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Influence of Recycled Construction Materials Aggregate on Mechanical and Physical Properties of Concrete

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Abstract: The main purpose of this research is to study the properties of re-use different types of construction materials such as PVC (polyvinylchloride) scraps, clay brick and recycled concrete as a partial replacement of coarse aggregate. Different proportions (1%, 3%, 5% and 7%) by weight were used for PVC. scrap, (10%, 20%, 30%, and 40%) by weight were used for recycled concrete and (5%, 10%, 15%, and 20%) by weight were used for clay brick. Mechanical tests such as compressive and tensile strength tests and physical tests such as ultrasonic pulse velocity, bulk density, porosity, specific gravity and water absorption tests were done to the samples after curing in normal water for 28 days. Test results showed slightly degradation in mechanical and physical engineering properties of concrete specimens that used partial replacement of recycled concrete coarse aggregate, degradation increased with increasing of replacement but test results still closely to reference samples. Use of polyvinyl chloride in proportions not more than 5% as a partial replacement of coarse aggregates given acceptable results in comparison with reference samples but all test results degraded at 7% replacements. Test results of partial replacement of crushed brick coarse aggregates unacceptable and the range of degradation are wide because of increased (water: cement) ratio to improve the concrete workability.

Key words: Recycled concrete, PVC. chips, clay brick, environment benefits, coarse aggregate replacements.

1. Introduction

The large amounts of building and construction materials waste considered as a main problem effect on environment. Recycling these materials and reusing it as a percentage replacement of fine and coarse aggregate reduce the waste and consumption of natural resources of sand and gravel. Many industrial countries specify the standards and applications for some recycling industrial and construction materials. This research study the effect of main building materials such as recycled concrete, clay brick and PVC scraps which were used as coarse aggregate replacement, and investigate the experimental results of recycled concrete specimens made from these materials and report it in figures and tables.

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2. Literature Review

Gomez-Soberon and Jose [1] presented an experimental analysis of recycled concrete aggregate replacement samples at ages 7, 28 and 90 days. The results showed some variation in the properties of recycled concrete with respect to ordinary concrete. Porosity increased considerably when natural aggregate is replaced by recycled concrete aggregate. Additionally, a reduction in the mechanical properties of recycled concrete is seen compared with ordinary concrete when porosity increased.

Ryu [2] investigated the effect of the recycled aggregate on interfacial property, permeability and strength characteristics of the concrete. Five types of recycled aggregate and four levels of *w*/*c* (water: cement) ratio were tested. The experimental results showed that the recycled aggregate has a significant effect on the properties of concrete.

Rahal [3] presented results of an experimental study on some of the mechanical properties of recycled concrete aggregate as compared to those of natural aggregate. The specimens tested at ages 1, 3, 7, 14, 28 and 56 days. The results showed that the 28 days cube and cylinder compressive strength, the indirect shear strength of the recycled aggregate concrete on the average 90% of those of natural aggregate concrete with the same mix proportions. Modulus of elasticity of recycled concrete aggregate was only 3% lower than that of natural aggregate concrete.

Puri, et al. [4] discussed an experimental study about the concrete made by partially replacing aggregates with waste materials like PVC scrap in proportions 5% and 10% .The results showed that fair value of compressive strength and workability when small percentage by weight was used. Construction debris which consists of concrete, plaster, metal, wood and plastics were used as a partial and completely replacement of coarse aggregate in proportions 50% and 100% by weight. The results showed a considerable increase in compressive strength of concrete made with construction debris coarse aggregate but minor reduction in workability of concrete was observed.

Cachim, and Paulo [5] evaluated the properties of concrete made with crushed bricks replacing natural aggregates. Replacement ratios of natural aggregates by 15% and 30% were investigated as well as *w*/*c* ratios of 0.45 and 0.5. Results indicated that ceramic residuals could be used as partial replacement of natural aggregates in concrete without reduction of concrete properties for 15% replacement and with reductions up to 20% and 30% replacement.

Xiao et al. [6] studied the compressive strength and stress-strain curve of recycled aggregate concrete with different replacement of aggregate percentages 0 to 100%. Compressive strength test results are closely for 50% to 100% replacement and 0 to 30% the results of compressive strength are closely but stress-strain curve results are closely for all recycled concrete aggregate and differs widely from the reference samples.

Tabsh and Abdlfatah [7] investigated the strength of concrete made with recycled concrete coarse aggregate. Toughness and soundness test results on recycled coarse aggregate showed higher percentage loss than natural aggregate but within the acceptable limits. The results showed that compressive strength of recycled concrete can be 10% to 25% lower than that of conventional concrete made with natural coarse aggregate.

Kwan et al. [8] observed in his study that the physical and mechanical properties of recycled concrete aggregates replacements up to 80% are good results for UPV (ultrasonic pulse velocity), compressive strength. Low water absorption less than 3% for RCA (recycled concrete aggregate) replacement up to 30% .Tests are done at ages 7, 14, 28, and 56 days for reference concrete samples and 15%, 30%, 60%, and 80% recycled coarse aggregate replacements.

