Producing of eco-friendly lightweight concrete using waste polystyrene particles as aggregates with adding waste plastic

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Abstract

This research includes studying the possibility of producing a new kind of No-fines concrete by replacing granules of coarse aggregates with grains results from the fragmentation of industrial waste of polystyrene. This replacing were with different volumetric proportions of coarse aggregate, and theses volumetric ratios were equal to (5%, 10%, 15% and 25%). Waste plastic fibers (WPFs) resulting from cutting of soft drinks bottles were added for strengthening this new kind of concrete. Mixing ratio was equal to (1:5) (cement: coarse aggregate) by weight. One reference mix was produced for comparative purpose. Compressive strength, flexural strength and density tests were conducted, it was examined three samples of each examination and taking the average.

Compressive strength values of the new sustainable concrete were ranged from 10 MPa to 12.4 MPa at age of test equal to 28 days, while the average value of the density of this concrete at the same age reaches 1930 kg/m3. This average value of modulus of rupture was equal to 2.36 MPa at 28-day age test.

Key Words: No-fines concrete, polystyrene, Waste plastic fibers (WPFs)

إنتاج خرسانة خفيفة الوزن صديقة للبيئة باستخدام نفايات جزيئات الفلين كركام ناعم مع إضافة النفايات البلاستيكية

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الخلاصة

تتضمن هذا الدراسة امكانية انتاج نوع جديد من الخرسانة الخالية من الركام الناعم عن طريق استبدال الحبيبات الناتجة من تفتيت فضلات البولستارين (polystyrene) الصناعي المستخدم في حفظ المواد المنزلية وبنسب حجمية مختلفة بحبيبات من الركام الخشن. لقد استخدمت نسب حجمية للاستبدال بالركام الخشن مساوية لـ (٥%، ١٠%، ١٥% و٢٥%) كما و تم تعزيز الخرسانة المصنعة للوحدات البنائية بألياف الفضلات البلاستيكية الناتجة من تقطيع قناني المشروبات الغازية (Waste Plastic Fibers) . كانت نسب الخلط نسب وزنية مساوية لـ(١:٥) (سمنت:ركام) كما و تم انتاج خلطة مرجعية واحدة لغرض المقارنة .اجريت عدة فحوصات منها مقاومة الانضغاط ، معاير الكسر والكثافة حيث تم فحص ثلاث نماذج من كل فحص واخذ المعدل.

تراوحت قيم مقاومة الانضغاط للخرسانة الجديدة الصديقة للبيئة ما بين (١٠) ميكا باسكال الى (١٢,٤) ميكا باسكال بعمر ٢٨ يوم في حين كانت اقل قيمة لكثافة هذه الوحدات وبنفس العمر تصل الى (١٩٣٠) كغم/م٣ . حقق هذا النوع من الوحدات البنائية اعلى قيمة لمعاير الكسر مساوية الى (٢,٣٦) ميكا باسكال بعمر فحص ٢٨ يوما.

1. Introduction

Since two thousand years ago was the first use of lightweight concrete.in the world there are many lightweight buildings especially in the Mediterranean region, the most important three buildings constructed in the Romanian Empire are the Coliseum, the Port of Cosa, and the Pantheon Dome [1].

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The use of lightweight concrete in buildings structural and non-structural as a material in construction it must have specific characteristics that meet the requirements of strength and performance for application. Before using any material in construction there is a need to study the mechanical properties to determine their suitability [2]. Recently the demand for lightweight concrete has been increasing in many of the modern building structures, because of the low density Which leads to great benefit by reducing the cross sections of the elements concrete therefore leads reducing the volume of the foundation [2].

