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The Influence of Waste Plastic Fiber on the Characteristics of Light Weight Concrete with Expanded Polystyrene (EPS) as Aggregate

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ABSTRACT

This research aims to create lightweight concrete mixtures containing waste from local sources, such as expanded polystyrene (EPS) beads and waste plastic fibers (WPFs), all are cheap or free in the Republic of Iraq and without charge. The modern, rigid, and mechanical properties of LWC were investigated, and the results were evaluated. Three mixtures were made, each with different proportions of plastic fibers (0.4%, 0.8%, 1.2%), in addition to a lightweight concrete mixture containing steak fibers (0.4%, 0.8%, 1.2%), in addition to a lightweight concrete mixture. It contains 20% EPS. The study found that the LWC caused by the addition of WPFs reduced the density (lightweight) of the concrete mixtures because EPS tends to form more blocks, absorb water, and dry the mixture. While the increase in WPF content increased in compressive strength, as the compressive strength of the concrete mix containing (EPS) was only 13.6 MPa, the compressive strength increased to 17.6 MPa when WPFs were added. The addition of plastic also increased the bending resistance, where the bending resistance of the concrete mix containing (EPS) was only 2.26 MPa and increased to 2.66 MPa when (WPFs) were added.

Keywords: Light Weight Concrete (LWC), Expanded Polystyrene (EPS), Waste Plastic Fiber (WPFs)

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تأثير إضافة نفايات الألياف البلاستيكية على خواص الخرسانة خفيفة الوزن الحاوية على البولسترين الممدد (EPS) كركام

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الخلاصة

الهدف من هذا البحث هو إنشاء خرسانة خفيفة الوزن تحتوي على نفايات من مصادر محلية مثل حبيبات البولسترين الممدد (EPS) ومخلفات الألياف البلاستيكية (WPFs) ، وكلها رخيصة أو مجانية في جمهورية العراق ومن غير تكلفة. تم فحص الخصائص الحديثة والصلبة والميكانيكية لهذا LWC ، وتم تحليل النتائج. تم تحضير ثلاث خبطات ، كل منها بنسب مختلفة من الألياف البلاستيكية (0,4٪ ، 0,8٪ ، 1,2٪) وكذلك خليط من الخرسانة خفيفة الوزن تحتوي على (EPS) بنسبة 20٪. أدت إضافة WPFs إلى تقليل الكثافة (الوزن الخفيف) للخرسانة لأن EPS يميل إلى تكوين المزيد من الكتل وامتصاص الماء وتجفيف الخليط. بينما أدت الزيادة في محتوى WPF إلى زيادة مقاومة الانضغاط ، حيث كانت مقاومة الانضغاط لمزيج الخرسانة المحتوي على (EPS) 13,6ميجا باسكال فقط ، زادت مقاومة الانضغاط إلى 17,6 ميجا باسكال عند إضافة WPFs. كما أدت إضافة البلاستيك إلى زيادة مقاومة الانحناء ، حيث كانت مقاومة الانحناء للخلطة الخرسانية المحتوية على (EPS)2,26 ميجا باسكال فقط وزادت إلى 2,66 ميجا باسكال عند إضافة (WPFs).

الكلمات الرئيسية: خرسانة خفيفة الوزن (LWC) ، بولسترين ممدد (EPS) ، نفايات ألياف بلاستيكية (WPFs)

1. INTRODUCTION

These beads are used to create lightweight packaging materials. Before the production of EPS blocks, EPS beads are produced in factories or on-site as round white gains **(Wang and Miao, 2009).** These granules are made of dissolved polystyrene and pentane and have fire-retardant additives **(ASTM C330/C330M-17a, 2017).** They are non-biodegradable and chemically inert in water and soil **(Horvath, 1994).** Because of the closed cell structure, EPS beads have a low water absorption capacity **(Rathan and Badwaik, 2015).** They are compressible and come in a variety of shapes for different applications.