Aliabdo et al. [9] focused on his research the effect of recycled aggregates physco-mechanical properties of concrete. The results showed that the use of recycled aggregate reduces the overall unit weight of concrete masonry units, higher thermal resistance and absorption rate than reference units. The recycled crushed clay coarse aggregate replacements in proportions 25%, 50%, 75% and 100% were used.

Ghazi [10] investigated the use of crushed clay brick aggregate concrete. Mechanical properties such as compressive strength and splitting tensile strength as well as physical tests such as UPV test were done. The test results of crushed clay aggregate concrete are compared with natural aggregate concrete and the results of compressive strength are lower than for natural aggregate concrete. The compressive strength of crushed brick aggregate concrete increased with age, the reduction is 33.5% at 7 days became 20% at 56 days. Other test results mentioned in the research are lower for crushed clay aggregate concrete than the

natural aggregate concrete.

Sharma and Singla [11] presented a study about recycled concrete aggregate properties and its structural applications. They used recycled concrete from buildings and pavements. They concluded that water absorption is about two times or more than natural coarse aggregate which reduces the density, mechanical properties and limited its applications.

Malesev et al. [12] analyzed the experimental results of their research about the use of recycled concrete aggregate by replacing 50% and100% in concrete samples. They concluded that the increasing of replacement will decrease the engineering properties of produced concrete.

Yang et al. [13] evaluated the test results of three types of recycled concrete aggregate which were classified according to specific gravity and water absorption. The replacement of recycled aggregate is 30%, 50% and 100%. Engineering test results for both fresh and hardened concrete depend on the relative water absorption of aggregates increasing.

Kumutha and VIjai [14] presented an investigation on the properties of using crushed concrete as coarse aggregate in proportions reach to 100% and crushed brick as fine aggregate in proportions reach to 100%. Engineering tests were done and the results are reduction in mechanical properties with increasing of replacement.

Hossain et al. [15] described an experimental study about using brick chips with different particle sizes as coarse aggregate. Many engineering tests were done and they concluded that particle size of brick aggregate affected on the properties of concrete, smaller particles increase the surface area of aggregate and increase the amount of cement paste bonding which leads to increase the strength of produced concrete. They found that increase in use of brick chips decreases the strength of concrete and vice versa.

3. Experimental Works

3.1 Material Characterizations

3.1.1 Cement

Local ordinary Portland cement type (I) was used in the mixes. Chemical and physical tests of cement are illustrated in Tables 1 and 2. The results showed that cement specify Iraqi Standard No. 5 [16].

3.1.2 Sand

Local sand was used as a fine aggregate in all mixes, sieve analysis test results illustrated in Table 3 and specify Iraqi Standards No. 45 [17]—third zone grading. Laboratory tests showed that specific gravity, water absorption and sulfates contents for fine aggregate are 2.6%, 1.6% and 0.27%, respectively.

3.1.3 Coarse Aggregate

Local gravel was used as a coarse aggregate and specify Iraqi Standards No. 45 [17] with maximum grain size 10 mm. Laboratory tests showed that specific gravity, water absorption and sulfates contents

Table 1 Chemical analysis of cement.

Compound type	Results (%)	Allowable limitations according to Iraqi Standards No.5 [16]
SiO_2	21.82	-
Al_2O_3	3.55	-
Fe_2O_3	4.2	-
CaO	62.32	-
MgO	2.13	No more than 5%
SO_3	2.48	No more than 2.5%
L.O.I	1.83	No more than 4%
I.R	0.65	No more than 1.5%
L.S.R	0.9	0.66 to 1.02
C_3A	2.3	-
C_3S	24.25	-

Table 2 Physical properties of cement.

Properties	Results	Allowable limitations according to Iraqi Standards No.5 [16]
Initial setting time	122 min	No less than 45 min
Final setting time	176 min	No more than 10 h
Soundness	1 mm	No more than 10 mm
Compressive strength at 3 days	26.6 N/mm^2	No less than 15 N/mm^2
Compressive strength at 7 days	43 N/mm^2	No less than 23 N/mm^2

Table 3 Sieve analysis of sand.

Sieve size (mm)	Passing (%)	Allowable limitations according to Iraqi Standards No.45 [17]
9.5	100	100
4.75	95	90 to 100
2.36	93	85 to 100
1.18	79	75 to 100
0.6	61	60 to 79
0.3	28	12 to 40
0.15	0	0 to 10

Table 4 Properties of clay brick.

Properties	Results	Allowable limitations according to Iraqi Standards No.25 [18]
Water absorption (%)	20.3	No more than 24%
Compressive strength (N/mm^2)	14.2	No less than 13 N/mm^2
Efflorescence	Moderate	Acceptable
Soluble salt (%)	3.6	No more than 5%

Table 5 Typical properties of PVC [19].