No-fines concrete classified as one of the lightweight concrete type [3]. The first use of this kind of concrete was at 1852 D.C., and it's used for production of warehouse and two houses in Holand [4]. Many studies conducted to study the properties of this concrete [5-9]. Some studies dealt with the effects of adding admixtures or polymers on the mechanical properties and structural behavior of such kind of concrete [10-13]

The lightweight aggregates are Divided into two types—Natural (pumice, diatomite, volcanic cinders, etc.) and Industrial (perlite, expanded shale, clay, slate, sintered PFA, etc.). polystyrene are a kind of industrial very lightweight (density of less than 300 kg/m3), non absorbent aggregate [14-15]. polystyrene is a stable, low density foam and non absorbent, hydrophobic, closed cell nature [16-17]. it can be used as a very lightweight material for concrete development for all elements construction (structural and non-structural) by changing the percentage ratio in concrete [18-19]. polystyrene commercially available all over the world, Unlike lightweight industrial aggregates (expanded clay, shale, slate, sintered pfa, etc.), Most of the polystyrene production plants are in Europe and Russia [3]. polystyrene has a closed cell structure consisting of 98% air [2]. Few studies dealt with the effects of adding EPS to cement mortar and concrete. Theses addition leads to decreasing in density and mechanical properties of both cement mortar and concrete[20-21].

It is well known that, concrete had a brittle behavior under tensile stresses. Adding fibers to concrete leads to increase the ductility by limiting the propagation of micro-cracks in the concrete. This addition makes the concrete more homogenous and increase its strength to tensile stresses and shrinkage. So, adding fibers to concrete mixes is considered as an effective way to enhance the strength of concrete structures against the up normal forces like, earthquakes and winds [22-26]. Strengthening of concrete with waste plastic fibers (WPFs) is one method for enhancing concrete properties and a smart way to save natural resources that cannot be replenished [27]. Many researches were done in studying the possibility of developing concrete by WPFs [27-32]. Moreover the use of WPFs as a material in elements concrete is Very useful economically and durability in addition to environmental aspects.

From the previous studies, it is clearly that there was no study dealt with the effects of adding the wastes of PET and EPS on the properties of No-fines concrete. This study focuses on the effects of replacing of aggregate with different volumetric ratios of EPS waste particles and strengthening this new material by volumetric ratio of WPFs for producing a new sustainable concrete material.

2. Experimental Program

2.1. Materials

Ordinary Portland cement (OPC Type I) has been used in casting all specimens throughout the experimental work. Physical and chemical tests proved that, this kind of cement confirms with the Iraqi Specifications I.Q.S. 5/1984[33]. Physical properties and Chemical composition are shown in Tables (1) and (2). Gravel is used for preparing mixes with a maximum size of aggregate equal to 12.5 mm. The sieve analysis and physical properties of this aggregate proved that, this aggregate conforms to the Iraqis specifications I.Q.S. No.45/1984[34] as shown in Table (3). Aggregate used with different sizes. The first has 7.2mm size beads and the second has 3.85mm size beads, and the sieve analysis of polystyrene is given in Table (4). The use of drinking water in the city of Ramadi water distribution network. The waste plastic fibers (WPFs) resulting from cutting of soft drinks bottles were used for strengthening of concrete and the geometrical characteristics of WPFs throughout the experimental work are illustrated in table (5).

Table 1. The physical Characteristics of cement.

physical Characteristics	Result	Limits of Iraqi spec. No.5/1984
Specific surface area, Blaine Method, (m^2/kg).	300	> 230
Setting time : - Initial setting (hrs: min) - Final setting (hrs: min)	1:40 4:00	≥ 45 min ≤ 10 hrs
Compressive strength of mortar (MPa) - 3-days - 7-days	21 27	≥ 15 ≥ 23
Soundness % (Autoclave)	0.02	≤ 0.8

Table 2. Chemical composition of ordinary Portland cement.

Oxide composition	Abbreviation	by weight %	Limits of Iraqi spec. No.5/1984
Lime	CaO	61	-
Silica	SiO2	19.84	-
Alumina	Al2O3	5.28	-
Iron oxide	Fe2O3	4.2	-
Sulphate	SO3	2.49	≤ 5%
Magnesia	MgO	2.48	≤ 2.8%
Loss on Ignition	L.O.I.	3.8	≤ 4%
Lime saturation Factor	L.S.F.	0.92	0.66-1.02
Insoluble residue	I.R.	1.13	≤ 1.5%
Main compounds (Bogues eq.)			**by weight of cement%**
Tricalcium silicate (C3S)			48.9
Dicalcium silicate (C2S)			20.07
Tricalcium aluminate (C3A)			6.89
Tetracalcium aluminoferrite (C4AF)			12.77

Table 3. Sieve Analysis of Coarse Aggregates.

