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REPLACEMENT OF WELL-GRADED PLASTIC PEARLS AS COARSE AGGREGATE IN CONCRETE

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ABSTRACT

Concrete is the most widely used construction material worldwide, so it faces a shortage of natural raw materials, as well as, concrete has a high-density drawback (about 2400 kg/m³). These problems can be overcome by looking for new artificial materials to replace natural construction materials. Therefore, In the present work, the replacement of well-graded plastic pearls as coarse aggregate in concrete was investigated. The compressive strength and density of four concrete mixes were examined, before and after exchanging the coarse aggregate partially (50%) and fully (100%) by plastic pearls. Test results revealed that both concrete density and concrete strength reduce due to natural coarse aggregate replacement by plastic pearls. It is concluded that concrete of compressive strength between (23.9-42.5) MPa and density in the range of (1766-2226) kg/m³ can be produced when plastic pearls are used as coarse aggregate. It is also concluded that the plastic pearls, can successfully replace the natural coarse aggregate in concrete for solving the deficiency problem of this material.

KEYWORDS: Plastic Coarse Aggregate, Compressive Strength, Concrete Density, Structural Lightweight Concrete, Plastic pearls

1. INTRODUCTION

Concrete is the most widely used construction material which faces a shortage of natural raw materials due to rapid growth in urban areas worldwide. Therefore the costs of the structure will increase, including the aggregates cost. [1, 2,and 3]

On the other hand, concrete has a drawback of high density (2200-2400 kg/m³), so any decrease in concrete density with sufficient structural strength will make an important economical positive influence on the construction cost. [3,4,5]

These two problems can be overcome by seeking new materials to replace natural construction materials. One of these natural materials is the aggregate which takes up about 70% to 85% of the concrete weight and greatly influences its properties in both fresh and hardened states.[4,6]

In the last years, many efforts have been carried out about consuming plastic materials in concrete as fine or coarse aggregates. The aims of these investigations were :-

1-To minimize environment pollution as much as possible.

2-To prevent the shortage of construction materials.

Hereunder the review of the studies and researches about utilizing the plastics as aggregates in concrete;-

Mahesh et al. [1] examined the effect of using polyethylene plastic as a partial replacement (2%, 4%, and 6%) of both fine and coarse aggregate in M25 grade concrete. The main conclusion in this research was that re-using waste plastic in concrete did not affect the mechanical properties considerably.

Thorneycroft, J., Orr, J., j., et al. [2] tried to choose an appropriate recycled plastic material to substitute the sand in concrete. They used five different types of plastic materials and two different chemical treatments were used. The results revealed that the appropriate recycled plastic material can be maintained with suitable mix design and replacing the sand by 10% plastic aggregate will save 820 million tons of sand in India every year.

Ali, M. R., et al. [3] developed thermal insulating lightweight concrete by replacing polyethylene beads instead of limestone coarse

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aggregates in concrete. Their tests were carried out to find unit weight, compressive strength, thermal resistance and durability of the new concrete. The compressive strength of the developed concrete was in the range of 17–27 MPa and the unit weight was in the range of 1366–1744 kg/m3. They found that the normal weight concrete is more durable than the developed one but in terms of heat insulation, the developed concrete is better.

Hossain, M. B., et al. [5] Examined the effect of replacing (5%, 10%, and 20%) of the coarse aggregate volume, by shredded waste polyethylene terephthalate (PET) plastic on concrete.

It was found that using (PET) plastic in concrete reduced the concrete density, and also helping in the disposal of waste plastic.

Vanitha, S., et al. [7] reused the waste plastic as partially replaced the coarse aggregate in M20 grade concrete. The replacement was done by (2%,4%,6%,8% and10%) of coarse aggregate .Their conclusions cleared that waste plastic can be used in cement concrete mixes and the best replacement of natural aggregate with plastic wastes for pavements is 2% and 4% for solid blocks.

