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Using recycled PET waste bottles clasp of ring strips in hollow concrete blocks in Iraq

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Abstract

Solid waste is becoming a worldwide issue that must be delt with to alleviate resource depletion and to face the pollution problem. One of the major components in solid wastes is plastic. The yearly waste generation of plastics has been rising significantly. With high health problem associated with plastic waste, many approaches were introduced for recycling. Using plastic waste in concrete mix is one approach for plastic recycling that is gaining more interest globally. In Iraq, where huge amounts of plastic waste are generating daily, the need for this approach is vital. Hollow concrete blocks are of the most public building bricks used around the country. This paper aims to examine how properties of compressive strength, flexural strength, water absorption, and dry density would affect when hollow concrete blocks are used for recycling plastic waste processed as clasps of ring strips. After cutting and arranged, PET ring clasps were introduced to the mix in varying quantities (3, 4, 6, and 8) and added to hollow blocks of size 360 mm x 200 mm x 200 mm. After concrete blocks casting and curing for 28 days, they were tested for their physical properties. Most of the central physical properties of these hollow blocks were identified and showed in this study. The results showed that there was no slump before adding the clasp of ring strips, a noticeable decrease in the fresh density of the concrete as the content of PET plastic waste increases, and an increase in the compressive strength with the increase of the number of PET clasps to 6 and then decreased when increasing to 8. Results showed an increase in flexural strength for samples with clasps of ring strips. The water absorption increases with the increase of the number of PET clasps to 3, and after that, the water absorption starts to decrease with the increase in the number of PET clasps. The dry density decreases with the increase of the number of PET clasps to 3, and after that, starts to increase with the increase in the number of PET clasps. The results revealed that 6 ring clasps strips of PET (2.4 kg plastic/cubic meter of concrete) added was the optimum mix.

Keywords: *Hollow concrete blocks in Iraq, recycling strips of PET plastic waste.*

1. Introduction

The production of plastic worldwide has seen a significant surge in recent years due to its indispensable role in our everyday activities. Annually, it is approximated that around 11 million tons of plastic waste is produced in the U.S., and around three million tons is generated in the United Kingdom [1]. Primary polymers used in packaging materials typically encompass polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), and polypropylene (PP). Dealing with plastic waste typically involves options like landfilling, recycling, or incinerating to recover energy. Importantly, recycling post-consumer plastics can take the form of either closed or open-loop systems, where the waste is repurposed into a product of a similar kind or transformed into a completely different product [2]. The escalating production of disposable goods in daily life has made waste management a critical global environmental concern. Inadequate waste disposal practices contribute to environmental pollution and can have harmful impacts on the soil, air, and both ground and surface water. Notably, plastic materials, which are not easily broken down or decomposed, make up a substantial portion of landfill or dumping site contents [3]. Currently, empty water and beverage bottles made of PET plastic are not being recycled due to challenges in their separation and/or insufficient domestic market for them. As a result, these items are merely incinerated or discarded in waste disposal sites.

PET is a semi-crystalline polymer known for its robust mechanical strength, durability, and resistance to hydrolytic chemicals and solvents. Its broad applications include packaging industries, such as food and pharmaceutical products, and the production of drinking bottles. It is also employed in precision molding for the creation of office and household appliances, electronic devices, and auto parts during manufacturing [4]. Plastic is composed of numerous hazardous chemical substances, and as a result, it leads to the pollution of air, water, and soil. When plastic waste is incinerated, a range of harmful chemicals are emitted into the atmosphere, including dioxins, which are among the most toxic substances known.

One potential remedy is to repurpose PET plastic waste as short fiber reinforcement in structural concrete. This application not only offers improved control over cracking and enhances the ductility of quasi-brittle concrete, but it also provides an alternative for large-scale consumption, a key consideration in recycling waste materials. Lately, the integrating of plastic wastes in the concrete industry has attracted substantial interest. Recycling or reusing plastic waste into construction materials, like concrete, carries numerous benefits, including reducing the cost of concrete production and providing an effective means of plastic waste disposal [5]. Integrating plastics into concrete can significantly enhance some of its characteristics, given that plastic boasts high toughness, excellent abrasion resistance, high heat capacity, and low thermal conductivity [1].

In the construction industry today, recycled plastic is being utilized in a variety of ways, including serving as polymer concrete resin and acting as synthetic coarse aggregate for the production of lightweight concrete [6]. Thus, it forms part of the initiatives aimed at recycling waste from plastic bottles, a material that is produced in substantial amounts and is difficult to break down [7].