Sieve Size in (mm)	Retained (g)	Passing (g)	% Passing
75	0	1450	-
63	0	1450	100
20	0	1450	100
14	0	1450	100
10	797	653	100
5	576	77	45
2.36	75	2	5

Table 4. Sieve Analysis of polystyrene.

Sieve Size in (mm)	Retained (g)	Passing (g)	% Passing
9.5	0	10	100
4.75	1.2	8.8	88
2.36	4.2	4.6	46
1.18	4.1	0.5	5
0.6	0.47	0.03	0.3
0.3	0.03	0	0
0.15	0	0	0

Table 5. Characteristics of waste plastic fibers.

Type of Fibers	Average Length (mm)	Average Width (mm)	Average Thickness (mm)	Specific gravity
Plastic fibers	30	4	0.30	1.12

2.2. Molds, Mixing and Casting

Three (100×100×500) mm prism molds were prepared to determine the flexural strength. Three cube molds with (100×100×100) mm were prepared for the test of the compressive strength. A (0.1) m3 pan mixer was used to mix all the compositions of the mixes. The interior surface of the mixer was cleaned and moistened before placing the materials. Raw materials were first mixed dry for about 15 minutes to achieve uniform distribution of the Polystyrene and Plastic waste fibers, then the water was gradually added and mixing was continued until a uniform and flowing mixture was obtained, after that water was added to the mix. The mixing process continued for about three minutes to get homogenous and consistence concrete. All the concretes were mixed in a planetary mixer in the concrete laboratory in College of Engineering -University of Anbar (See Fig.1). Mixture pouring into oiled molds and then, the molds were vibrated on a vibrating table for 1 min and then smoothed with a float to facilitate compaction and decrease the number of air bubbles. The specimens were demolded after 24 h and stored in water for curing until testing (See Fig. 2).

Figure 1. Different compositions in pan mixture.

Figure 2. Samples made from reference mix.

2.3. Concrete Mixes

Five concrete mixes were used in this work in addition to the reference mix. Table (6) shows that the proportion of the prepared concrete mixes with (1:1.5) (by weight) of ordinary Portland cement: coarse aggregate and the water to cement ratio of 0.45. Waste plastic fibers were used as a ratio by volume of the mix as 1.

Table 6. Mix Proportion used in this study

No.	Cement: Aggregate	(Water/Cement) %	(WPFs) %	(Polystyrene/Aggregate) %
Ref.1	1:5	45	-	-
2	1:5	45	1	-
3	1:5	45	1	5
4	1:5	45	1	10
5	1:5	45	1	15
6	1:5	45	1	25

2.4. Program of Tests

Compressive strength tests were carried out according to B.S.1881, Part 116[34], on 100 mm cubes at the age of (7,14 and 28) day with a testing machine (ELE) of (2000)KN capacity at a loading rate of (2.5) KN/s. Flexural strength was conducted on prisms of (100,100,500mm). The test was carried out using two point load according to ASTM C78-86[35]. Flexural strength was determined using (50 KN) capacity (ELE) machine,. The density value was found by dividing the weight to the volume for each specimen.

3. Results and discussion

3.1. Compressive strength

Fig. 3 shows that there is a continuous increase in the compressive strength with age up to 28 days, and this increasing is due to progress in cement hydration operation with age. A comparison between the compressive strengths in different specimen at the age of 7,14, and 28 days were given in Fig. 3.