Chen, C. C., et al. [8] tested the compressive strength and tensile strength of concrete in which natural fine aggregate was replaced by fine waste plastic aggregate. They concluded that the compressive strength of concrete decreases with increasing the fine waste plastic aggregate percentage. While the tensile strength of concrete increased up to 30% waste plastic fine aggregate replacement.

Alqahtani, F. K., et al. [9] utilized lightweight coarse aggregate made from waste plastic and red sand in concrete samples tested for durability and compressive strength. Their test results appeared a reduction in compressive strength due to waste plastic inclusion but an improvement in concrete durability was observed as compared to natural lightweight aggregate (volcanic origin). Furthermore, they advised using the new produced concrete only for non-structural purposes.

Jibrael, M. A. and Peter, F. [10] examined the effect of adding recycled plastic aggregate to concrete on its mechanical properties. Their results showed that all the above properties were decreased due to the replacement of the sand by plastic bottles or plastic bags and the effect of the plastic bottle is less in decreasing the concrete strength.

Guenduz et, M., Debieb, et al. [11] tested how utilizing waste plastic (polyethylene and low-density polyethylene) as a replacement of sand, affects the physical and mechanical properties of concrete. The sand is replaced by(10%,20%,30% and 40%) of plastic aggregates. They also used (0.5%,1%,1.5% and 2%) fibers. The test results revealed that there is an increase in both compressive strength and flexure strength for 10% and 20% replacement and the inclusion of plastic fibers in concrete increases its tensile strength.

Herki, B. A., & Khatib, J. M. [12] examined properties of concrete containing lightweight aggregates made by mixing (80% EPS, 10% cement and 10% clay) and named Stabilized Polystyrene (SPS). They studied both compressive strength, concrete density. Their test results revealed that concrete density is reduced by 8%-52 %, while the concrete compressive strength was between 4.6-16.4 MPa.

Alqahtani, F. K., et al.[13] investigated the influence of replacing both pumice lightweight aggregate and Lytag aggregate by manufactured plastic aggregate on concrete. The manufactured aggregate was made of 30% red dune sand and 70% mixing recycled plastic. The test results demonstrated that all mechanical properties of concrete decrease with increasing the aggregate replacement and the concrete mixes with plastic aggregates has more ductility.

From the previous surveying about using the plastic as aggregates in concrete, it is clear that the above studies have several drawbacks which are;-

1-Almost all the studies were done about using the waste plastic material and they did not use virgin material.[1,2,3,5,8,9, and 13]

2-Some of the investigations used small percentages of aggregate replacement by waste plastic aggregates.[2,5, and 7]

3-Some of the researches were done on using recycled plastic, and this process (recycling) raizes the concrete cost.[3,9,10, and 13]

4- In some studies, other materials like fibers were used to overcome the loss in strength due to using plastic aggregates, which also increases the concrete cost.[11]

5- The process of collecting wastes also needs a cost.

As it is mentioned above, it was shown that very few researches were done on using the actual or unused plastic (virgin) material in concrete. [3]

So, it was decided to investigate the performance of well-graded plastic pearls as coarse aggregate in concrete by studying its effect on both its density and compressive strength.

The aims of this investigation is to:-

1-Overcome the problem of the coarse aggregate leakage anywhere in the world.

2-Reduce the concrete density as the plastic aggregate has a low density.

In the present study, the natural coarse aggregate was replaced by spherical plastic beads (plastic pearls). The plastic pearls were made from acrylonitrile butadiene styrene (ABS) plastic-type. These plastic pearls were chosen with different particle sizes so that their grading was close to the natural coarse aggregate (gravel) grading.

METHODOLOGY

To investigate the possibility of using plastic coarse aggregate (PCA) partially or fully instead of the natural coarse aggregate (NCA) in concrete, firstly the materials used in the concrete (cement, sand, gravel and plastic pearls) were tested for finding their properties, then a nominal concrete mix (1:1:2) was chosen for replacing its natural coarse aggregate by plastic pearls. This mix was chosen as it's considerably strong and needs the least amount of coarse aggregate with respect to other nominal mixes (1:1.5:3), (1:2:4) or (1:3:6).