Properties	Results
Density (kg/m^3)	1.35
Compressive strength (N/mm^2)	90
Tensile strength (N/mm^2)	40
Elongation at break (%)	60

for coarse aggregate are 2.64%, 0.9% and 0.07%, respectively.

3.1.4 Crushed Concrete

Reference concrete samples were crushed and used as a partial replacement recycled coarse aggregate 10%, 20%, 30% and 40% by weight with maximum grain size 10 mm.

3.1.5 Crushed Clay Bricks (CCB)

CCB (Iraqi clay bricks) were crushed and used as a partial replacement coarse aggregate 5%, 10%, 15%, and 20% by weight with maximum particle size 10 mm. Clay bricks properties are illustrated in Table 4.

3.1.6 Polyvinyl Chloride Scrap

It cleaned to remove dust by using drinking water, then crushed and sieved with maximum chip size 10 mm. PVC properties are illustrated in Table 5.

3.2 Materials Preparations

3.2.1 Concrete Mixture

Concrete prepared for reference samples with mix proportion 1:2:4 (C:S:G)[1] by weight and w/*c* ratio 0.5 to obtain slump equal to 40 mm [20].

3.2.2 Recycled Concrete

Reference concrete samples were reused as recycled coarse aggregates after crushing and sieving in proportions 10%, 20%, 30% and 40% by weight of coarse aggregate. Concrete mix proportion is 1:2:4 (C:S:G & RA)[2] with *w*/*c* 0.52 to obtain slump equal

[1]Cement: sand: gravel.
[2]Cement: sand: gravel and recycled aggregate.

to 40 mm [20].

3.2.3 Crushed Clay Brick

Clay brick were used as a partial coarse aggregate replacement in proportions 5%, 10%, 15% and 20% by weight after crushing and sieving. Concrete mix proportion is 1:2:4 (C:S:G & CCB)[3] with *w*/*c* ranging from 0.64 for 20% replacement, 0.60 for 15% replacement, 0.56 for 10% replacement and 0.52 for 5% replacement of crushed clay brick to obtain slump equal to 40 mm [20].

3.2.4 PVC Scrap

It used in proportions 1%, 3%, 5%, and 7% by weight as a partial replacement of coarse aggregate. Concrete mix proportion is 1:2:4 (C:S:G & PVC) with *w*/*c* 0.52 to obtain slump equal to 40 mm [20].

3.3 Samples Casting and Curing

Steel cubes with 150 mm size were used to cast concrete specimens. Perfect compaction was achieved by using compacting vibrating table; concrete surface was leveled and covered by using polyethylene sheet for 24 h in ambient laboratory temperature. Specimens cured in drinking water for 28 days and used in this experimental study.

3.4 Samples Mechanical and Physical Tests

3.4.1 Compressive Strength

This test was done according to BS 1881: Part 116 [21] for concrete cubes and the results represent average results of two cubes.

3.4.2 Tensile Strength

This test was done according to ASTM C293-02 [22] for concrete prisms (400 × 100 × 100) mm and the results represent average results of two prisms.

3.4.3 Ultrasonic Pulse Velocity

This test was done according to ASTM C597-02 [23] for concrete cubes and the results represent average results of two cubes.

3.4.4 Bulk Density

This test was done according to ASTM C642-97 [24] for concrete cubes and the results represent average results of two cubes.

3.4.5 Apparent Specific Gravity

This test was done according to ASTM C642-97 [24] for concrete cubes and the results represent average results of two cubes.

3.4.6 Apparent Porosity

This test was done according to ASTM C642-97 [24] for concrete cubes and the results represent average results of two cubes.

3.4.7 Water Absorption

This test was done according to ASTM C642-97 [24] for concrete cubes and the results represent average results of two cubes.

3.4.8 Slump Test

This test was done according to ASTM C143-01 [20] for all concrete mixtures and the average result equal to 40 mm.

4. Results and Discussion

The results indicated that compressive and flexural tensile strength for reference concrete samples with ordinary (natural) aggregate higher than for concrete with different recycled aggregates proportions. Maximum cube compressive strength is 31.3 MPa and flexural tensile strength is 3.5 MPa for reference samples and decrease sharply when increasing the addition percentage of PVC chips as a coarse aggregate replacement as shown in Table 6 and Fig. 1. Cube compressive strength and flexural tensile strength decrease respectively from 31.3 MPa, 3.3 MPa for 1% PVC replacement coarse aggregate to 19.77 MPa, 1.85 MPa for 7% replacement coarse aggregate. The reduction in compressive and flexural tensile strength may be due to a poor bond between cement paste and PVC chips.

Recycled concrete aggregate replacement in amounts 10%, 20%, 30%, and 40% decreases compressive and flexural tensile strength, cube compressive strength and flexural tensile strength test results range respectively between 30.66 MPa, 3.1 MPa

[3]Cement: sand: gravel and crushed clay brick.

Table 6 Compressive and flexural tensile strength of PVC samples (N/mm^2).