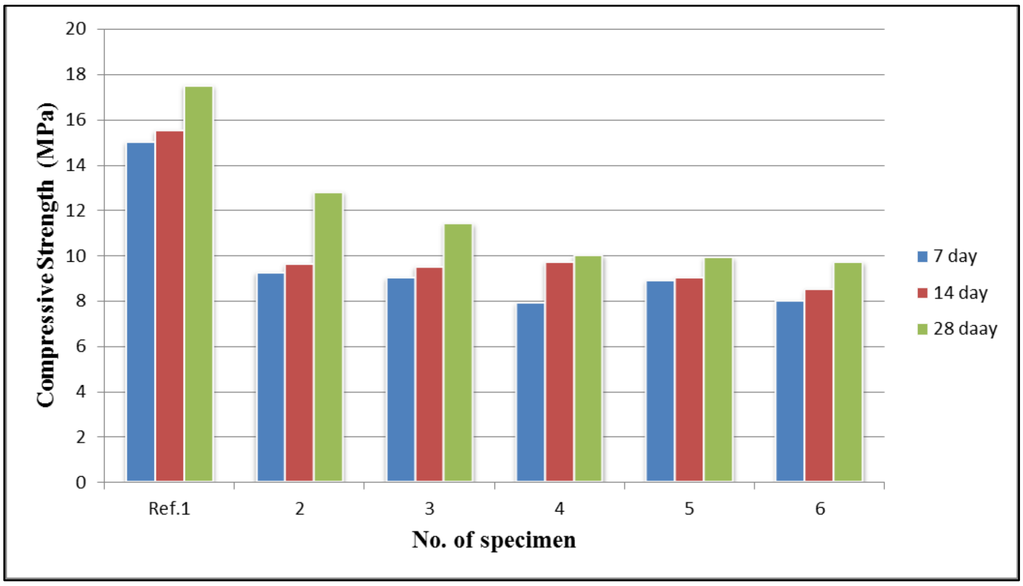

Figure 3. Variation of compressive strength with age.

From Fig. 4, it can be noticed that, the decrease in compressive strength of the no-fines concrete containing Polystyrene and WPFs observed when (P/Agg) ratio was 5% and more. It indicates that the compressive strength decrease in the amount of Polystyrene. This may be due to the fact that, the lower density concrete generally has high amount of Polystyrene, inherently has lower strength. In the case of higher density concrete mixes, which contain lower amounts of Polystyrene usually have higher strength as Fig. 4, but when the (P/Agg) ratio equal to 15% of polyester and more, the compressive strength is very little effect, and that can be attributed in this case to the amount of Polystyrene particles occupies the existing gaps which resulting from the absence of fine aggregate, as well as that the compressive strength for Polystyrene less than compressive strength for fine aggregates. It can be seen that the strength is decreasing with the increase of Polystyrene amount, similar to the normal concretes. The variation of compressive strength at 7,14 and 28 days was given in Fig. 4.