Since geofoam blocks are unsuitable for filling irregular shapes and sizes, EPS geometry and bottom ash can be used as alternatives enhanced with natural fibers. Concrete is a mixture of mortars, aggregates, and separate (non-continuous) fibers. Making use of fiber is not a new concept; thatch was used to reinforce roasted bricks 3,500 years ago. Asbestos fibers were the first fibers used in concrete, around 1900, but they were discontinued due to health concerns. Steel, glass, carbon, polypropylene, plastic, nylon, and sisal were among the fibers used in concrete at the time. Ordinary concrete, due to a lack of tensile strength and tensile stress capabilities, requires reinforcement before it can be utilized as a construction material. To improve tensile and shear strength, concrete is typically reinforced with continuous reinforcing bars strategically placed throughout the structure. Whereas the fibers are used infrequently and randomly throughout the matrix **(ACI commitee 544, 2002; Bentur and Mindess, 2006).**

Recently, industrial development, including the plastics industry, has accelerated. Since plastics have a long analytical life and pollute the environment, studies have focused on reusing recycled plastic waste (sustainable plastic) to create environmentally friendly concrete **(Qasim et al., 2022).** The increasing demand for new infrastructure facilities and buildings, as well as the world's population growth, indicates an increased consumption of resources, particularly in the form of more durable concrete, such as High-Performance Concrete (HPC) **(Al-Hadithi and Allani, 2015).** The first synthetic plastics were developed nearly a century ago. Then, rapid population growth leads to an unprecedented increase in plastic production. Plastic was used in strategic sectors, including wrapping, construction, mass transit, medical devices, and sports, due to its efficacy and competency. Increased plastic use leads to increased waste at the end of plastic use.

Plastics are non-biodegradable materials that accumulate in landfills because the moiety used in the petrochemical industry, such as both ethylene and propylene, are deduced from fossil hydrocarbons **(Al-Salem et al., 2009; Geyer et al., 2017)**. PET (Polyethylene Terephthalate) is the most commonly used plastic. PET's basic raw materials are ethylene and terephthalic acid. It is widely utilized in filling water and fizzy drinks because of its clear, powerful, secure, flexible, lighter weight, clear, and non-toxic properties. Only a small portion of PET bottles are recycled, with the remainder ending up in landfills or incinerated, both polluting the environment **(Abdulkarim and Abiodun, 2012).** Much research has been done on the reuse of plastic waste in reaction to these dangers. However, one solution is to use plastics in concrete, the world's second most used material after water, with a global production of about 5.3 billion cubic meters per year **(Hasanbeigi et al., 2012).** The use of recycled plastic in concrete started in two ways: PET aggregates partially or completely replaced aggregates after cracking the plastic and then passing the ground particles through a set of sieves to ensure the required size distribution of the PET aggregates. 2-Polyethylene terephthalate fibers are used to enhance the properties of concrete. There has been some research on PET fiber-induced concrete, but they all show the most promising characteristics **(Chowdhury et al., 2018).**

This work aims to study the effect of replacing coarse aggregates with EPS granules of different volume ratios on the mechanical properties of concrete. Plastic waste fibers with varying volume proportions (0.4% - 1.2%) are added, and mechanical tests such as compressive strength and flexural strength are performed. Depending on the results obtained from the examinations mentioned above, a scientific analysis of the results was conducted, and the various relationships were drawn and discussed scientifically

2. EXPERIMENTAL PROGRAM

2.1. Materials Used

2.1.1 Cement

All samples were poured with Ordinary Portland cement throughout the experiment (OPC Type I). Physical and chemical tests confirmed that this cement meets Iraqi specifications I.Q.S. 5/2019. **(Iraqi Standard No. 5, 2019).** The physical properties and chemical compositions are given in **Table 1**.

Table 1. Physical and chemical compositions for used cement

Physical characteristics		Cement test results	IQS No. 5/2019 Limits
Time setting -Initial setting (min) -Final setting (hrs.)		 106 4.83	 45 min 10 hrs. max
Compressive Strength (MPa) 2-days 28-days		 11.25 33.31	 Min. 10 Min. 32.5
chemical properties			
Oxide composition		Result	Limits of IQS No. 5/2019
(SiO_2)		21.62	No limited
(Al_2O_3)		5.94	No limited
(Fe_2O_3)		3.32	No limited
(CaO)		61.55	No limited
L.S.F %		0.86	No limited
(MgO)		2.85	Max. 5
SO_3%) Max.	C_3A<5%	Not applicable	2.5
	C_3A >5%	2.25	2.8
(L.O.I.)		1.07	Max. 4
(I.R.)		0.88	Max. 5
(C_3S)		35.11	No limited
(C_2S)		35.07	No limited
(C_3A)		10.13	No limited
(C_4AF)		10.09	No limited

2.1.2 Coarse Aggregate

In all mixes, natural gravel with a nominal aggregate size (5-10 mm) was used as coarse aggregate. I grew up in the Spring neighborhood. The physical and chemical properties of the used aggregate, as shown in **Table 2**, follow Iraqi specifications IQS No. 45/1984 **(Iraqi Specification No. 45, 1984).**

Table 2. The coarse aggregate's chemical and physical characteristics

Sieve Size (mm)	Test Results	Iraqi Standard (IQs) No.45/1984
14	100	90-100
10	75.1	50-85
5	1.2	0-10
2.36	--	No limited
physical properties		
SO_3% content	0.092	Max. 0.1%

2.1.3 Fine Aggregates

This study used natural sand from the Al-Ekhadir (Karbala city) area as fine aggregate. It is zone 2 and complies with IQS (No. 45/1984)'s physical and chemical standards. **(Iraqi Specification, No.45, 1984),** as given in **Table** 3.