Type of test / Type of samples	Compressive strength (MPa)	Flexural tensile strength (MPa)
Reference concrete	31.3	3.55
1% PVC. replacement	31.3	3.30
3% PVC replacement	29.77	3.27
5% PVC replacement	27.3	3.0
7% PVC replacement	19.77	1.85

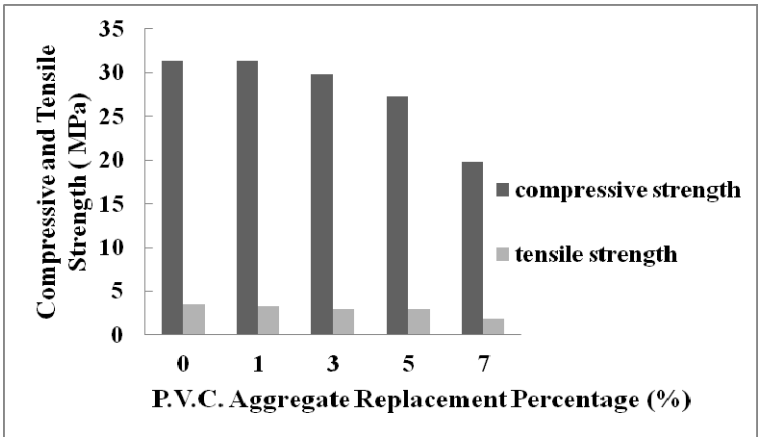

Fig. 1 Compressive and flexural tensile strength of PVC samples.

for 10% replacement to 24.22 MPa, 2.5 MPa for 40% replacement as shown in Table 7 and Fig. 2. The reduction in compressive and flexural tensile strength may be due to a poor bond between cement paste and recycled aggregate particles which contain hydrated cement paste particles.

Increase (water/cement) from 0.52 to 0.64 to keep the limit of slump test equal to 40 mm leads to sharp decrease in compressive and flexural tensile strength respectively for clay brick aggregate replacement (5%, 10%, 15% and 20%. Test results range between 10.66 MPa, 0.95 MPa for 5% replacement and 7.2 MPa, 0.67 MPa for 20% replacement. Test results illustrate in Table 8 and Fig. 3.

Compressive strength is a major indicator for many physical properties of concrete such as UPV, bulk density, apparent specific gravity, porosity and water absorption. Increase compressive strength value means increasing the bulk density, specific gravity and UPV value and decreasing the porosity and water absorption percentage. UPV test results are 5.41 km/s for reference samples and range between 4.95-4.8 km/s for PVC aggregate replacement in proportions 1%-7% as shown in Table 9 and Fig. 4. UPV test results range between 5.37-5.06 km/s for recycled concrete aggregate replacement in proportions 10%-40% as shown in Table 10 and Fig. 5. UPV test results range between 3.5-2.5 km/s for clay brick aggregate replacement in proportions 5%-20% as shown in Table 11 and Fig. 6.

Bulk density test results are 2.309 g/cm^3 for reference samples and range between 2.301-2.1 g/cm^3 for PVC aggregate replacement in proportions 1%-7% as shown in Table 9 and Fig. 7. Bulk density test results range between 2.302-2.22 g/cm^3 for recycled concrete aggregate replacement in proportions 10%-40% as shown in Table 10 and Fig. 8. Bulk density test results range between 2.28-2.10 g/cm^3 for clay brick aggregate replacement in proportions 5%-20% as shown in Table 11 and Fig. 9.

Water absorption test results are 3.972% for reference samples and range between 3.950%-3.702% for PVC aggregate replacement in proportions 1%-7% as shown in Table 9 and Fig. 10. Water absorption

Table 7 Compressive and flexural tensile strength of recycled concrete samples (N/mm^2).

Type of test / Type of samples	Compressive strength (MPa)	Flexural tensile strength (MPa)
Reference concrete	31.3	3.5
10% RC replacement	30.66	3.1
20% RC replacement	29.2	3.0
30% RC replacement	27.6	2.9
40% RC replacement	24.22	2.5

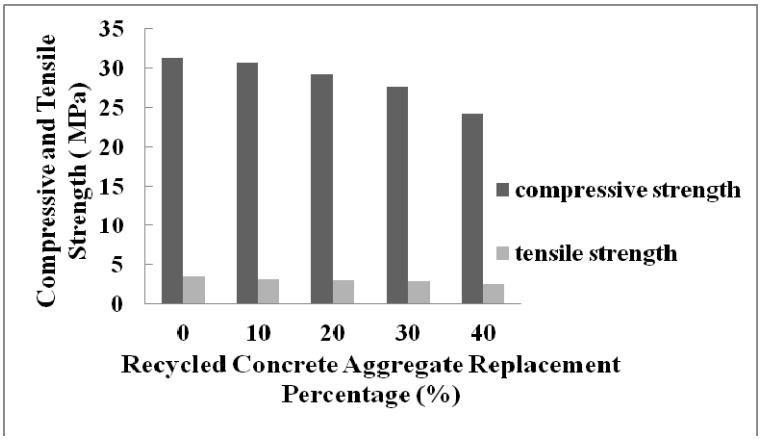

Fig. 2 Compressive and flexural tensile strength of recycled concrete samples.