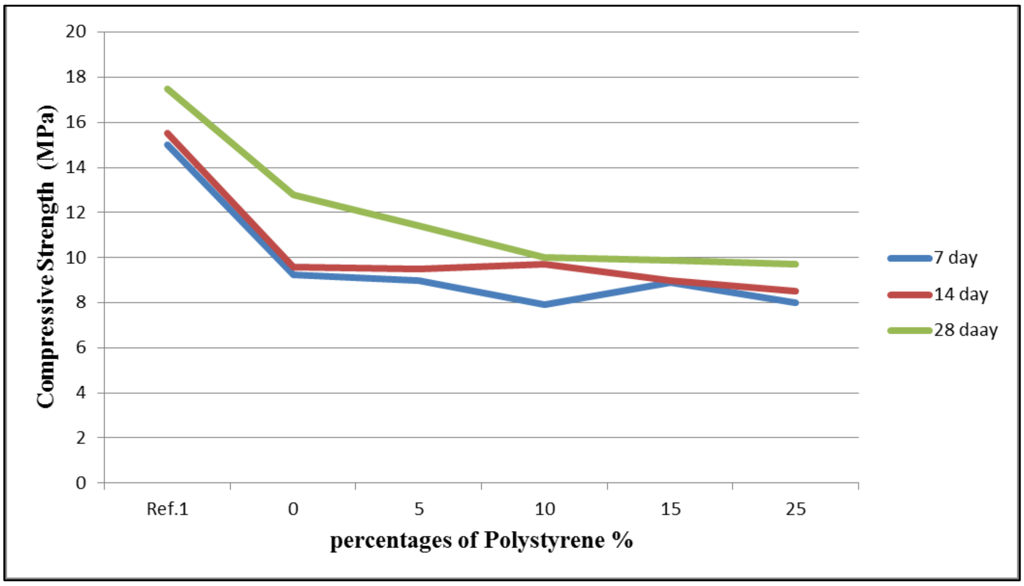

Figure 4. Variation of compressive strength with percentages of Polystyrene %.

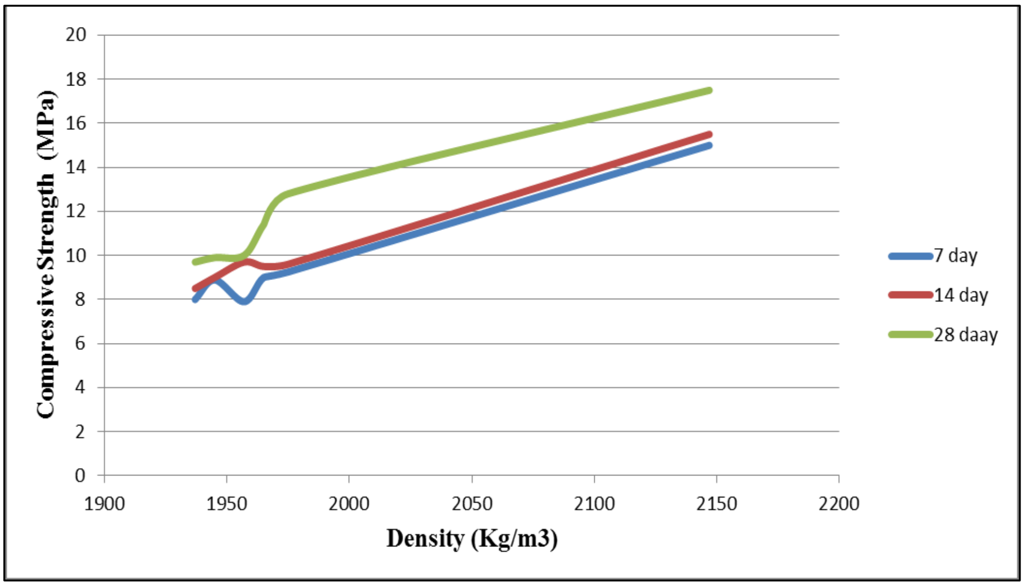

Figure 5. Variation of compressive strength with density.

The no-fines mixes with higher densities showed higher compressive strength value at all ages as shown in Fig. 5.

From the test results of all specimens tested in this research, it can be clearly noticed that, the failure of cubes which do not contain WPFs and Polystyrene more brittle than these contain these materials. In the case of the reference cubes fail with the loss of a part of the cube as seen in the Fig.6, whereas the cubes which contain WPFs and Polystyrene were more ductile in failure and appear coherent with tiny cracks (see Fig.7). That means adding of WPFs and Polystyrene leads to production more ductile concrete with acceptable compressive strength.

Figure 6. Mode of failure for reference mix.

Figure 7. Mode of failure of samples containing WPFs and Polystyrene.

3.2. Flexural strength

From Fig. 8 it can be clearly noticed that, there was a continuous increase in the flexural strength with age for all prisms made from no-fines mixes. A comparison of the variation of flexural strength values with different percentages of Polystyrene at the age of 7,14, and 28 days were given in Fig. 8. When comparing with reference mix all prisms produced from no-fines concrete contains WPFs and Polystyrene have modulus of rupture values less than that of reference mix prisms. The flexural strength increased with the increment in (P/Agg) ratio up to equal to (15%). As seen in Fig. 9, and the modulus of rupture values increases with increase in the time of test because of absence of fine aggregate (sand) in this kind of concrete (No-fines concrete), a large number of big porous exist inside the structure of concrete (see Fig. 10). Adding of WPFs with Polystyrene grains leads to the no-fines mixes contains WPFs causing a decrease in the volume of porous, leading to enhancement in modulus of rupture values up to (P/Agg) equal to (15%) (see Fig. 11). After that the flexural strength will be decreased at (P/Agg) equal to (25%), because of the big Polystyrene percentage according to coarse aggregate.