Applications of PET fibers in concrete have been developed in many studies [6, 8]. Choi et al. used granulated blast-furnace slag which is a light-colored glassy sand with size of0.4 mm produced by the rapid quenching of molten blast furnace slag with huge volumes of water [9]. Foti conducted a comparison of the behaviors of samples with and without fibers during bending tests. The results demonstrated an increase in residual strengths after cracking, thereby positioning recycled PET fiber reinforced concrete as an advanced material [8]. Ochi et al. tested other properties and showed a sufficient alkali resistance when compared with other fibers making PET good as concrete-reinforcing fibers [7]. Guendouz et al showed an increase in compressive strength when adding PET fibers. They showed that adding 2% of sand weight to concrete may increase its compressive strength by 25% [10]. Thomas and Moosvi used recycled waste PET bottle fibers (RWPBF) as an additive to cement. According to their research, the addition of RWPBF enhanced the 28 days compressive strength up to 10.67%. Furthermore, concrete specimens' tensile, elastic, and flexural strengths were all markedly increased by the use of RWPBF. They showed that 0.4% was the ideal amount of RWPBF addition, after which the strength decreased and was lower than in control specimens [11].

In Ochi et al. study, a process was utilized in which the materials were extruded to create monofilaments, or the fiber surfaces were treated with maleic anhydride grafted polypropylene and subsequently cut to achieve the anticipated fiber length. However, these elongated manufacturing procedures tend to erode the cost-effectiveness of the process [7]. Marzouk et al. used granulated PET particles and small shredded PET particles for partial and total replacement of sand [12]. Sule et al. also used granular PET particles to replace fine aggregate [13]. In a study, Hameed and Ahmed used recycled plastic PET in different weight percentages (1%, 3%, 5%, 7%, and 10%) to substitute cement and demonstrated that in comparison to the concrete without PET, the addition of 1% PET resulted in a considerable increase in the split tensile and compressive strength by 58% and 30%, respectively. Moreover, they showed that when 1% and 3% PET were added to the concrete, the flexural strength increased by 23% and 25%, respectively, compared to the concrete without PET. As the concrete's density fell with increased percentage of PET, their investigation came to the conclusion that PET may be used to create lower-density concrete and use less cement mortar. [14]. Frigione investigated replacing 5% of the fine aggregate by weight with PET aggregates made from leftover unwashed PET bottle debris. The results show that when the cement concentration is between 300 and 400 kg/m3 and the water to cement ratios (w/c) are between 0.45-0.55, the concrete containing unwashed PET retains a similar slump to regular fresh concrete. Moreover, this kind of concrete has somewhat lower tensile and compressive strength as well as a smaller modulus of elasticity, which translates to increased flexibility, in comparison to the reference concrete [3]. By analyzing the behavior of PET waste particles, Albano et al. discovered that there was a decrease in modulus of elasticity, compressive and tensile strengths, and average PET particle size, between 0.26 cm and 1.14 cm, at volume change ratios of 10% and 20%. The addition of PET to the concrete mixture results in a decrease in the concrete's stiffness. This may be helpful in circumstances where a more flexible substance is needed. According to non-destructive testing, adding PET particles to the concrete mix results in a decrease in slump, an increase in water absorptions, and a decrease in the propagation speed of ultrasonic pulses [15]. In their review, Siddique et al. classified four categories for recycling plastic in concrete. Notably, none of these classifications involved cutting plastic into strips [1]. It shows that limited number of studies has tested the use of PET plastic as strips in hollow concrete blocks. The current paper explores the properties of concrete reinforced with PET strips derived from waste bottles and arranged in a clasp of ring. PET fibers were obtained using a simpler method: waste bottles were cut in an uncomplicated manner to circumvent expensive manufacturing procedures. While this work contributes to the expanding field of studies on fiber-reinforced concrete, the primary objective is to demonstrate the effects of adding strips in a different way to the concrete.

Hollow concrete brick is one type of the most used bricks in Iraq. Its low price, workability, and lightweight enhancing the widely usage of this type of bricks. Hundreds of concrete brick factories are located in various areas of the country. In Al-Muthanna Governorate in Southern Iraq in particular, where the poverty rate is the highest in the country (52.5% according to the Statistics Directorate in Al-Muthanna, 2014) [16], the application of hollow concrete bricks, due to its cheapness and availability, is more common. Concrete bricks could be an efficient way to deal with a huge amount of plastic solid waste that is generated on a daily basis in the governorate. However, there is a lack of studies on the properties of hollow concrete bricks when PET plastic waste is used in it.