Table 3. Analysis using a sieve for fine aggregates

Size of Sieve(mm)	Passing %	Iraqi specification limitations No.45/1984 Passing % (Zone 2)
10	100	100
4.75	92	90-100
2.63	85	75-100
1.18	56	55-90
0.6	42	35-59
0.3	13	8-30
0.15	5	0-10
Fine Aggregate Physical and Chemical Properties		
Physical Characteristics	Test Results	Iraqi Standards' Limits
Specific gravity	2.5	-----
(SO_3 %)	0.4%	0.5 % (max)
Absorption (%)	0.7%	-----

2.1.4 Water

Portable water (tap water) was obtained from the laboratory and used for mixing and processing. It complies with IQS 1703 **(Iraqi Specification, No.1703, 1992).**

2.1.5 Expanded Polystyrene Beads (EPS)

This study used spherical EPS beads with a maximum nominal size of 10 mm as a complete replacement for coarse aggregate. The gradient and physical properties of EPS beads are shown in **Table 4** and **Fig. 1**.

Table 4. Analysis of sieves and physical properties of expanded polystyrene beads (EPS)

Sieve Size	Passing %	ASTM C330
12.5mm	100	100
9.5mm	91	80-100
4.75mm	6.5	5-40
2.36mm	1.5	0-20
Physical Properties		
Specific gravity	--	--
Water absorption	0	--
Maximum particle size (mm)	10	--

Figure 1. Expanded Polystyrene Beads (EPS)

2.1.6 Waste Plastic Fibers (WPFs)

In this work, reinforcing fibers were made from PET bottles of a crystalline carbonated beverage that had been cleaned to remove impurities and shaped into strips. These pieces were then cut into 4 mm wide pieces in length using a paper shredder. **Table 5** and **Fig. 2** show the PET fibers' physical properties.

Table 5. Physical properties of the composite PET fiber

Fiber color	Density (gm/cm^3)	Water absorption (%)	Thickness (mm)	Width (mm)
Crystal	1.37	0	0.3	4

Figure 2. Waste Plastic Fibers (WPFs)

2.1.7 Superplasticizer (SP)

Sika ViscoCrete 5930 (Egypt) superplasticizer was used in the modified mixtures in the study. It meets the requirements of ASTM C494 type G superplasticizer **(ASTM C494 / C494M-1, 2017). Table 6** lists the properties of the superplasticizer.

Table 6. Properties of superplasticizer Sika ViscoCrete 5930

Density	1.08 kg/liter
PH	8.0±1.0
Chloride content	NIL (EN934-2)

2.2 Molds, Mixing, and Casting

To determine the bending strength, three (100*100*400) mm prismatic molds were prepared for each age (7, 14, and 28). Three cube molds (100*100*100) mm for each age (7, 14, and 28) were prepared to test the compressive strength. The interior surface of the mixer was cleaned and wet before depositing the materials. The raw components were combined and allowed to dry for around three minutes to ensure that the polystyrene was evenly distributed throughout the mixture. After PET has been added, Water is added to the mixture, and mixing continues until a homogenous and flowing liquid is achieved. The mixing procedure takes roughly three minutes to produce homogeneous and uniform concrete. In the concrete lab of the Baghdad College of Engineering, all concrete was mixed using a planetary mixer **(**see **Fig. 3).** To enhance compaction and lessen the number of air bubbles, the mixture was put into oiled molds, which were then vibrated on a vibrating table for one minute. The samples were degassed after 24 hours and kept in water for processing before testing.

Figure 3. Different compositions in pan

2.3 Concrete Mix

Three distinct concrete mixes, in addition to the reference mix, were employed in this study. **Table 7** displays the percentage of the prepared concrete mixes.

3. RESULTS AND DISCUSSION

3.1. Compressive Strength

Results of strength properties at (7, 14, and 28) days for all LWC mixtures are shown in **Table 8** and **Fig. 4.** The addition of WPF in different volume ratios has a positive effect on the compressive strength. All blends containing WPF have higher pressure resistance than the reference mixture. This increase can be attributed to the fact that WPFs are uniformly distributed within the concrete mixture structure, which increases homogeneity and reduces the amount of voids within the concrete body, resulting in a more cohesive and rigid concrete body.