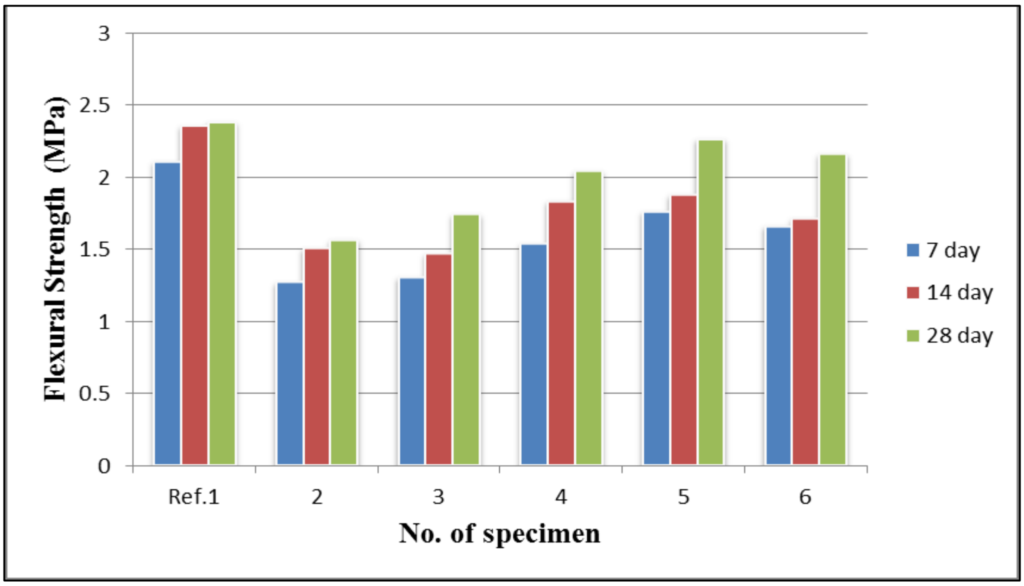

Figure 8. Variation of Flexural strength with age.

The relationship between flexural strength and density of Polystyrene concrete is shown in Fig.12. The higher density mixes showed the higher flexural strength values at 28 day age. Variation of flexural strength with density show the flexural strength increases with an increase in the Polystyrene ratio and reaches a maximum 2.16 MPa at Polystyrene ratio of 15%, with low density and reaches a minimum 1937 Kg/m3 Equals approximately value the flexural strengths without Polystyrene reaches 2.38 MPa at density 2147 Kg/m3.

3.3. Density

The density is one of the most important factors to control many physical Characteristics in lightweight concrete through the amount and density of lightweight aggregates. The Previous