Nonetheless, the primary element of the concrete masonry unit (CMU) matrix remains the natural aggregate, placing further strain on the finite natural resources. In addition, compared to other building materials like stone and wood, the

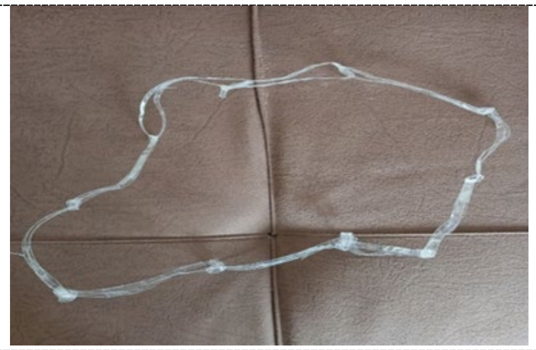
embodied energy of CMUs is the largest due to the cradle-to-gate energy processing of natural aggregate, which includes extraction, production, and transportation, which worsens environmental damage [17]. Energy-efficient masonry units must be developed immediately to lower the high operational energy of masonry buildings [18].
The utilization of waste materials for recycling purposes has been employed as a means to substitute materials, so promoting the gradual reduction of natural resources that are now experiencing excessive exploitation [19]. Although the fundamental purpose of waste recycling is to minimize the quantity of discarded materials and mitigating its detrimental impact on the environment, it also should focus on enhancing concrete properties. This study will examine a new way of mixing plastic strips with concrete for such purpose.

2. Experimental programme

2.1. Material characteristics

For this research, we made use of Ordinary Portland Cement of type V. Its features are in alignment with the guidelines stipulated in the Iraqi Standard No. 5/2019 [20].
Natural gravel coarse aggregate was used with size of up to 10 mm while the fine aggregate was selected from sand (maximum size of 4.75 mm). There are types of plastic waste in the country, such as empty water bottles, that are not recycled now because people in industry do not find market for it in the country. Hence it is simply open burned now or disposed to dumping areas. To test possibility of recycling such plastic in concrete in form of clasps, the clasps of rings produced using the (O fibers) and linking them together to form a ring chain that is placed in the mold during the casting process. Figure 1 shows the type of plastic waste added to the mix in the study.

(a)



(b)

Fig. 1: Plastic waste cut used in the study in shape of clasp of ring strips;(a) (O fibers) linking them together to form a ring chain. and (b) clasp of ring.

The gradations of both fine and coarse aggregates are presented in Table1. These aggregates complied with the guidelines set out in the Iraqi Standard No. 45/1984 [21].

Table 1: Breakdown of fine and coarse aggregate sizes used in the study

Sand/ Gradient area No. 1								
Sieve size (mm)	10	5	2.36	1.18	0.6	0.3	0.15	bowl
passing %	99.53	96.61	75.39	53.06	36.32	14.65	3.09	0
Iraqi specification*	(100)	(100-90)	(95-60)	(70-30)	(34-15)	(20-5)	(10-0)	
Gravel/ Nominal size of single size aggregate is 10mm								
Sieve size (mm)	14	10	5	2.36	bowl			
passing %	100	97.85	17.4	1.35	0			
Iraqi specification*	(100)	(100-85)	(25-0)	(5-0)				

* Percentage Cumulative Pass, in Accordance with the Limits of Iraqi Specification No.45/1984

The PET strips were obtained through a straightforward method. Circular strips, 80mm in diameter with an approximate cross - section of 5 mm x 0.1 mm, were produced after cups removal of the Empty 1-liter plastic bottles. The cutting of bottles and cups was performed as perpendicular to their longitudinal axis as possible. The (O fibers) linking them together to form a ring chain.