The natural coarse aggregate of the mix was replaced by plastic pearls. The replacement was done by absolute volume method in two percentages (50% and100%), then compressive strength and density of the plastic coarse aggregate concrete (PCAC) were examined and compared with the reference natural coarse aggregate concrete (NCAC) properties.

For investigating the effect of this replacement on different concrete mixes the amount of the sand in the mix (1:1:2) was gradually increased, thus the new examined concrete mixes were a concrete mixture (1:1.5:2), concrete mixture (1:2:2) and concrete mixture (1:3:2).

For each concrete mix, suitable water to cement ratio was chosen, so that all the mixes' workabilities were within very low workable range (0-25) mm slump, which was expected to be proper for the motion of spherical and smooth plastic pearls in the mortar.

Also, the maximum aggregate size was chosen to be 20mm as it was restricted by the small size cubes used in this research and the structural concrete type. Details of the experimental program for this study were listed in the table (1), while slump test results for the reference concrete mixes were recorded in the table (2).

2.1 Materials

Materials utilized in this research are cement, fine aggregate (sand), coarse aggregate (both gravel and plastic pearls) and water.

2.1.1-Cement

Iraqi Ordinary Portland Cement (OPC) was used in this investigation. The cement was manufactured by Tasloja Company and agrees with Iraqi standards No.5- 1984 and B.S (12/1996). Cement properties were listed in the table (3).

2.1.2- Fine aggregate

Natural river sand was utilized as fine aggregate, it was sourced from the north of Iraq. The sand was carefully washed and oven-dried before mixing. Table (4) shows the properties of the used sand, while the sieve analysis result is cleared in the table (5).

Table (1): Experimental program for the variables studied in this research

Mix No.	Mix Proportions	Plastic Aggregate %	W/C	NO. of Cubes
Mix 1	(1:1:2)	0%	0.33	4
Mix 2	(1:1:2)	50%	0.33	4
Mix 3	(1:1:2)	100%	0.33	4
Mix 4	(1:1.5:2)	0%	0.33	4
Mix 5	(1:1.5:2)	50%	0.33	4
Mix 6	(1:1.5:2)	100%	0.33	4
Mix 7	(1:2:2)	0%	0.35	4
Mix 8	(1:2:2)	50%	0.35	4
Mix 9	(1:2:2)	100%	0.35	4
Mix 10	(1:3:2)	0%	0.39	4
Mix 11	(1:3:2)	50%	0.39	4
Mix 12	(1:3:2)	100%	0.39	4
Total number of the cubes				48

Table (2): slump test results for the reference concrete mixes used in this study

Mix proportion	W/C	Slump(mm)
1:1:2	0.33	11
1:1.5:2	0.33	6
1:2:2	0.35	3
1:3:2	0.39	12

Table (3): Properties of OPC cement used in this research

Test	Result	BS (12/1996)
Specific gravity	3.03	3-3.25
Initial setting time	195 min.	min.1 hr
Final setting time	4:50 Hours	max. 10 hr
Fineness(surface area)	308 m²/kg	min. 230 m²/kg
Strength at 3 days	35 N/mm²	min.15 N/mm²
Strength at 7 days	40 N/mm²	min. 23 N/mm²

Table (4): Properties of the materials used in current research

property	Sand	Gravel	Plastic
Specific gravity	2.68	2.7	1.044
Unit weight (kg/m³) (Compacted)	1860	1739	596
Water Absorption %	1.06	0.6	0.2
Melting point (°c)	***	***	200 °c
Fineness Modulus	2.75	6.67	6.61

2.1.3- Coarse aggregate (natural)

Natural coarse aggregate (NCA) utilized in this project was locally natural river gravel sourced also from the north of Iraq.