Table 7. Concrete mixtures proportion ratios after adding the PET

Mix Code	PET 0.4%	PET 0.8%	PET 1.2%
Cement (kg/m^3)	395.25	393.72	362.5
Superplasticizer (kg/m^3)	1.169	1.169	1.169
Fine aggregate (kg/m^3)	640.50	637.62	587.28
Coarse aggregate (kg/m^3)	986.27	947.86	902.26
Expanded polystyrene (EPS) (kg/m^3)	1.94	1.88	1.80
Water (kg/m^3)	177.79	176.94	163.05
Waste Plastic Fibers (WPFs) (kg/m^3)	5.49	11	16.50

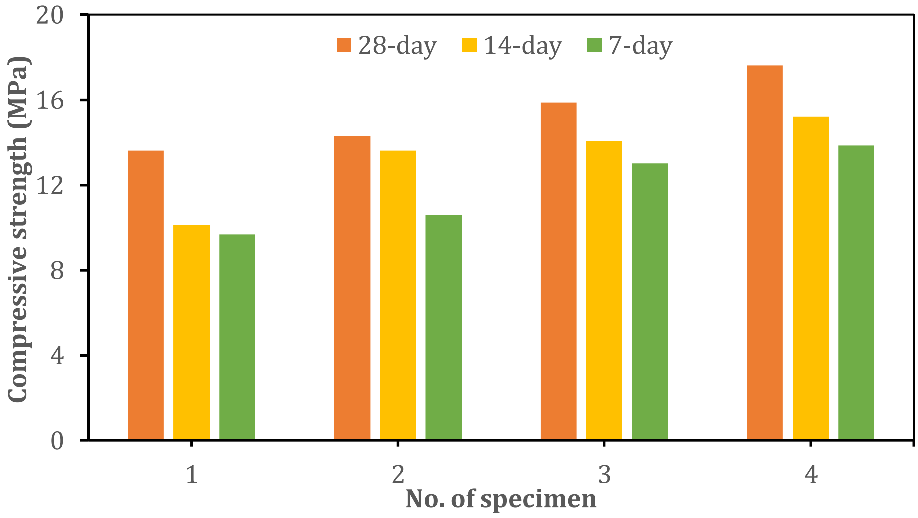

Figure 4. The correlation between variation in compressive strength (MPa) and (WPF %) for LWC

When microcracks form within the matrix, WPFs attempt to stop and limit the spread of these cracks in the adjacent development. As a result, the crack propagation path is wound, which requires more energy to continue crack propagation, and therefore this process must reach high pressures for the presence of failures **(Ganesh and Saradhi, 2003)**.

Table 8. Compressive strength for all concrete admixtures

Mix Code	7-day	14-day	28-day
PET 0%	9.67	10.12	13.6
PET 0.4%	10.58	13.60	14.3
PET 0.8%	13	14.06	15.87
PET 1.2%	13.86	15.2	17.6

3.2 Flexural Strength Test

Compared to the reference mix, the addition of WPFs in various volumetric proportions to LWC positively affected the value of the modulus of rupture. When these types of fibers with Vf equal to (0.4-1.2%) were added, the addition of WPFs was significantly visible. This increase can be attributed to the fact that WPFs are regularly distributed within the structure of the concrete mixture, which increases homogeneity and decreases the amount of voids within the concrete body, resulting in a more cohesive and hard concrete body. When micro-cracks form within the matrix, WPFs attempt to halt and limit the spread of these cracks in the neighboring region's development. As a result, the path of crack propagation is wound, requiring more energy for continued crack propagation, and thus this operation must reach high stresses for the existence of failures, as shown in **Fig. 5 and Table 9.**

