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UTILIZATION OF WASTE PLASTIC BOTTLES AS FINE AGGREGATE IN CONCRETE

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ABSTRACT

As human communities grow larger and larger, the problem of waste management becomes one of urgent need that should be solved. Recycling and reusing of the waste materials is an efficient measure in management of the waste materials, which in addition to preventing the pollution, it conserves natural resources. Plastic bottles made of polyethylene terephthalate (PET), constitutes a major fraction of household wastes. They are classified as non-biodegradable waste materials which are harmful for public health. So making use of PET in concrete production can be useful method to get rid of plastics solid waste damage on environment.

In this research, effect of using waste PET that was converted to granules in concrete has been studied experimentally. Different proportion of sand ranging from 1% to 8%, were replaced by granulated plastic. The resulting concrete was compared with normal concrete without any addition of granulated plastic. Then the specimen were tested at 7 and 28 days after curing, and some engineering properties of the mixtures including slump test, fresh and dry density, compressive, and slip strength have been investigated. Analyzing experimental results of this work indicated that optimum dosage of waste bottles replacement is 2% as fine aggregate-substitution aggregate to get maximum compressive strength and slip strength.

KEYWORDS: Waste Polyethylene Terephthalate Plastic Bottles, Recycling, Concrete, Compressive Strength.

استخدام عبوات المياه المستهلكة كبديل عن الركام الناعم في الخرسانة

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الخلاصة

كلما أخذت المجتمعات البشرية بالنمو أصبحت مشكلة ادارة النفايات واحدة من القضايا الملحة التي تتطلب معالجة. وتعتبر إعادة التدوير وإعادة استخدام النفايات هي من التدابير الفعالة في إدارة النفايات، والتي بالإضافة إلى منع التلوث، فهي تحافظ على الموارد الطبيعية. ان العبوات البلاستيكية المصنوعة من البولي ايثلين تيريفثاليت تشكل مكونا كبيرا من النفايات المنزلية. وتصنف على أنها مواد غير قابلة للتحلل والتي تسبب ضررا للصحة العامة. إن إعادة تدوير البولي ايثلين تيريفثاليت واستخدامها في الخرسانة تساعد في حل بعض مشاكل النفايات الصلبة التي يشكلها البلاستيك.

في هذا البحث تم دراسة تأثيرنفايات البولي ايثلين تيريفثاليت في الخرسانة عن طريق استبدال نسب مختلفة من الركام الناعم تتراوح من 1٪ إلى 8٪ من نفس الحجم من البلاستيك ومقارنتها مع خلطة مرجعية. من ثم تم اختبار عينات بعد 7 و 28 يوما من التقسية، وفحص بعض الخواص الهندسية والميكانيكية للخلطات بما في ذلك فحص الهطول، والكثافة الرطبة والجافة، مقاومة االانضغاط، ومقاومة الانزلاق. تشير نتائج هذا البحث امكانية استعمال نفايات العبوات البلاستيكية كبديل عن مادة الركام الناعم لاستخدامها في الخرسانة بنسبه مثلى هي 2% حيث حققت اعلى مقاومة انضغاط ومقاومة انزلاق.

الكلمات المفتاحية: عبوات البولي ايثلين تيريفثاليت المستهلكة، إعادة التدوير، الخرسانه ، فحص الانضغاط.

1. INTRODUCTION

Plastics are one of the most widely used materials that change the human life for more than six decades ago. Today, plastics are used in almost every area, from small bottle caps, to large containers, such as laundry baskets and garbage pails. In present time we produce and use twenty times more plastic amount than we did five decades ago (Plastic the facts, 2015). Global production of plastic materials through the last decade has increased dramatically. This growth in plastics manufacturing is due to its many benefits like their lighter weight, durability and lower economic cost when compared to many other material kinds (Andrady and Neal, 2009). The recorded growth in plastic manufacturing industry within the last five years was 4-5% (Plastics - the facts, 2013).