Table 8 Compressive and flexural tensile strength of crushed clay brick samples (N/mm^2).

Type of test / Type of samples	Compressive strength (MPa)	Flexural tensile strength (MPa)
Reference concrete	31.3	3.5
5% brick replacement	10.66	0.95
10% brick replacement	9.15	0.9
15% brick replacement	7.33	0.7
20% brick replacement	7.2	0.67

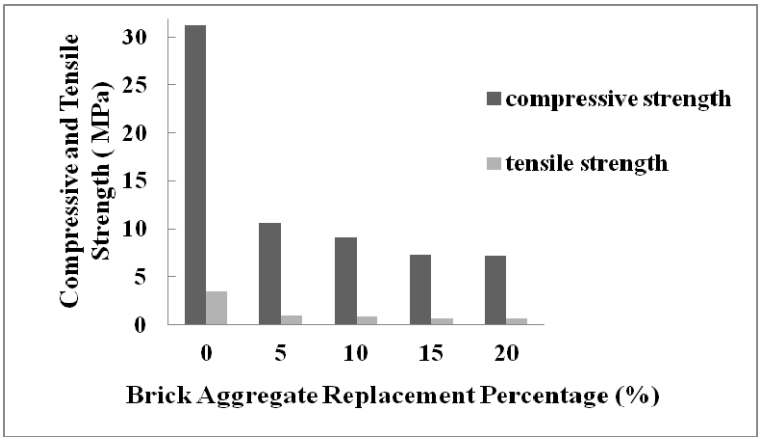

Fig. 3 Compressive and flexural tensile strength of brick aggregate samples.

Table 9 Physical tests of PVC samples.

Test type of / Type of samples	UPV (km/s)	Bulk density (g/cm^3)	Water absorption (%)	Specific gravity	Porosity (%)
Reference concrete	5.41	2.309	3.972	2.538	8.993
1 % P.V.C. Replacement	4.95	2.301	3.950	2.510	8.910
3 % P.V.C. Replacement	4.93	2.266	3.834	2.483	8.755
5 % P.V.C. Replacement	4.9	2.189	3.810	2.460	8.67
7 % P.V.C. Replacement	4.8	2.10	3.702	2.30	8.62

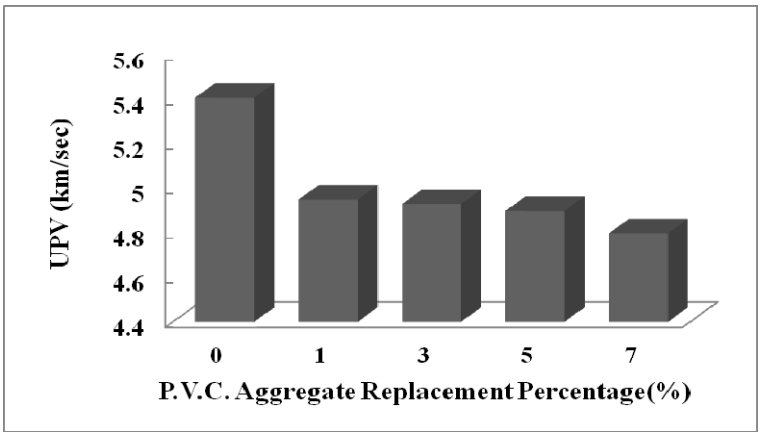

Fig. 4 UPV of PVC samples.

Table 10 Physical tests of recycled concrete (RC) samples.

Test type of / Type of samples	UPV (km/s)	Bulk density (g/cm^3)	Water absorption (%)	Specific gravity	Porosity (%)
Reference concrete	5.41	2.309	3.972	2.538	8.993
10% RC replacement	5.37	2.302	3.977	2.528	9.370
20% RC replacement	5.3	2.278	3.981	2.520	10.678
30% RC replacement	5.2	2.250	3.987	2.50	10.98
40% RC replacement	5.06	2.22	3.991	2.489	11.2

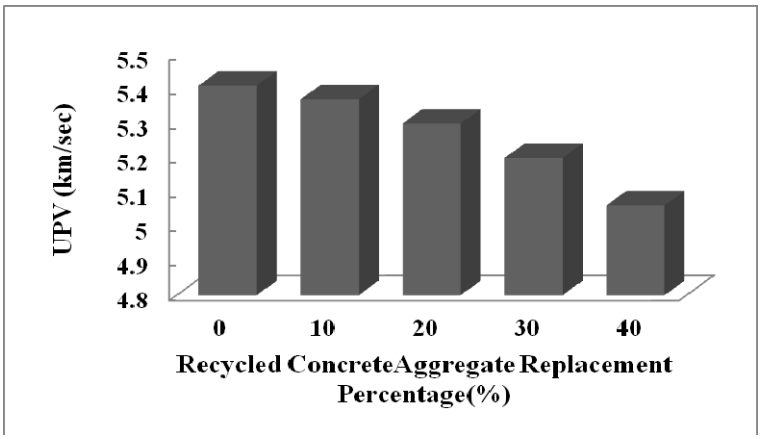

Fig. 5 UPV of recycled concrete samples.

test results range between 3.977%-3.991% for recycled concrete aggregate replacement in proportions 10%-40% as shown in Table 10 and Fig. 11 and the increasing of water absorption due to cement paste in recycled concrete aggregate. Water absorption test results range between 4.1%-5.89% for clay brick aggregate replacement in proportions 5%-20% as shown in Table 11 and Fig. 12.

