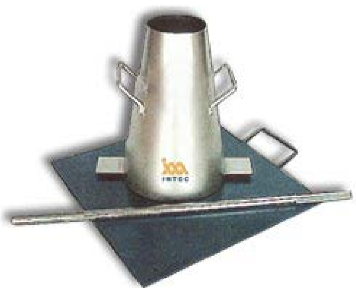

Figure 2. Slump test apparatus

2.3.2. Rupture Test

Rupture strength has been carried out on simply supported prisms with clear span of 400 mm under one point loading according to B.S.1881: part 112:1989. The average of three specimens was adopted for each type of precast concrete panels tested at 28 and 90-days

Figure 3. Rupture test apparatus

2.3.3. Impact Test

The impact resistance test can be measured by a test method that is simple and easy to carry out. This test has also been developed by ACI committee 544 [8], which recommends the use of repeated impact drop weight test to estimate this important property since there's no recognized standard test to assess the impact resistance of tiles required to cause failure. The apparatus mainly consists of three parts as shown in Figure 4, which are described as follows : -

1. The main supported frame: A steel frame is strong enough to be held rigidly during impact loading. The columns of the base are fixed in the concrete block to insure the stability of the frame during test. The specimens are placed in a position in the testing frame using a continuous square steel angle to provide simply supported boundary conditions in all four sides of the specimen.

2. Drop weight guide system: A tube of circular section with an inside diameter of 105mm is held vertically above the center of the slab. This tube is used to drop the falling mass from a control height of 1000 mm with accurate guidness. A hard rubber is placed between the specimen and the continued square steel angle to insure a good contact along the slab edges.

3. Striker: A falling ball with a mass of 1.25 kg is used as a striker which is repeatedly dropped throughout the guide system onto the slab until failure.

Figure 4. Apparatus of impact resistance test

3. Results and Discussion

3.1. Effect of (PET) on Concrete Workability

The slump cone test is adopted to assess the workability of fiber reinforced. The test results are presented in Table 7 and the following have been observed:-

1. The addition of waste PET fibers to plain concrete increases the stability and cohesion of the mix and reduces its workability. This concurs with N. Shamskia and Nibudey [9,10] who have claimed that fibers tend to reduce the workability of concrete due to the resistance offered by the fibers to the movement of aggregates.
2. From Table 7 the slump value reduces as the percentages of the waste PET fiber increase. This concurs with Irwan and Asyraf [11] who observe that high dosages of fiber will cause workability problems by the phenomenon of balling, which occurs when large volume fractions are used and resulted in unworkable and segregated mixture

Table 7. Slump values of different concrete mixes

Mix	Vf (%)	Slump (mm)
R*	0	90
PF*	0.5	80
	1.0	60
	1.5	10

R*= Reference concrete, PF*=Plastic fiber.

3.2. Effect of (PET) on Concrete Rupture Strength

Precast slabs of plain and fiber reinforced concrete are used to assess the load at rupture. The test results are presented in Table 8. From these results the following can be observed: -

1. It is clear that there is a significant improvement in the load at the rupture of plain concrete panels compared with waste PET fiber reinforced concrete panels having different thicknesses for both curing period of (28 and 90)-days.

2. It has been noticed that the load at the rupture of fiber concrete slabs improves by the addition of waste PET fiber and increases up to 68.95% for 1.0% by volume at period of 90-days. This concurs with Al-Hadithi and Jameel [12] who figure out that the cause of that increase may be due to the influence of mixing action. The fibers are uniformly distributed throughout the concrete in all directions against the formation of plastic shrinkage cracks. The uniformly distributed fibers bridge and hold together the existing micro cracks which result in reinforcing the concrete against disintegration.

3. It is noticed that the load at rupture increase up to 1% then decreases as fiber volume fraction increases. This can be attributed to the curling and bundling of fibers during mixing.

4. It is also noticed that the load at rupture increases along the age for different concrete mixes.

5. The results show that the addition of waste PET fiber to the precast slabs improves the load at rupture and compensated for the decrease in depth for (30 cm × 30 cm × 3 cm). The increase is 22.58% and 34.27% for PF0.5and PF1.0 respectively compared with plain concrete slabs of (30 cm × 30 cm × 4 cm) tested at the same period of 90-days.

6. The visual observation unveils that all fiber reinforced concrete slabs remain together in one piece though broken, whilst plain concrete slabs exhibit total disintegration. This is probably due to the effect of fibers "bridging" across some of the cracks trying to hold the entire slab together. This observation concurs with that done by Ramirez [13].

4.2. Effect of (PET) on Concrete Impact Resistance

The results of the impact resistance in terms of the number of blows of precast concrete slabs are shown in Table 9. Regarding these results, the following observations can be made: -

1. It is noticed that the impact resistance increases as fiber volume fraction increases up to 1.0%, and it

decreases as the fiber volume fraction increases. The results show the increase in the impact resistance is 128.57%, 228.57% and 71.43% for PF0.5, PF1.0 and PF1.5 respectively and is 71.43%, 157.14%, and 42.85% for PE0.5, PE1.0 and PE1.5 respectively for concrete panels tested at age 90-days.