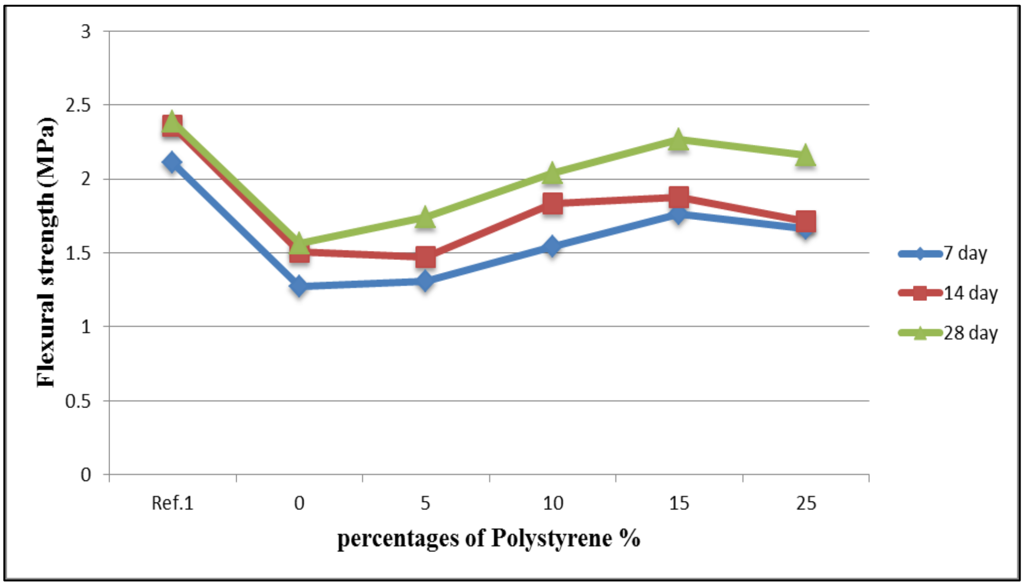

Figure 9. Variation of Flexural strength with percentages of Polystyrene %.

Figure 10. Photo of a cross section of prism made from a reference mix failed in flexure.

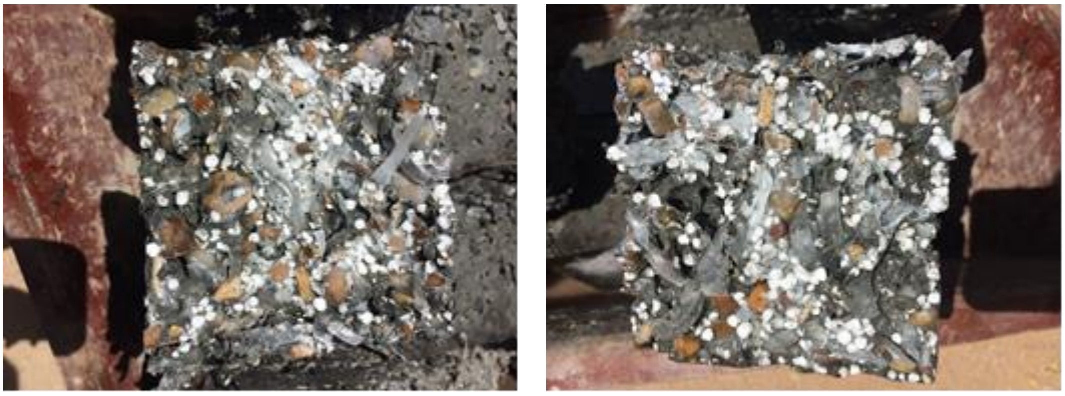

Figure 11. Photo of a cross section of prisms made of the mixes contain WPFs and Polystyrene and failed in flexure.

studies confirm that the density of lightweight concrete decreases with increase in volume of Polystyrene aggregate which causes a decrease in compressive strength of the concrete [35,36].