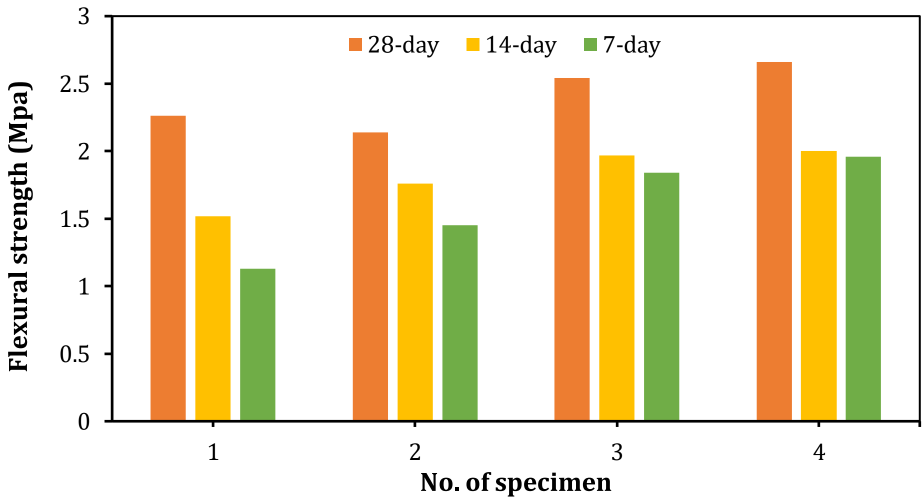

Figure 5. The relationship between modulus of rupture (MPa) variation and (WPF %) for LWC mixes

Table 9. Flexural strength for all concrete admixtures

Mix Code	7-day	14-day	28-day
PET 0%	1.13	1.52	2.26
PET 0.4%	1.45	1.76	2.14
PET 0.8%	1.84	1.97	2.54
PET 1.2%	1.96	2	2.66

3.3 Density

As shown in **Fig. 6**, curing ages influence density for various concrete types, and testing results reveal that concrete has a significantly lower density than a control concrete mixture without plastic. Because PET has a lower unit weight, adding it to the mix reduces the unit weight of the mix for a specific age. **Table 10** compares the results of LWC concrete to the control mix.

Table 10. Density for all concrete admixtures

Mix Code	7-day	14-day	28-day
PET 0%	2266	2283	2295
PET 0.4%	2246	2263	2267
PET 0.8%	2235	2239	2250
PET 1.2%	2230	2235	2243

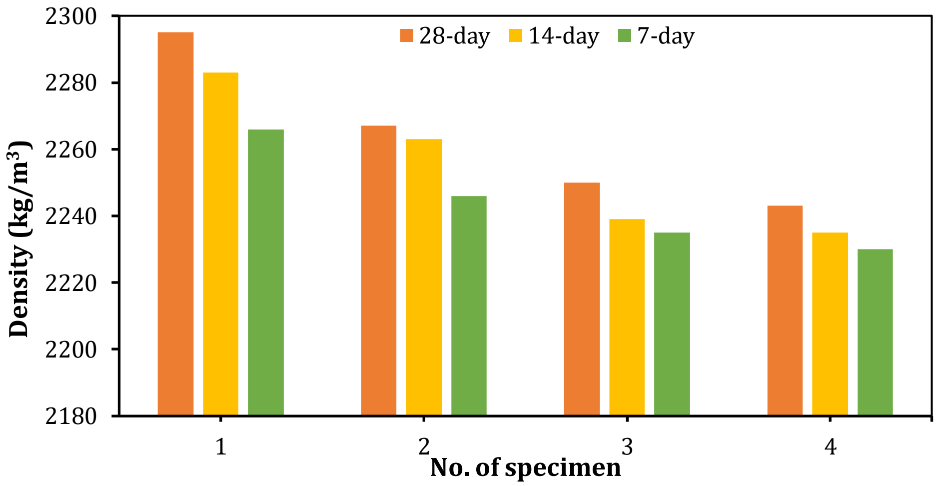

Figure 6. The relationship between density kg/m³ variation and (WPF %) for LWC mixes

4. CONCLUSIONS

This work is concerned with using plastic wastes in concrete as fibers and replacing EPS granules instead of coarse aggregates. This approach is one of the effective methods to eliminate the bad environmental effects of these wastes and to improve some of the properties of concrete. Based on the analysis and discussion of the obtained results in this study, the following conclusions can be drawn:

1 - Adding WPFs with different volumetric rates to LWC improves compressive strength. When WPFs were added by volumetric ratio, the maximum increase in compressive strength ranged between (14.3) and (17.6) compared to the reference mix.

2 - When WPFs are added to LWCs at different volumetric rates, the rupture modulus of the LWC reinforced with these fibers increases when compared to the reference mixture.

3 - Lightweight concrete using EPS as coarse aggregate with different contents of WPF showed that the density of LWCFRC decreased, with increased contents of WPF in the concrete mixtures revealing lower density.

4 - According to the results of this study, the optimal PET fiber content in LWC could be 1.2%. However, adding PET fibers with moderate to high content (0.4% to 1.2%) may be acceptable to avoid further workability loss and improve the LWC's properties.

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