Although the maximum aggregate size was 20mm, the gravel was passed through a sieve of 16mm with circular openings to be closer to the shape and grading of the plastic pearls. The gravel was washed and oven dried before mixing. Properties of used gravel are in Table (4) and its sieve analysis result is in the table (6).

Table (5): Sieve analysis of the sand used in current research

sieve opening (mm)	**Passing %**	**B.S 882:1992**
10	100	100.0
5	99	89-100
2.36	81	60-100
1.18	66	30-100
0.6	47	15-100
0.3	31	(5-70)
0.15	0	(0-15)

Table (6): Sieve analysis of the gravel used in current research

Sieve Opening (mm)	Passing%	B.S 882:1992
20	100	100
14	92.0	90-100
10	40.6	40-70
5	0.0	0-15
2.36	0.0	0-5

2.1.4-Plastic Coarse Aggregate

The utilized plastic coarse aggregate (PCA) were spherical plastic beads (pearls) made from ABS-plastic. The available plastic pearls were hollow shiny pearls as they are used for false jewelry. Plastic pearls of different sizes (6, 8, 10, 12, and 14) mm were mixed to make a well-graded aggregate. Properties of plastic pearls were listed in the table (4), while table (7) clears the sieve analysis result for this material.

The impact value test for both coarse aggregates (natural and plastic) was carried out according to BS 812-112 (1990). [14]

Table (7): Sieve analysis of the plastic coarse aggregate used in current research

Sieve Opening mm	Passing %	B.S 882:1992
20	100	100
14	92.0	90-100
10	48.4	40-70
5	0.0	0-15
2.36	0.0	0-5

Fig. (1): Coarse aggregates used in this research

2.1.5-water

Potable water is used throughout this research in concrete mixing and for concrete curing.

Fig.(2): Impact value test for plastic pearls

1.2 Preparation of specimens

2.2.1-Batching of the materials

For concrete production, batching of materials was done by weight ratios for each mix according to the variables studied in this research (see table 1).

The absolute volume method was used for finding the weight of plastic coarse aggregate which replaced the natural coarse aggregate volume.

2.2.2-Casting, curing, and testing

The raw materials were mixed carefully by hand then water was added and mixing was continued to ensure a homogenous concrete mixture. The slump of the reference concrete

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mixes was taken in accordance with the (ASTM C 143). [15]

For each variable studied in this research, four cubes of (100x100x100) mm size were cast in accordance with B.S1881-108:1983. [16]

The concrete was cast in the molds and compacted by two layers, concrete compaction was done by the vibrating table, and then the surface of the cubes was finished. The next day the concrete samples were removed from the molds, kept in a water tank for curing until the testing age (28 days). Cubes were dried in room temperature for about twenty minutes before testing, then the density and compressive strength of the cubes were found.

A compressive strength test was carried out on the samples using a universal testing machine of (2000 kN capacity); the rate of loading was (0.2 MPa/sec.). [6]

For each variable, the average value of three concrete samples was taken as the compressive strength of the concrete, after neglecting the farthest sample result from the average of the four samples results..

Fig. (3): Concrete cubes curing

Fig. (4): Universal compression testing machine

2.2.3- Strength computing

Compressive strength is computed according to B.S 1881-116:1983. [17]

Compressive strength was calculated according to the formula:-

Compressive strength= P/A = N/mm^2= (MPa)

Where P=Failure Load (N)

A=Bearing Area (mm^2)

2.2.4-Concrete Density calculation

The density of each sample was calculated in accordance with B.S 1881-114:1983. [18]

Concrete density was calculated at the age of 28 days. After taking out the concrete cube from the water tank, drying in the air for twenty minutes, its mass was taken; this mass (kg) was divided by the sample volume which is equal to 0.001 m^3 to find concrete density (kg/m^3). The mean value of three concrete samples was taken as the density of the concrete after neglecting the farthest sample result from the average of the four samples results**.**

3.Experimental outcomes

Test results of this investigation were discussed in detail for these four aspects; concrete density, concrete compressive strength, mix proportions effect and mode of concrete failure.