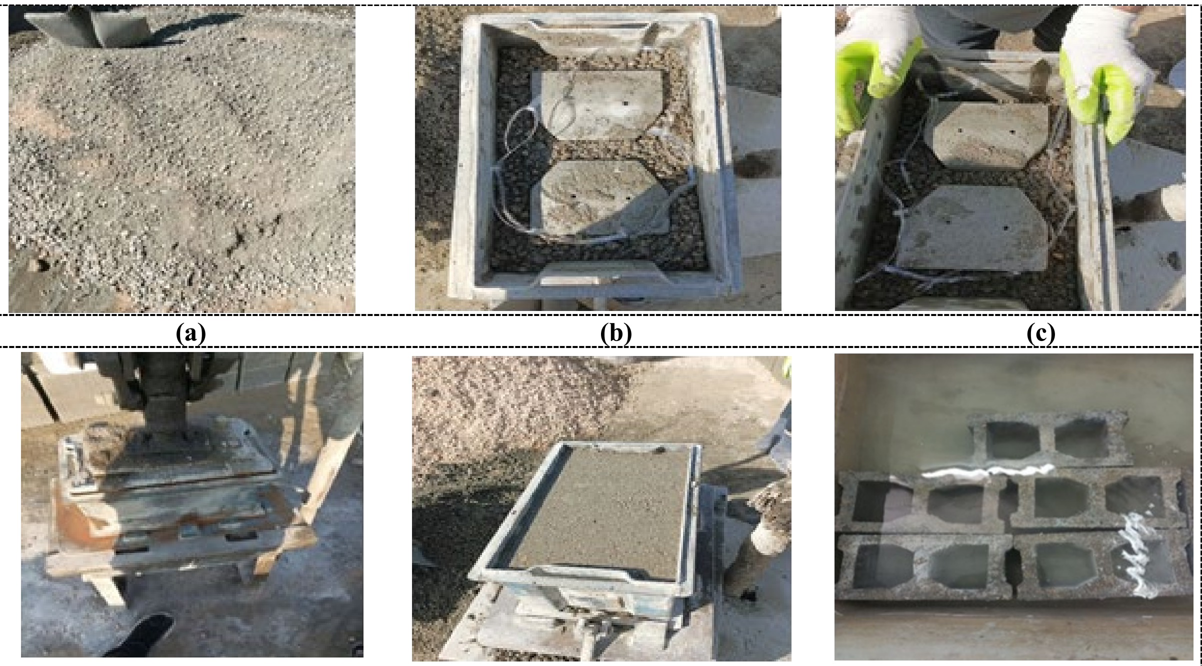
2.2. Mixing, casting and curing

Tap water in the concrete blocks factory was used for mixing and later for curing. Usually, M20 concrete is used for most constructional works of this blocks. M20 can be used as bedding of footings, domestic floors with reduced cost. M20 (1:1.5:3) concrete was chosen as a control mix and compared with trial blends. Each mixture incorporated 364.5 kg/m^3 of cement, 546.75 kg/m^3 of sand, 1093.5 kg/m^3 of gravel, and a water-to-cement ratio of 0.43. The calculated density of the newly mixed concrete was 1900.2 kg/m^3. Clasp of rings plastic was added in different numbers to the concrete mix (3, 4, 6, and 8), which is equivalent to the percentages of (0.06%, 0.08%, 0.12%, and 0.16%) of the concrete weight respectively. There were three bricks casted for every number of clasp of rings tested. Components of other elements in concrete (cement, aggregates and water) were unchanged as shown in Table 2.

Table 2: Concrete mixture proportion with different percentage of PET

Materials for one block, kg	No. of clasps				
	0	3	4	6	8
Cement	3.426	3.426	3.426	3.426	3.426
Sand	5.139	5.139	5.139	5.139	5.139
Gravel	10.279	10.279	10.279	10.279	10.279
Water	1.473	1.473	1.473	1.473	1.473
PET plastic	0	0.011	0.015	0.023	0.030
% PET of fine aggregate	0%	0.2%	0.3%	0.45%	0.58%
% PET of coarse aggregate	0%	0.1%	0.15%	0.22%	0.29%

The mixing procedure commences with the addition of sand and gravel aggregates to the mix of concrete, followed by the cement. Subsequently, water should be added gradually. This approach allowed for a nearly homogeneous concrete mix. The clasp of ring strips was added to the concrete mixture when placed in the mold as depicted in Figure 2 (a, b, and c).
Following the mixing process, a mold suitable for hollow concrete blocks, measuring 360 mm x 200 mm x 200 mm, was prepared. The hollow space in the concrete block constitutes 37% of the total volume and consists of two partial hollows, each extending from the top to a depth of 160 mm. The remaining 40 mm from depth forms the solid part of the concrete block. The mixture was subsequently layered into the mold in three sections and compacted using a vibrating tool. The top surface of the concrete was subsequently leveled and mechanically pressed. After a duration of 24 hours, all the specimens were transferred to a water tank for a curing period of 28 days, preparing them for testing, as depicted in Figure 2 (d to f). All casting procedures were carried out at a block factory located in the rural region of the City of Al-Samawah.



(a) **(b)** **(c)**

(d) **(e)** **(f)**

Fig. 2: (a) shows the mixture; (b), and (c) show the addition of clasp of ring strips plastic waste to the mixture in the mold;(d) shows pressing of the hollow concrete brick molds; (e) shows the sample in the mold; and (f) shows the curing in the water tank.