An amount of about 107 ton of PET is used every year to produce about 250×109 bottles all over the world. According to a recent study by Smithers Pira (2014), the global consumption of PET packaging is expected to increase at a rate of 5.2% to reach 19.1 m tones by 2017. Its unique properties such as impact resistance, excellent barrier properties, reflective and opaque increased its usage for the bottles for a lot of liquids and drinks. In the total production, about 30 % of the PET is used for the manufacturing of bottles (Saiter et al., 2011).

The mass industrial production of PET bottles in such large quantities has developed huge environmental challenge, since these bottles are used for one time only and left to be a plastic waste, which are slow biodegradation in nature. Recycling is one of three ways for utilization and minimization of the huge amount of waste. The others are landfilling and incineration with or without energy recovery (Abbas and Shubbar, 2008). Plastic materials are slowly degraded materials, so should not be dumped or left in landfills due to its accumulation and gathering. On the other hand incineration has received much social resistance due to the environmental pollution created by combustion process that causes poisonous gases.

Developed countries realized that recycling of plastic wastes is a necessary step to control environmental pollution and make use of waste material as new resources. So, one method of saving the environment, of this waste bad effect, is to use these waste in any useful application especially applications of low cost. During the latest decades many researchers have centered their works in using plastic waste as raw materials from second degree as an alternative to natural resources.

In construction industry, concrete is the widely used material all over the world countries and it’s the second one after water as the most available substance on earth planet. It's well known that concrete brittleness increases as it's subjected to higher load and this is a major drawback since it makes the prediction of failure more difficult, especially in structures which are subjected to blast or suddenly applied loads, so making use of polymer waste in concrete would be an effective use because of its desired properties. In addition to the benefits of using plastics waste, the blending of plastics like PET wastes in concretes is useful way for the making a lightweight concrete. Decreasing the unit weight of concrete is one of the building structures aims in order to withstand earthquakes (Sulyman et al., (2013); Ahmed and Raju, (2015)). Johnny Bolden et al., 2013 pointed that plastic represents 5% of the most globally used recycled materials in construction field. Shamskia (2012) pointed that the notion of using PET fibers in concrete is being researched more and more because of the environmental pollution concerns.

Different investigations have been done on the use of plastic waste in producing concrete. Choi et al. (2005) studied addition effects of deposed PET bottles on mechanical properties of concrete and they stated that plastic can lessen the weight of traditional concrete by 2.0-6.0 %. But a reduction in compressive strength by 33% was noticed to that of ordinary concrete. Also the observations of Batayneh et al. (2007) indicated a drop of compressive strength with increasing plastic percentage proportion.

Semiha et al. (2009) replaced a fraction of coarse aggregates with waste PET granules and mentioned various benefits such as dead weight reduction of the structural members, reduction of the use of natural resources and environmental pollution. Ismail and Al Hassani (2008) stated that PET bottles can be used in producing concrete as a fiber or as substitution of aggregate to get lighter weight concrete insured that using deposed plastic as a fine aggregate-substitution aggregate in concrete represents a successful method to lessen the economic burden of construction materials and to get rid of plastic waste. Al-Manaseer and Dalal (1997) investigated the variation of the bulk density of concrete due to plastic aggregation. They found that the bulk concrete density reduced as the proportion of plastic aggregates increases.

Rebeiz and Fowler (2012) studied the flexural behavior of steel-reinforced polymer concrete (PC) using recycled PET waste. Test results show that a good improvement in flexural strength can be gained by reinforcing PC using recycled PET, and stated that Concrete with recycled PET can be used in applications including precast components; repair materials for Portland cement concrete; and bridge, wall, and floor overlays.

In another study, Ramadevi et al. (2012) showed that the addition 1 to 2% of PET fiber causes an increase in both the compressive and flexural strength of the obtained concrete, while above 4%, the compressive and flexural strength decreases.

Magalhães et al. (2015) studied the effect of recycled PET fibers as reinforcement of cementations' matrix. The bending performance of the mixtures was assessed. The results illustrated that the utilization of PET fibers dramatically enhances the post-cracking behavior of mortars and improves its toughness and deflection capacity. The maximum volume of PET fibers to get best workability and performance of the composite was 2 %.

Patil (2015) concluded that modifying concrete mix, when adding plastic aggregate up to proportion of aggregate up to 20% gives strength with in accepted values. Density of concrete is reducing after 20% replacement of coarse aggregates in a concrete.