3.1- Concrete density

The results for concrete density were shown in table (8) and drawn in figure (5). The concrete density is decreased when (PCA) was included to the concrete, this reduction in concrete density is caused by the lighter material used in concrete production as the specific gravity of (PCA) was equal to (1.044) but the specific gravity of (NCA) was (2.7). For (NCAC), the maximum density (2489 kg/m³) was shown in the mix (1:1.5:2), while the minimum density (2471 kg/m³) was shown in the mix (1:3:2).

For the replaced concrete by 50% of (PCA), the maximum density (2226 kg/m³) was shown in the mix (1:3:2), while the mix (1:1:2) exhibited minimum density (2137 kg/m³). Concrete of full replaced (NCA) by (PCA) which had a maximum density (1995 kg/m³) was of mix proportions (1:3:2), but the minimum density (1766kg/m³) occurs in concrete mix (1:1:2).

In general, it is concluded that the concrete density is linearly decreased with the percentage inclusion of the plastic aggregate.

3.2- Compressive strength

The results for concrete density were shown in table (9) and plotted in figure (6) which revealed that for normal concrete the maximum compressive strength (63.16MPa) was found in the mixture (1:1.5:2), but mixture (1:1:2) showed the minimum strength (49.56MPa). After replacing the (NCA) by 50% of (PCA), the concrete mix (1:2:2) showed maximum strength value (42.5 MPa) and the mix (1:1:2) exhibited minimum strength value (37.22MPa). It is clear from the figure that both concrete mixes (1:2:2&1:3:2) of 100% plastic coarse aggregate gives the highest strength value (31.2MPa), while the lowest strength (23.94MPa) appears in concrete mix (1:1:2) of 100% plastic coarse aggregate.

Table (8): Density of the Concrete Samples (kg/m³)

Mix No.	Mix Proportions	Plastic Agg.	Sample1	Sample2	Sample3	Sample4	Density (kg/m³)
MIX 1	(1:1:2)	0%	2472	2480	2484	2470	2474
MIX 2	(1:1:2)	50%	2151	2086	2128	2131	2137
MIX 3	(1:1:2)	100%	1774	1763	1768	1766	1766
MIX 4	(1:1.5:2)	0%	2503	2494	2489	2485	2489
MIX 5	(1:1.5:2)	50%	2209	2193	2195	2168	2199
MIX 6	(1:1.5:2)	100%	1830	1850	1908	1865	1848
MIX 7	(1:2:2)	0%	2467	2491	2484	2478	2484
MIX 8	(1:2:2)	50%	2191	2198	2166	2182	2190
MIX 9	(1:2:2)	100%	1877	1918	1924	1899	1914
MIX 10	(1:3:2)	0%	2431	2460	2477	2477	2471
MIX 11	(1:3:2)	50%	2195	2218	2221	2240	2226
MIX 12	(1:3:2)	100%	2011	1981	1993	1961	1995

Table (9): Compressive strength of the Concrete Samples (MPa)

Mix No.	Mix Proportions	Plastic Aggregate	**Sample1**	**Sample2**	**Sample3**	**Sample4**	Strength (MPa)
MIX 1	(1:1:2)	0%	50.037	53.695	40.013	44.949	49.560
MIX 2	(1:1:2)	50%	35.366	39.26	31.402	37.042	37.223
MIX 3	(1:1:2)	100%	24.662	23.915	23.243	25.529	23.940
MIX 4	(1:1.5:2)	0%	65.691	61.039	46.515	62.755	63.162
MIX 5	(1:1.5:2)	50%	38.437	39.431	39.588	42.342	39.152
MIX 6	(1:1.5:2)	100%	26.286	24.613	23.363	31.675	24.754
MIX 7	(1:2:2)	0%	56.436	60.961	64.97	58.491	58.629
MIX 8	(1:2:2)	50%	41.242	41.565	37.26	44.736	42.514
MIX 9	(1:2:2)	100%	28.048	31.246	31.377	31.04	31.221
MIX 10	(1:3:2)	0%	50.294	45.107	55.124	56.221	53.880
MIX 11	(1:3:2)	50%	39.396	40.601	39.684	39.58	39.553
MIX 12	(1:3:2)	100%	31.165	30.502	32.01	28.894	31.226