2.3. Concrete tests

İn the fresh state of concrete, mixture was tested for slump and fresh density to determine its workability. Experimental tests in hardened state were including oven dry density, water absorption, compressive strength, and flexural tensile strength. Tests were conducted in the laboratories of College of Engineering at Al-Muthanna University.
The slump test was performed by ASTM, 2003, C143/C143M – 15a standards [22]. This test aimed to determine if the concrete had the appropriate consistency and cohesiveness, ensuring that it maintained its homogeneity and compactness when poured, with minimal segregation of its constituents. For the fresh mix, a slump cone test was performed to assess the concrete's workability. During the mixing process of concrete, a leveled surface was set, and the slump cone was positioned on it. After that, the cone was filled with concrete mix and packed to remove any air voids. The measurement of the vertical settlement of the freshly prepared concrete within the cone is known as the "slump". The slump value was determined by

raising the cone vertically and calculating the height difference between the concrete sample and the cone. Fresh density test was performed according to BS 1881 Part 107 83 [23].
To evaluate the concrete strength, compressive tests were carried out after the curing period of 28 days. The hydraulic compression testing machine (CTM) was employed to crush the concrete block samples, adhering to the guidelines outlined in the Iraqi Standard Specification No. 1077 of 1987 [24]. The concrete block samples were positioned within the CTM, and a load was gradually applied to the samples until failure occurred, with the testing conducted at a specified rate.
The flexural strength of masonry is of prime significance in earthquake-prone areas as the masonry walls are predominantly subjected to flexure and shear [25]. One of the objectives of the test is to determine the flexural strength under varying normal stress levels. The study attempts to compare the test results of hollow concrete blocks with a concrete mixture free of plastic waste with hollow concrete blocks that include specific proportions of plastic in their concrete mixtures to determine the impact on flexural strength. The major reason for testing flexural strength is the observation of cracks in the building's walls as a result of exposure to bending and shear stresses due to differential settlement in the foundations in many areas around the governorate. Therefore, flexural strength test is needed for the hollow block industry in the area.
For that, blocks were subjected to testing to determine the concrete flexural strength. As the Iraqi standard specification No. 1077 of 1987 [24] for concrete blocks does not include tests of flexural strength, Construction Laboratory in Al-Muthanna Governorate usually conducts this test according to the Iraqi standard specifications No. 1106 of 1987 [24] that are related to curbstone works. Later, the laboratory adopted the specification of BS EN 1340:2003 [26], which pertains to the edges of precast concrete sidewalks and driveways for this test. Hence, the flexural strength for concrete blocks was carried out based on these BS standards, taking into account the difference in shape and dimensions. Flexural strength tests were conducted for hollow concrete a lot of research around the world. For example, in the study of Yang and Li (2019), the flexural strength of recycled concrete hollow blocks was tested according to the national “Test Methods for the Small Concrete Hollow Blocks” standards in China. Similar to BS standards, China’s national standard, requires designing a bending-resistant bearing and a hydraulic universal testing machine is used. The bearing consists of three steel bars and steel plates with a diameter of 35–40 mm and a length of 210 mm, and weld a groove to fix the steel bar on the steel plate so that one of the steel bars can roll freely [27].
The test was performed utilizing a flexural device by a three-point bending test; the readings are recorded at each phase of loading. Then flexural strength was calculated according to Equation (1). Three specimens were taken for each test to report an average value.

$$\text{Flexural strength} = (M*c / I) \quad (1)$$

Where “M” represents bending moment, “I” is the moment of inertia, and “c” is the distance from farthest fiber to neutral axis (N. A).
Furthermore, after the 28-day curing period, additional samples underwent water absorption testing. These samples were initially placed in an oven at 105 ºC for 24 hours to achieve complete drying. The dry weight of the samples was then measured. Subsequently, the samples were immersed in a water tank for 24 hours, after which their wet weight was measured. The calculation of water absorption was performed using Equation (2) as specified.

$$\text{Water absorption} = ((WW-DW)/DW) *100 \quad (2)$$

Where “WW” is the wet weight, and “DW” is the dry weight after drying in oven.
Dry densities or volumetric weight of the concrete specimens were also measured. The technical characteristics of the materials are related to the volumetric weight such as durability and heat transfer. The volumetric weight is included in calculating the thickness of the walls for residential buildings and in calculating the degree of compaction and porosity of the materials.
It is the ratio between the weight of the material in the dry condition to its normal size (the volume of the solid particles with the pores and voids). The samples were placed in oven for 24 hours at 105 ℃. The samples were then weighed to determine oven dry weight in accordance with the Iraqi standard specifications No. 1077 of 1987 [24]. The volumetric weight was calculated according to Equation (3):

$$\gamma_o = (G / V) \quad (3)$$

Where “γ_o” is the Volumetric weight, “G” is the weight of the material, and “V” is the material volume.