Table 11 Physical tests of crushed clay brick samples.

Test type of / Type of samples	UPV (km/s)	Bulk density (g/cm^3)	Water absorption (%)	Specific gravity	Porosity (%)
Reference concrete	5.41	2.309	3.972	2.538	8.993
5% brick replacement	3.5	2.280	4.10	2.525	9.11
10% brick replacement	3.25	2.241	5.410	2.520	11.696
15% brick replacement	2.86	2.225	5.75	2.48	12.10
20% brick replacement	2.5	2.10	5.89	2.40	12.27

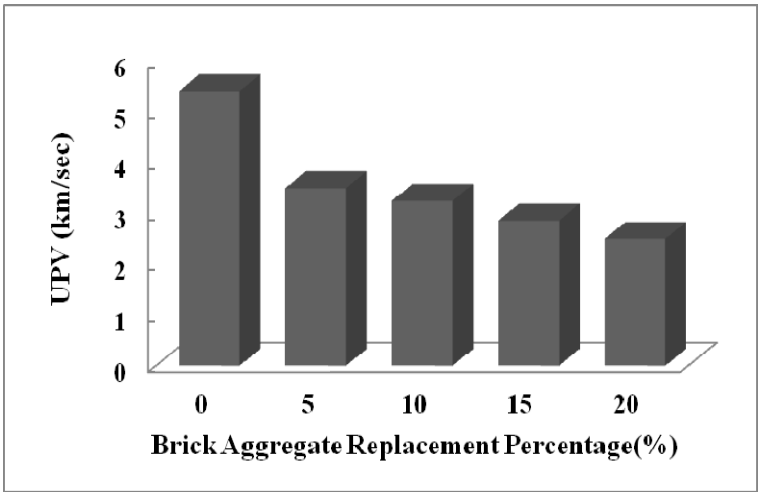

Fig. 6 UPV of brick aggregate samples.

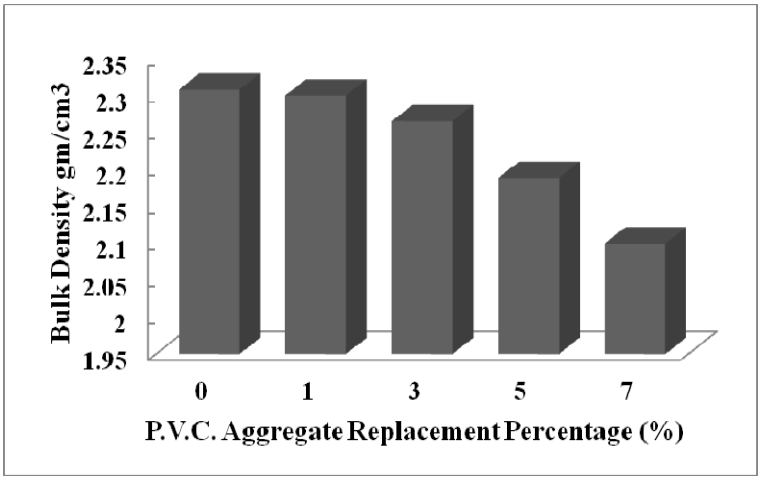

Fig. 7 Bulk density of PVC samples.

Specific gravity test results are 2.538 for reference samples and range between 2.510-2.30 for PVC aggregate replacement in proportions 1%-7% as shown in Table 9 and Fig. 13. Specific gravity test results range between 2.528-2.489 for recycled concrete aggregate replacement in proportions 10%-40% as shown in Table 10 and Fig. 14. Specific gravity test results range between (2.525-2.40) for clay brick aggregate replacement in proportions 5%-20% as shown in Table 11 and Fig. 15.

Porosity test results are 8.993% for reference samples and range between 8.910%-8.62% for PVC aggregate replacement in proportions 1%-7% as shown in Table 9 and Fig. 16. Porosity test results range between 9.370%-10.98% for recycled concrete

aggregate replacement in proportions 10%-40% as shown in Table 10 and Fig. 17. Porosity test results range between 9.11%-12.27% for clay brick aggregate replacement in proportions 5%-20% as shown in Table 11 and Figs. 18-22.

The partial replacement of PVC chips as a coarse aggregate decreases the porosity and as a result reduces the water absorption of concrete.