Córdoba et al. (2013) showed that concretes consisting finer PET particle sizes in lower concentrations has an enhancement on compressive strength and strain. While Young's modulus of elasticity reduces as the PET particles size was increased.

Saikiaa (2013) studied the effect of adding 3 different shapes of waste PET to concrete. They reported that the incorporation of any kind of PET-aggregate lessens the compressive strength of produced concrete. The PET-aggregate incorporation enhances toughness behavior of produced concrete, and they stated that this behavior is depending on PET-aggregate's shape and is maximized for concrete that contains coarser, flaky PET-aggregate.

Although, PET waste has been used as a concrete reinforcing material by a number of research studies; however, the findings are not consistent, because the shape and size of PET waste is different in each study and most of them focused on the fiber form. The present work aims to study the plastic granules partial substitution of plastic granules, obtained from recycling of rejected waste PET bottles, on engineering mechanical properties of concrete, and to find the proportion of plastic pellets which raises values of strength compared to control concrete strength values.

2. MATERIALS AND METHODS

2.1. Materials Used

Cement: Sulfate-resisting Portland cement – Type V according to I.Q.S No.5/1984 was used in all the mixtures. Table 1 illustrates the physical properties of cement used. The chemical properties of cement used are mentioned in Table 2.

Table 1. Cement chemical composition.*

Chemical compounds	Chemical symbol	% Weight	Limits of (I.Q.S No.5/1984)
(Lime)	(CaO)	62.2	-
(Silica)	(SiO_2)	22.30	-
(Alumina)	(Al_2O_3)	3.40	-
Iron oxide	(Fe_2O_3)	4.5	-
(Sulfite)	(SO_3)	2.1	<2.8%
(Magnesia)	(MgO)	3.1	<5%
(Ignition loss)	(L.O.I)	2.1	<4%
(Lime saturation factor)	(L.S.F)	0.84	(0.66-1.02)
(Insoluble residue)	(I.R)	1.00	<1.5%
(Tri calcium aluminate)	(C_3A)	2.7	-

*(According to Kufa University field laboratory testing report)

Table 2. Cement physical properties.*

Physical properties	Cement results
Finesse(m^2/kg)	283
Specific Gravity (kg/litter)	3.20
Initial setting time(min)	1:40
Final setting time(h)	3:35
compressive strength with 3 days age (Mpa)	19.29
compressive strength with 7 days age (Mpa)	24.75

*(According to Kufa University field laboratory testing report)

Fine aggregate: Locally available river fine aggregate was used as full/partial fraction fine aggregate which conforms to the requirements of Zone II. Fine aggregate properties was determined and achieved according to IQS 45/1984. Table 3 shows the fine aggregate properties and its gradation is listed in Table 4.

Coarse aggregate: The coarse aggregate used was of maximum size 20 mm and average density of 1750 kg/m^3 was taken from Al-Nibaey in Iraq.

Mixing water: Potable tap water was used for concrete making and to cure specimens.

Recycling of waste polymer: The recycled PET used in this study is the discarded water bottles PET plastic waste collected from Najaf streets. After collection that bottles, it was washed in a local factory, and then they were grinded to get flakes that were extruded to produce pellets by a plastic granulator machine with a diameter of approximately 1.5 mm and a length of 3 mm. Properties of used PET are, density: 1380 kg/m^3, young's modulus of elasticity: 3100 N/mm^2, tensile strength about 410 MPa and ultimate elongation: 11.2%

Table 3. Fine aggregate properties.*

Properties	Limit
Sulfate (%)	0.15
Max size (mm)	4.75
Density (kg/m^3)	1600
Specific gravity	2.596

*(According to Kufa University field laboratory testing report)

Table 4. Fine aggregate and waste PET pellets sieve analysis.*

Sieve size(mm)	% Passed of fine aggregate	% Passed of waste PET pellets
10	100.00	100.00
4.75	98.30	96.33
2.36	87.80	2.36
1.18	82.90	0.02
0.6	57.60	0.00
0.3	14.00	0.00
0.15	7.00	0.00

*(According to Kufa University field laboratory testing report)

2.2. Experimental Plan

In this study, the casting, curing, physical and mechanical tests was done on both fresh and cured concrete specimens using test devices available in the concrete laboratory at Kufa University. Mixing of materials was done following guides of ASTM C-305.