3. Results and discussion

3.1. Slump test

A small amount of water is retained in the concrete mix during the preparation and manufacture of the concrete block because it passes through stages of vibration and pressure when placed in the mold. The w/c ratio used in this study was 0.43. Therefore, no slump occurred in the reference concrete, zero slump is one of the types of concrete slump tests as per ASTM, 2003. Designation: C143/C143M- 15a [22]. The method of casting concrete blocks includes lifting the mold from the specimen immediately after the casting process to entrust its use again, where the casting process is carried out successively using the same mold (one mold), in addition to placing the concrete blocks one next to the other (i.e. vertically) after pouring so as not to take up wide space and this requires that no slump occurs in the concrete to avoid changing the dimensions and shape. Therefore, the result of the slump test (Zero slump) is consistent with the requirements for pouring concrete blocks.

A slump test for concrete with PET was not conducted because the clasps of rings strips are added after the mixing process is completed and the concrete mixture is placed in the molds.

3.2. Fresh density

Table 3 displays the fresh density of the reference concrete mix, as well as concrete mixtures incorporating different quantities of PET plastic waste as clasps of rings strips. The findings indicate that as the content of PET plastic waste aggregates increases, there is a noticeable decrease in the fresh density of the concrete. The likely explanation for this trend is that PET typically possesses a lower specific gravity than natural concrete, and the density of concrete is influenced by the properties of its constituents. Consequently, as the level of PET plastic waste aggregates increases, the density of the concrete decreases accordingly.

Similar findings were observed by Saikia and De Brito [28], as well as by Adnan and Dawood, who noted that the density of fresh concrete mixtures decreased as the percentages of plastic waste increased. Adnan and Dawood reported a decline in density of approximately 0.997%, 0.993%, and 0.986% when plastic box waste percentages (PBWPs) of 2.5%, 5%, and 10% were added to the reference mixture, respectively. As the replacement percentages increased, it was observed that the densities of all mixtures containing PBWPs exhibited a consistent downward trend [29].

Table 3: Averages of fresh density and compressive and flexure strength for hollow concrete blocks samples with clasp of rings strips used in this study.

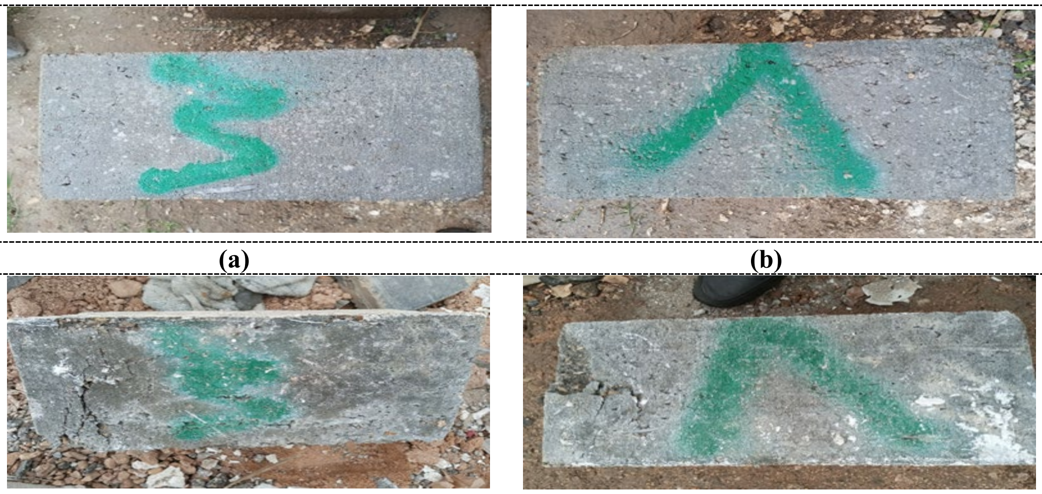
No. of clasps		0	3	4	6	8
Fresh density, kg/m^3		1900.2	1865.5	1847.1	1810.0	1788.8
Compressive strength (28 days), MPa	Average	7.06	7.45	7.58	8.16	6.01
	Range	6.15-7.94	6.05-9.60	5.15-12.03	7.47-9.02	4.64-8.70
Flexural strength (28 days), MPa	Average	2.27	2.47	2.36	2.53	2.50
	Range	2.18-2.44	2.37-2.59	2.11-2.52	2.31-2.67	2.21-2.7
No. of vibrating runs		3	3	4	6	8

3.3. Compressive strength

Averages of compressive strength for hollow concrete bricks samples with clasps of rings strips used in this study are shown in Table 3. The result increases in percentage of 5.52%, 7.37% and 15.58% with the increase of number of PET clasp to 3, 4 and 6 respectively compared with control mix. However, with increasing the number of PET clasp to 8, the compressive strength decreased by a percentage of 14.87%. The increase in compressive strength is due to the resistance of the PET against the dilation of the concrete core when compressed [30].