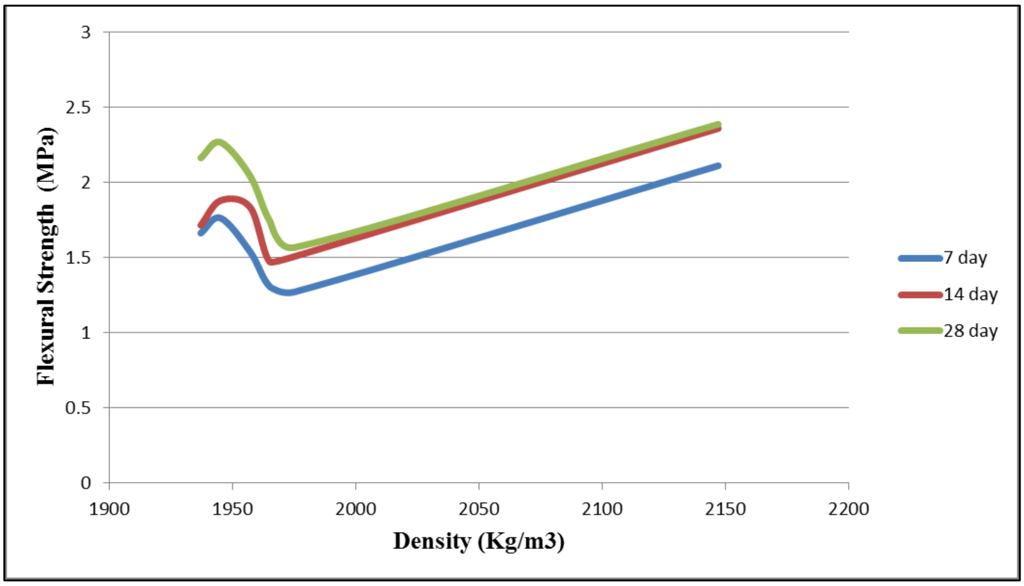

Figure 12. Variation of Flexural strength with Density.

The relationship between density and percentages of Polystyrene for all the mixes is shown in Fig. 13. This figure showed that, the increase in (P/Agg) leads to decrease in density of no-fines concrete mixes and the lowest value of density was equal to 1937 Kg/m3 for percentages of Polystyrene to coarse aggregate equal to 25%.

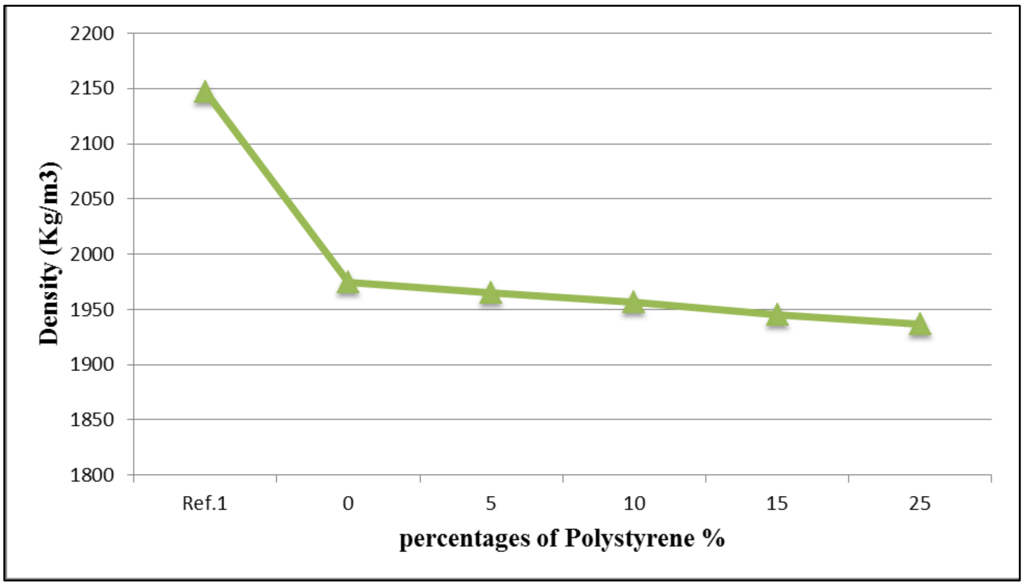

Figure 13. Variation of density with percentages of Polystyrene %.

4. Conclusion

• The compressive strength of no-fine concrete increase with increase of P/a g ratio.
• The failure of cubes which do not contain WPFs and Polystyrene more brittle than these contain these materials.
• Adding of Polystyrene grains to the no-fines mixes contains WPFs causing a decrease air between coarse aggregate, leading to enhancement in modulus of rupture values up to (P/Agg) equal to (15%).
• The increase in (P/Agg) leads to decrease in density of no-fines concrete mixes and the lowest value of density was equal to 1937 Kg/m3 for percentages of Polystyrene to coarse aggregate equal to 25%.
• Production of new kind of eco-friendly lightweight concrete by benefits from waste materials..

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