More than 30 cubes and 30 cylindrical specimens were prepared including controlled concrete and then concrete were mixed with waste PET pellets in four mixing values of 1%, 2%, 4%, 8% of the volume of concrete respectively. Tests were performed on the various samples to notice the effect of the plastic waste addition. Standard testing device was used to test samples after two curing periods of 7 and 28 days.

2.3. Concrete Mix

Depending on trial mixes the final used mixing design was done as shown in Table 5. The granules of plastic were added to mix of concrete in the following different volume ratios of: 0%, 1%, 2%, 4%, and 8% by volume of cement. Three specimens were used for testing every category and average value was plotted.

Table 5. Proportion of mixes containing PET waste

Specimens symbol	Material mass, (kg/m^3)				PET volume replacement	
	Cement	Fine aggregate	Coarse aggregate	W/C ratio	(%)	(kg/m^3)
0P%	410	706	1024	0.5	0	0
1P%	410	698.5	1024	0.5	1	6.08
2P%	410	693.86	1024	0.5	2	12.14
4P%	410	681.65	1024	0.5	4	24.35
8P%	410	657.3	1024	0.5	8	48.7

2.4. Preparation of Specimens

The casting, compaction and curing of specimens were achieved according to B.S.1881, part 6. In order to prepare the specimen for determining the compressive strength, steel molds of standard size 150 × 150 × 150 mm were used. The mold is filled with fresh concrete. For the perfect compaction of concrete proper attention is needed.

Each of the three samples tested criteria mean in practice it is placed. The casted specimens were de-molded after 24 hours and left to cure in curing tub for a time of 7 to 28 days. Then tests were done to specify dry density and compression strength.

Dimensions of cylindrical molds, used for splitting test, is 0.1 m and 0.2 m for each diameter and height respectively. To prevent probable adhesion, each mold was coated with a thin layer of high viscous oil. Then, concrete was added to the concrete molds incrementally with taking care that no air is remaining inside the mold.

Three specimens in each percentage of addition were tested and then the average value was computed. The results were analyzed and comparison was done with reference mix results.

2.5. Tests on Fresh Concrete

Two tests were measured for fresh concrete:

a/ The slump tests: The slump tests were implemented according to B.S.1881, part 2 in order to recognize and quantify the ease with which concrete perform. The slump was reported by measuring distance between the original and displaced locations of concrete top surface center vertically.

b/ Fresh densities: after molding and compacting processes, Fresh densities were measured directly for all cubes according to B.S.1881, part 5.

2.6. Tests on Hardened Concrete:

a/ Dry densities: were measured directly for all cubes when taking from the curing tub just before compression strength according to B.S. 1881, part 5.

b/ Compressive strength test : Compressive strength tests to were done after both 7and 28 days. When removed from the water tub, the concrete cubes were left to surface dry and then measuring their weight was done. Each property value mentioned in this paper is the average value gained from testing three specimens.

To evaluate compressive strength of the samples, the load applied on specimens was increased gradually at rate of 6.8 KN/sec. When the software indicates reduction in the load acting on sample, load addition was ended and test regarded to be over.

c/ Split tensile strength : To determine splitting tensile strength, test was performed according to ASTM C496 -04. This test was done at ages of 7 and 28 days. The load was gradually added to the specimens, at a rate of 1 KN/sec. The average splitting tensile strength of three cylinders was calculated. Concrete was subjected to air-cure for an interval of 24 hours, then extracted from the molds and immersed in water for the remainder of the curing period.

3. RESULTS AND DISCUSSION

3.1. Slump Test

The slump test was considered as the primary measure of concrete workability in this study. The results obtained from these tests are presented below in Fig. 1. An initial slump of 115 mm was obtained for the control concrete mix. With mixes containing 1%, 2%, 4% and 8% waste PET exhibiting slumps 14%, 22.6 %, 37.4% and 61.7 % lower than that of the control. It can be noticed depending on these results, that when waste content increases the concrete fluidity enhances, which is preferred for concretes. Although declination existence in the slump values, the PET waste modified concrete mixes were regarded workable as stated by Koehler and Fowler (2003).