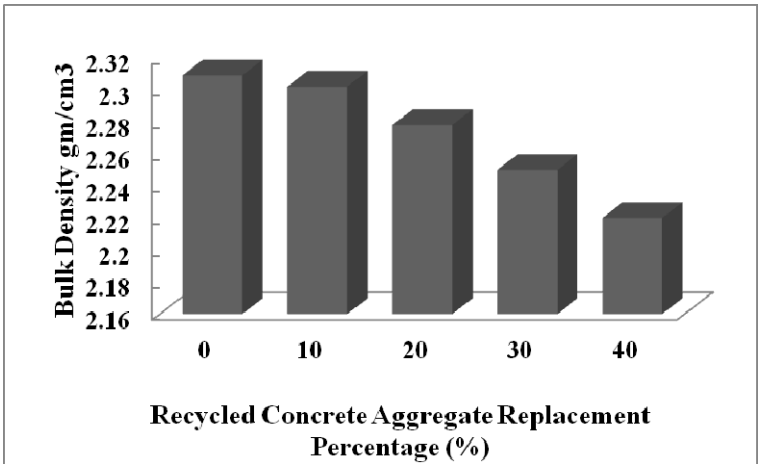

Fig. 8 Bulk density of recycled concrete samples.

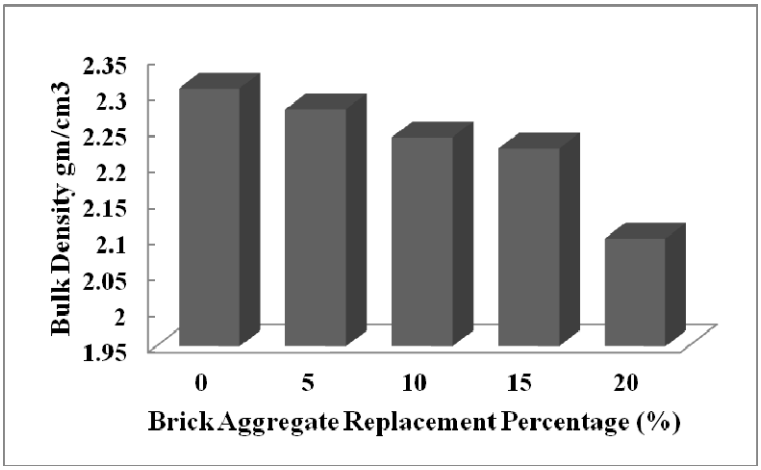

Fig. 9 Bulk density of brick aggregate samples.

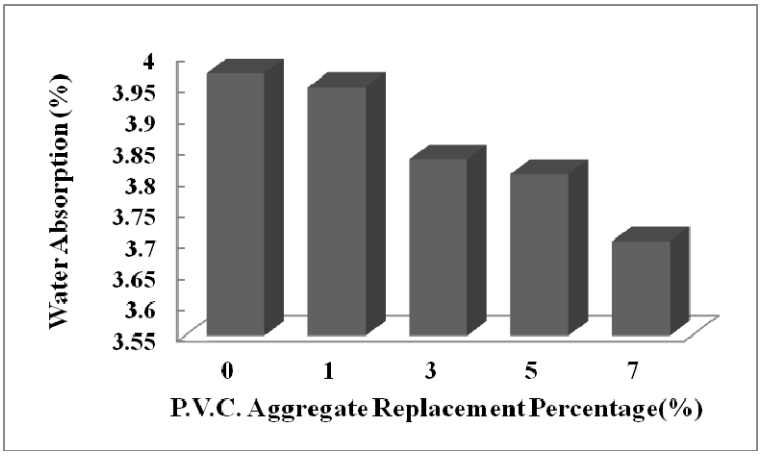

Fig. 10 Water absorption of PVC samples.

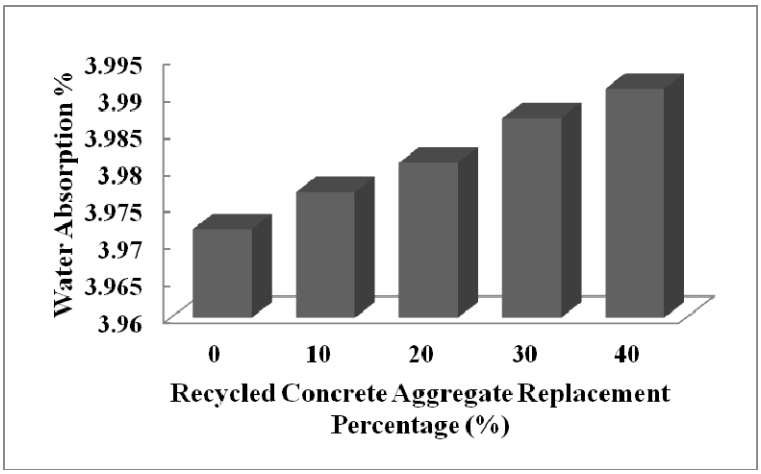

Fig. 11 Water absorption of recycled concrete samples.