In many studies, it was detected that compressive strength was decreasing when plastic waste content is increasing for various % replacements [9]. The observed reduction in compressive strength can be related to a decrease in the adhesive strength between the cement paste and the plastic aggregate.

Figure 3 depicts the sample with PET before and after test of compressive strength. The specimens that included PET did not disintegrate into pieces but maintained their shape, despite several surface cracks.



(a) (b) (c) (d)

Fig. 3: Concrete blocks with (4 and 8) claps of rings;(a, and b) before the test of compressive strength; (c, and d) after the test.

3.4. Flexural strength analysis

Averages of flexural strength for samples with clasps of rings strips are shown in Table 3. There were increases in percentage of 8.81%, 3.96%, 11.45% and 10.13% with the increase of number of PET clasps to 3, 4, 6 and 8 respectively. The results of flexural strength from Hameed and Ahmed exhibited that the use of PET at 1%, 3%, and 7% led to an

increase in flexural strength compared to the reference batch by (23.11%, 25.59%, 37.93%) respectively. However, at 5% and 10% PET content, the flexural strength decreased by (23.86%, 0.41%) respectively. The material's resistance to bending depends on the compressive strength of the upper surface and the tensile strength of the lower surface, as well as the interfacial shear strength of the internal layers [14]. The presence of PET aggregate within certain percentages in the concrete structure hinders crack propagation, leading to an increase in flexural strength. However, excessive addition of aggregate may result in defects, such as voids, inside the concrete, subsequently decreasing its strength. In many studies, it was observed that there was a decrease in compressive and flexural strength with an increase in plastic content for various % replacements. The reduction mostly related to reduce in adhesive strength between plastic aggregate and cement paste.
An observation was made that in samples reinforced with clasps, as the bending increased, failure occurred progressively without complete collapse of the composite structure. This is attributed to the fact that while the concrete experienced breakage, the load previously sustained was transferred to the clasps. Consequently, the clasps exhibited their contribution to the structural integrity of the composite material once the point of maximum tensile strength was reached [8].
For samples reinforced with these strips or clasps, an increase in bending led to a gradual failure progression. Despite this, the composite did not collapse because, even when the concrete broke, the load that it had been supporting was transferred to the strips. This indicates that the strips start to play a significant role after the point of maximum tensile strength is reached [8]. In contrast, the reference mixture failed abruptly, splitting entirely into two parts. On the other hand, the inclusion of PET in the concrete mixture merely resulted in the appearance of a surface crack but did not separate the sample into parts. This maintained the original form of the specimens, showcasing that the incorporation of PET enhances both the ductility and performance of the concrete mixture [27], as depicted in Figure 4. The findings suggest plastic aggregate in form of clasps of rings could help prevent catastrophic failure when buildings are subjected to such loads [14]. Figure (5) depicts the sample with PET before and after test of flexural strength.

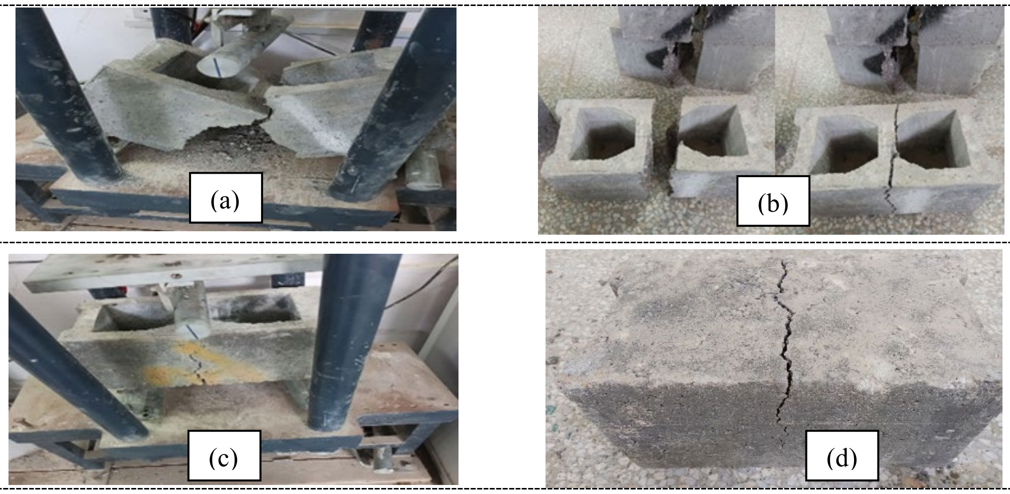


Fig. 4: Failure modes of concrete blocks; (a, and b) without plastic; (c, and d) with plastic, (a, b, and c) top and side views, and (d) bottom and side views, respectively.