The spherical and smooth shape of plastic aggregate is not only reason for this behavior but also this possibly referred to not absorbing water by waste PET causing some abundant water to be left in the mixture which increases the workability. Ismail and AL-Hashmi (2008) have found that the slump is prone to decrease as ratio of plastic increases.

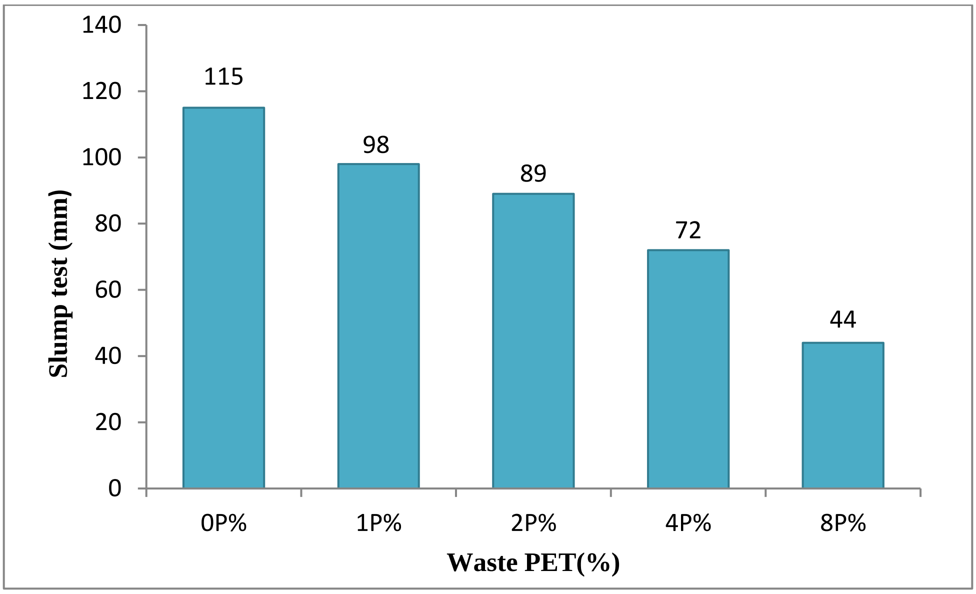

Fig. 1. Slump of waste PET concrete.

3.2. Fresh and Dry Density Tests

As can be seen below in Fig. 2, the replacement of fine aggregate with waste PET has a measurable effect on both fresh and dry density, with a decreasing trend resulting from the addition of waste plastic to the mix. This results in lowering the cost of transportation of structural parts. The results indicate that at a PET replacement level of 1%, 2%, 4%, and 8%, a decrease by 0.5 %, 2.8 %, 7.3 % and 9 % in fresh density and at a level of 0.15%, 2.3%, 6.5%, and 8.8% for dry densities when compared to the reference mix. This probably belongs to the lighter specific gravity of the plastic aggregate, which was 13.75% lighter than the fine aggregate used.

The results reached by Al-Manaseer et al. (1997) indicated that concrete density was drop down by 13.0% for concrete consisting of 50% plastic waste.