Structural lightweight concretes can be produced using plastic pearls instead of natural coarse aggregate with strength>17.2MPa and density <1920kg/m³ in three cases when replacing the (NCA) by 100% of (PCA), in the mixes (1:1:2), (1:1.5:2) and (1:2:2). [19]

These outcomes disagree with the findings of the researchers used waste plastic as aggregates; they concluded that waste plastic aggregate concrete can be used only for nonstructural purposes. [1, 2 and 12]

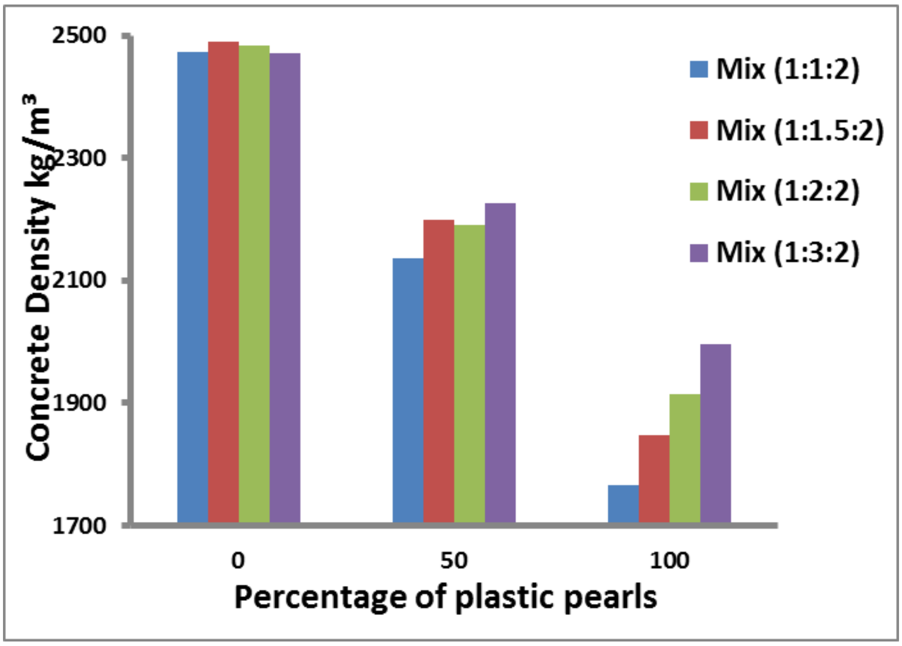

Fig. (5): Variation of concrete density with a percentage of (PCA)

From the above discussion, it is clear that the concrete strength decreased when the (PCA) included to concrete, this reduction in concrete strength is because of the poor bonding between the plastic aggregate and the cement paste, in addition, the hydrophobic property of the plastic pearls may also restrict the cement hydration. (5, and 11). In general, the compressive strength for the (NCA) concrete mixes is between (50-63) MPa, the compressive strength was reduced to

(37-42) MPa when using 50% (PCA), and the strength was in the range (23.9-31) MPa due to full replacing the gravel by plastic pearls. It is clear from the above results that the compressive strength of all the mixes agrees with structural concrete limitations (> 17.2 MPa)[19].