Fig. 5: Concrete blocks with (4 and 6) claps of rings;(a, and b) before the test of flexural strength; (c, and d) after the test, respectively.

3.5. Flexural strength analysis

The results presented in Table 4 indicate that the water absorption of concrete containing clasps of rings strips of PET increases in 0.8% with the increase of number of PET clasps to 3. After that, the water absorption starts to decrease in 0.4%, 1.0 % and 1.0 % with the increase in the number of PET clasps to 4, 6 and 8, respectively. Increasing the vibration of the concrete in the block's molding during the placement of the clasps of ring strips of PET in the concrete contributed to improving its compaction which leads to a decrease in water absorption. Generally, all absorption values are within the limits of the Iraqi standard as shown in Table 5.

Table 4: Averages of oven dry density and water absorption for hollow concrete blocks samples with clasp of rings strips of PET at the age of (28) Days used in this study.

Clasps of rings added	Average dry density (kg/m^3)	Average Water Absorption, %	Changing in Oven Dry Density, %	Changing in Water Absorption, %	Maximum Water Absorption of Single Block, %	No. of vibration
0	2220.440	3.7	---	---	4.0	3
3	2172.949	4.5	-2.14	+0.8	4.9	3
4	2282.927	3.3	+2.81	-0.4	3.7	4
6	2302.993	2.7	+3.72	-1.0	3.0	6
8	2253.547	2.7	+1.49	-1.0	4.1	8

Table 5: Compressive strength and absorption requirements for loaded and unloaded concrete blocks

Block type	Class	The Minimum compressive strength, MPa		Maximum water absorption, %
		Average of 3 blocks	One block	
Loaded (Hollow)	A	7	6	15
	B	5	4.5	20
Unloaded	-	4	3.5	22 for one block and 18 for average of 3 blocks

4. Conclusion

The experimental findings presented in this study highlight the potential of utilizing PET waste plastic material in the production of hollow concrete blocks as a viable solution to mitigate the environmental impact caused by inadequate disposal of plastic waste in Iraq. This approach offers an alternative avenue for recycling and reusing plastic waste, contributing to environmental sustainability. PET plastic waste formed in (3, 4, 6, and 8 clasps of rings) were added to every single hollow block and tested for its physical properties. The followings were concluded from the study:

- Compared with control mix, Compressive strength for hollow concrete brick samples with clasps of ring strips used in this study increases in percentage of 5.52%, 7.37% and 15.58% with the increase of number of PET clasp to 3, 4 and 6, respectively. However, with increasing in number of PET clasps to 8, the compressive strength decreased by 14.87%.
- Calculations indicated that incorporating the samples with 6 clasps of rings strips of PET added will increase the compressive and flexural strength of hollow concrete blocks to 15.58%and 11.45% respectively, and offers a substantial reduction in plastic waste in the country, with approximately 2.4 kg of plastic waste (equivalent to around (88) 1.5-liter bottles) being effectively utilized in every cubic meter of concrete used for producing hollow blocks.
- Tests conducted to determine compressive strength and absorption showed that type A and B loaded hollow concrete blocks can be achieved with (3, 6) and (4, 8) PET clasps of rings strips addition, respectively. Manufacturers still able to produce loaded concrete blocks with the addition of all dosages of PET.
- The addition of clasps of rings strips with all percentages tested had caused increasing in flexural strength of the hollow concrete blocks.
- Evidence indicates that dry density and absorption rate are clearly affected by the number of vibrations of the concrete in the mold containing (4, 6, 8) PET clasps of rings strips. The results of these tests show the combined effect of the PET clasps of ring strips and the number of vibrations of the concrete mixture in the mold compared to the reference mixture.

5. Recommendations

1. Standardization of optimal PET-added ratios: It is recommended to add six clasps of ring strips to the concrete mix to improve the compressive and flexural strength of hollow concrete blocks, while reducing plastic waste.
2. Explore Different PET Forms for Concrete Improvement: 1) Continue investigating the usage of PET plastic waste in the form of clasps and at varying percentages, 2) Determining the number of times the concrete mold is vibrated (3 times), for concrete containing PET in the form of clasps with different numbers to identify further opportunities for its application in concrete block production, and 3) Chemical and mechanical treatment of PET plastic waste may be used when added to the concrete mix to improve connection of plastic to concrete.
3. Develop Regulations for PET Plastic Waste Usage: Encourage the development of industry regulations that support the use of PET plastic waste in concrete block production, considering its potential to address environmental concerns and improve concrete properties.

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