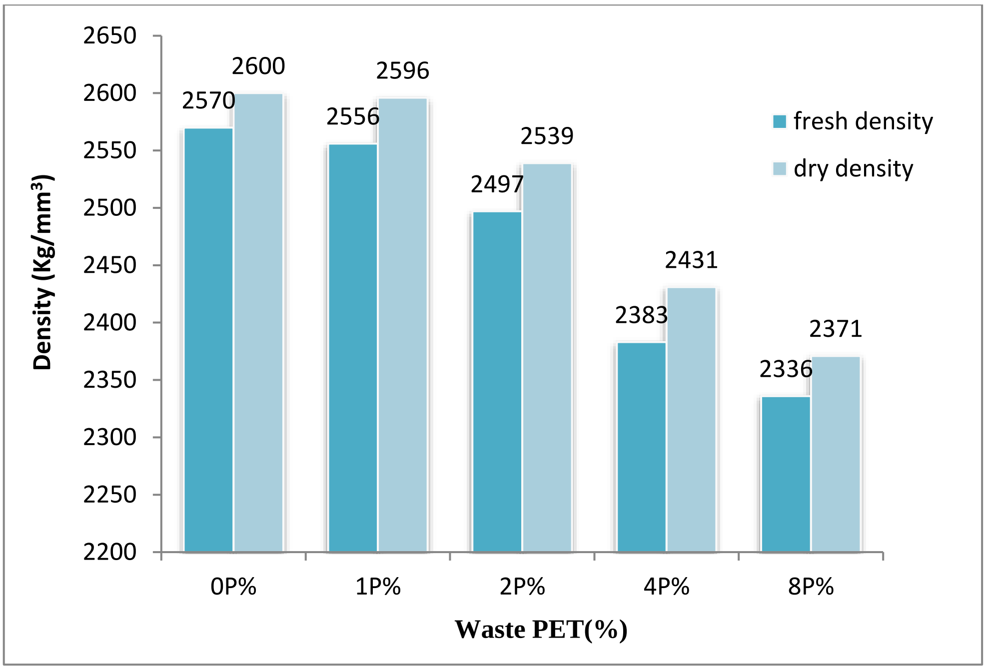

Fig. 2. Fresh and dry density.

3.3. Compression Tests

The results of compressive strength tests for PET concrete mixes are drawn in Fig. 3. It was noticed a slight rise in compressive strength with rising PET percentage of waste in the concrete from 0% to 1% by a 3.7% and 1.6 % for 7 and 28 days curing time respectively. But an obvious increase was noticed by adding 2% PET waste approximated by 15% and 13% for 7 and 28 days curing respectively, followed by drop that reaches around 25% for 8% replacement at both curing periods. It is clear that the compressive strength of cube increases with increase in PET waste and it gives peak value at 2% of PET. Thereafter, it starts decreasing to get minimum value at 8%. The obtained data were in good agreement with Ramadevi (2012).

Rebeiz and Fowler (1996) also found that very good flexural strength enhancement can be acheived by reinforcing polymer concrete with unsaturated polyester resins based on recycled PET.

The drop in compressive strength likely caused by reduce in adhesive strength between the surface of the waste plastic and the cement paste since PET aggregate was not contribute on the hydration process with the binder.

Though there is a consistent strength loss, it can be observed that all the mixes have attained satisfactory compressive strengths varying between 27.5 and 40.84 MPa for 28 day curing period.

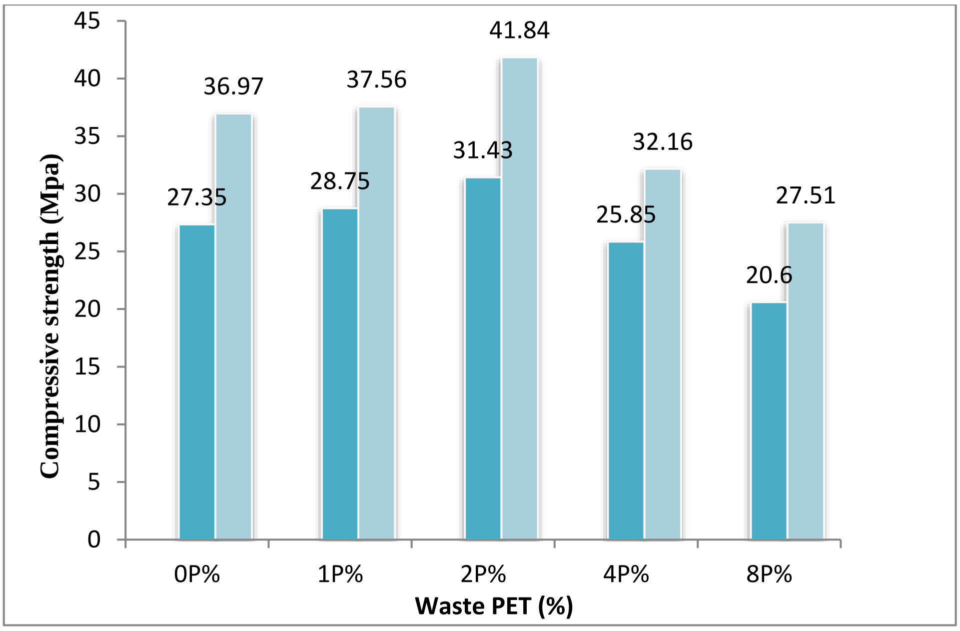

Fig. 3. Compressive strength.