The relation between the compressive strength of (PAC) concretes and their densities were clearly plotted in figure (7), the figure shows that the decrease in concrete density clearly causes a decrease in concrete compressive strength, and the regression analyses of the results clear that best equation for this relation is the power- equation

($y=0.0000004X^{2.3813}$) with ($R2=0.9438$).

This equation helps in estimating the compressive strength of the plastic pearls aggregate concrete with respect to its density.

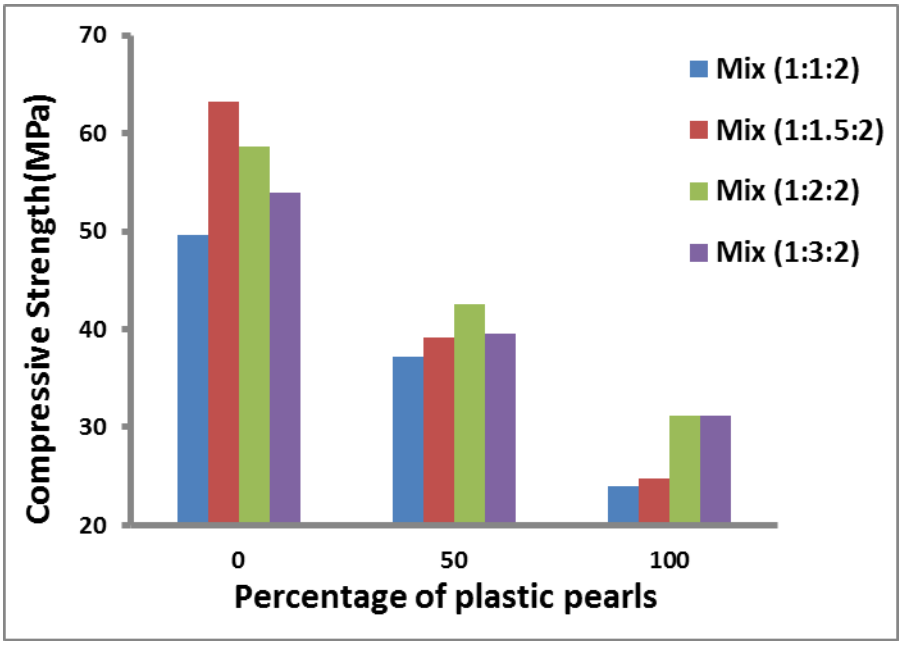

Fig. (6): Concrete compressive strength variation of with a percentage of (PCA)

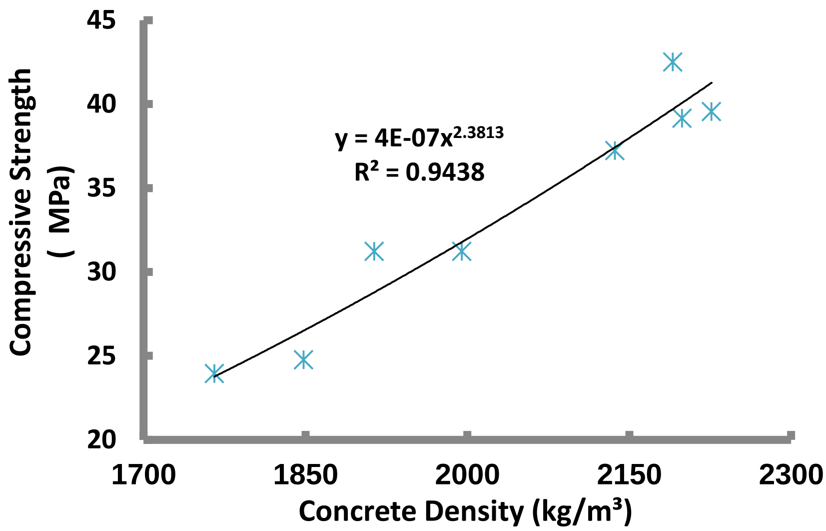

Fig. (7): Relationship between the compressive strength and density of (PCAC)