2. It is also observed that the impact resistance of (30 cm × 30 cm × 4 cm) precast panels reinforced with waste PET fiber is higher than the impact resistance of concrete panels of (30 cm × 30 cm × 3 cm).

3. The results show that the addition of waste PET fiber to the precast slabs improves the impact resistance and compensates for the decrease in depth for (30 cm × 30 cm × 3 cm). The increase in the impact resistance is 71.43% and 157.14% for PE0.5 and PE1.0 respectively compared with plain concrete panels of (30 cm × 30 cm × 4 cm) tested at the same period of 90-day.

4. The important visual observation can be inferred from the Figure 5, Figure 6, Figure 7 and Figure 8 is that the mode of failure under low velocity impact for all specimens for all mixes is the cracks starts from center point (mean the center of slab where mass is falling) then extend in all direction, the failure in all fiber reinforced concrete panels was fiber pull-out and the panels remain together in one piece though broken, whilst plain concrete panels exhibited total disintegration and shattering. This concurs with the conclusion made by Al-Hadithi and Jameel [12].

Table 8. Rupture strength results of precast concrete panels

Mix Designation	Vf (%)	Dimension (cm)	Rupture strength (MPa)		Rate of increase (%)	
			28-days	90-days	28-days	90-days
R	0	(30×30×4)	2.39	2.48	--------	------
PF 0.5	0.5	(30×30×4)	2.81	3.28	17.57	32.25
PF 1.0	1.0	(30×30×4)	3.94	4.19	64.85	68.95
PF 1.5	1.5	(30×30×4)	2.55	2.98	6.70	20.16
PE 0.5	0.5	(30×30×3)	2.61	3.04	9.21	22.58
PE 1.0	1.0	(30×30×3)	3.07	3.33	28.45	34.27
PE 1.5	1.5	(30×30×3)	2.33	2.41	0.0	0.0

Table 9. Impact resistance results of precast concrete panels

Mix Designation	Vf (%)	Dimension (cm)	Number of blows to failure		Rate of increase (%)	
			28-days	90-days	28-days	90-days
R	0	(30×30×4)	5	7	--------	------
PF 0.5	0.5	(30×30×4)	13	16	160	128.57
PF 1.0	1.0	(30×30×4)	18	23	260	228.57
PF 1.5	1.5	(30×30×4)	10	12	100	71.43
PE 0.5	0.5	(30×30×3)	11	12	120	71.43
PE 1.0	1.0	(30×30×3)	15	18	200	157.14
PE 1.5	1.5	(30×30×3)	9	10	80	42.85

Figure 5. Plain precast concrete panel

Figure 6. Precast concrete panel (PE 0.5)

Figure 7 . Precast concrete panel (PE 1.0)

Figure 8. Precast concrete panel (PE 1.5)

4. Conclusions

Based on the experimental results obtained from this study, the following conclusions can be drawn:

1. The addition of waste PET fiber reduces the workability of all concrete mixes. And the reduction increases as fiber volume fraction increases.
2. The addition of waste PET fiber improves the rupture load significantly at rupture of plain concrete panels.
3. The load at rupture for plain concrete panels of (30 cm × 30 cm × 4 cm) is enhanced and improved by the addition of 1.0% by volume of waste PET fiber and the percentages of increase are 64.85% for panels aged at 28-days and 68.95% for panels aged at 90-days.
4. The specimens of waste PET fiber reinforced concrete remain together in one piece though broken whilst plain concrete specimens exhibit total disintegration.
5. The addition of 1.0% (by volume) of waste PET fiber to the plain precast concrete panels improves the load at rupture and compensates for the decrease in depth for (30 cm × 30 cm × 3 cm) and the percentages of increase are 28.45% and 34.27% for reinforced concrete panels aged at 28-days and 90-days respectively compared with plain panels of (30 cm × 30 cm × 4 cm).
6. The additions of 1.0% (by volume) of waste plastic fiber improve the impact resistance by increase the energy absorption to 228.57% for precast panels aged at 90-days.
7. The important visual observation is that the mode of failure under low velocity impact of all specimens for all mixes is that the cracks starting from center point then extending in all direction. The failure in all fiber reinforced concrete panels is fiber pull-out and the panels remain together in one piece though broken, whilst plain concrete panels exhibit total disintegration and shattering.
8. The addition of waste PET fiber to the plain precast concrete panels of (30 cm × 30 cm × 4 cm) compensates for the reduction in thickness of them and improves their impact resistance and load at rupture which provides an economical production of precast concrete panels.

5. Recommendations

More experimental work is needed in the future to efficiently evaluate:

1. Properties of adding the waste PET fiber to higher grades of concrete.
2. Properties like shrinkage and creep of waste PET fiber reinforced concrete.
3. Effect of utilizing different aspect ratios of waste PET fibers and different shapes of fiber on the properties of concrete.
4. The microstructure properties of waste PET fiber reinforced concrete in different soaking periods.
5. The durability of waste PET fiber reinforced concrete.
6. Possibilities of improving and enhancing the performance of waste PET fiber reinforced concrete by using natural pozzolanic materials.

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