3.4. Split Tensile Strength

Gradual increase in split tensile strength can be noticed from Fig. 4 that reaches 2% replacement of the fine aggregate with PET bottle waste to reach a maximum point (2.57, 3.423 MPa) for 7 and 28 days curing respectively, which represents 18.2 and 11.5%. After this there was a decreased for 8% replacements to reach approximately 18.5% compared with plain concrete for both 7 and 28 curing days. Patel et al. (1989) noticed that the addition of 1.0% volume of polyester fibers to concrete has showed a 9% increase in split tensile strength.

The drop in split strength may belong to aggregate density and adhesive strength between aggregate and cement. Fig. 5 demonstrates the failed specimens in split test.

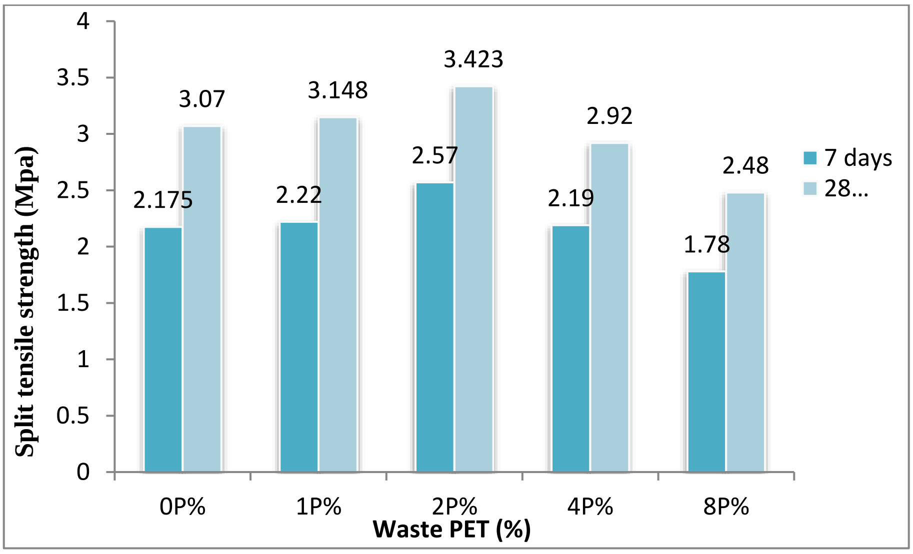

Fig. 4. Split tensile strength.

Fig. 5. Split tensile test specimens after test.

4. CONCLUSION

The most important conclusions that extracted from this research may be listed as follows:

- Employing discarded plastic bottles made of polyethylene terephthalate (PET) in concrete is an efficient promising approach to get rid of such waste.
- The slump test values of modified concrete with PET bottle waste decreased with increasing PET bottle waste. Although this slump values declination, the polymer-concrete mixes were still workable.
- Both Fresh and dry density of PET bottle waste -concrete mix was reduced with the rise in polymer content due to the low weight of PET aggregate compared to fine aggregate, so it can be used as a possible choice for decreasing the concrete dead load therefore the inclusion of PET aggregate reduces the density of the concrete respectively.
- It was noticed that the compressive strength increased up to 2.0% replacement of the fine aggregate with PET bottle and it dropped step by step for 4.0% and 8.0% replacements. Therefore replacement of fine aggregate with 2.0% replacement is regarded reasonable.
- The split tensile strength was found to be improved up to 2.0% replacement of the fine aggregate with PET bottle and it dropped step by step for 4.0% and 6.0% replacements. So, fine aggregate replacement with 2.0% replacement ensures highest split tensile strength compared to other used specimens.

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