3.3- Effect of mix proportions

The loss in strength of concrete mixes due to plastic aggregate inclusion was shown in Tables (10 and 11). Table(10) clears that the most compatible mix with the 50% (PCA) with respect to strength consideration is the concrete mix (1:1:2) as its strength loss is 24.89%, while the mix (1:1.5:2) is the less compatible mix with this percentage of (PCA) as the strength loss of this mix is about (38%). For 100% replacement of (NCA) by (PCA), the better mix in accordance of its compatibility with plastic aggregate is the mix (1:3:2) with strength loss of 42%, while mix (1:1.5:2) is the worst mix with strength loss of 60.81% (see table11).

Table (10): Percentage Loss in compressive strength for 50% of (PCA) samples

Mix No.	Proportions	Plastic Agg.	Compressive Strength Loss %
MIX 2	**(1:1:2)**	**50%**	**24.89**
MIX 5	**(1:1.5:2)**	**50%**	**38.01**
MIX 8	**(1:2:2)**	**50%**	**27.49**
MIX 11	**(1:3:2)**	**50%**	**26.59**

Table (11): Percentage Loss in compressive strength for 100% of (PCA) samples

Mix No.	Proportions	Plastic Agg.	Compressive Strength Loss %
MIX 3	**(1:1:2)**	**100%**	**51.70**
MIX 6	**(1:1.5:2)**	**100%**	**60.81**
MIX 9	**(1:2:2)**	**100%**	**46.75**
MIX 12	**(1:3:2)**	**100%**	**42.05**

3.4 Mode of concrete failure

The mode of failure in all the concrete mixes is bond failure between the cement paste and aggregate surface in both (NCA) and (PCA) concretes. This failure mode in (NCA) concrete is belonging to the Iraqi aggregate high strength which is clear from its impact value result (8%), while the bond failure in (PCA) concretes is caused by the weak bond between cement paste and smooth surface of the pearls which was coated by a shiny paint. (See figure 8)

In this investigation the used plastic pearls were very smooth and hollow as unfortunately, the solid and rough pearls were not available, so the bond strength between the cement paste and the plastic pearls can be greatly increased using solid and rough plastic pearls. The roughness of the pearls can be increased by omitting the coating process during manufacturing the pearls because the raw material is rough but the coating color made the pearls smooth as its clear in figure (9).

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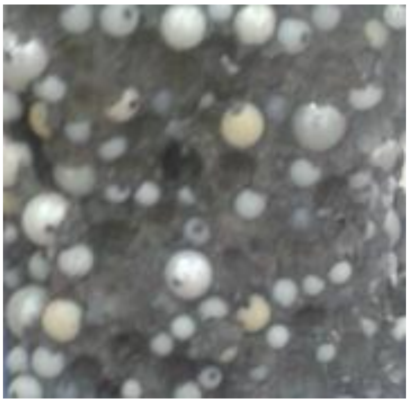

Fig.(8): Mode of failure in plastic and normal concrete samples

Fig. (9): Difference between plastic pearl material roughness and its surface roughness

4. CONCLUSIONS

From test results of the current research these conclusions can be derived:-

1- Concrete density is linearly decreased with the percent inclusion of the plastic aggregate.
2- The concrete compressive strength decreases with the plastic pearls inclusion in concrete.
3- The compressive strength of concrete mixes containing plastic pearls is within the structural strength limits (> 17.2 MPa).
4- Structural lightweight concretes can be produced using plastic pearls instead of natural coarse aggregate with strength >17.2MPa and density < 1920kg/m³.
5- Concrete of compressive strength between (23.9-42.5) MPa and density in the range of (1766-2226) kg/m³ can be generated when using plastic pearls as coarse aggregate in concrete.
6- Plastic pearls, can successfully replace the natural coarse aggregate in concrete for solving the deficiency problem of this material.
7- Bond failure mode occurs in both natural coarse aggregate concretes and plastic pearls coarse aggregate concretes.

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