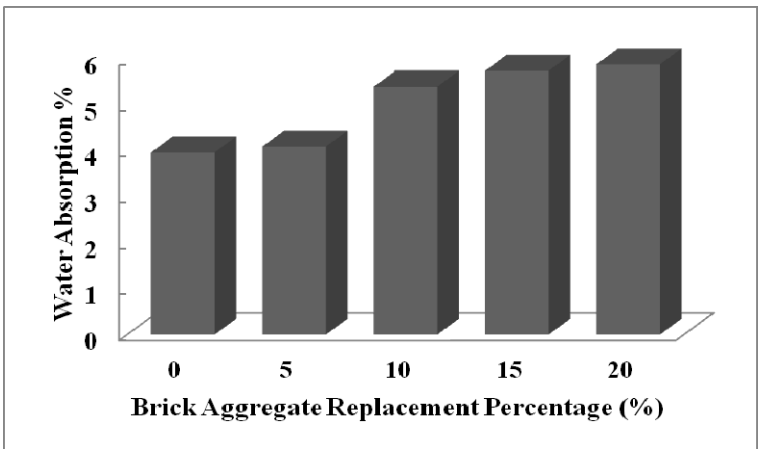

Fig. 12 Water absorption of brick aggregate samples.

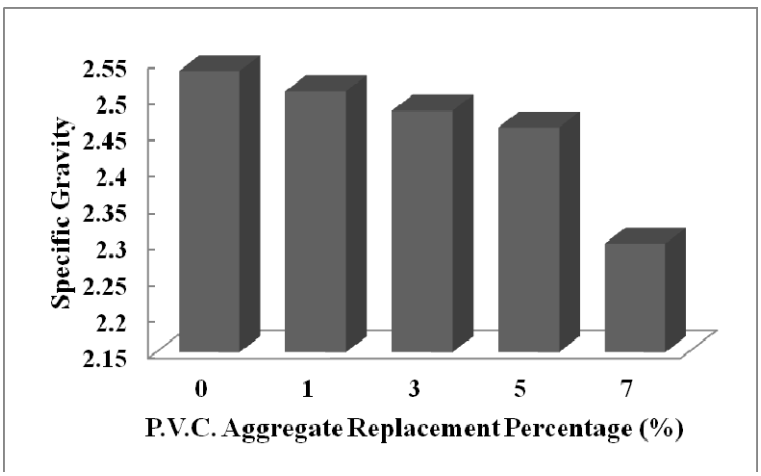

Fig. 13 Specific gravity of PVC samples.

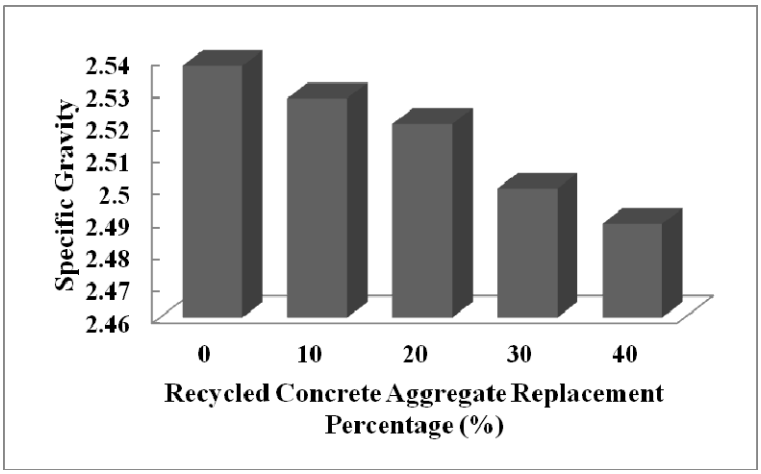

Fig. 14 Specific gravity of recycled concrete samples.

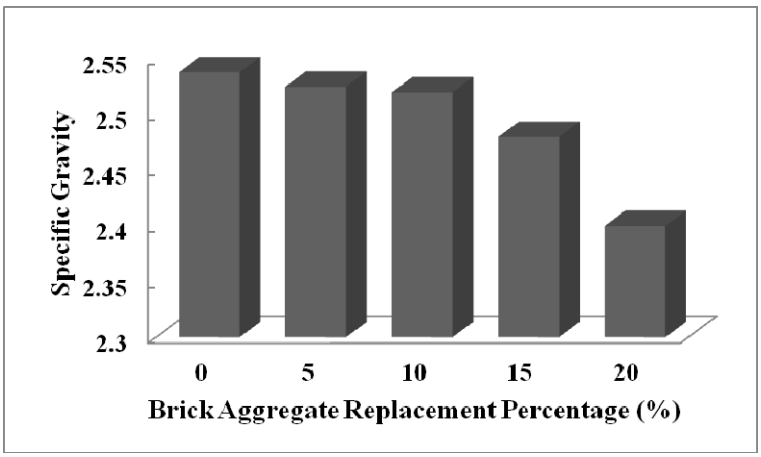

Fig. 15 Specific gravity of brick aggregate samples.

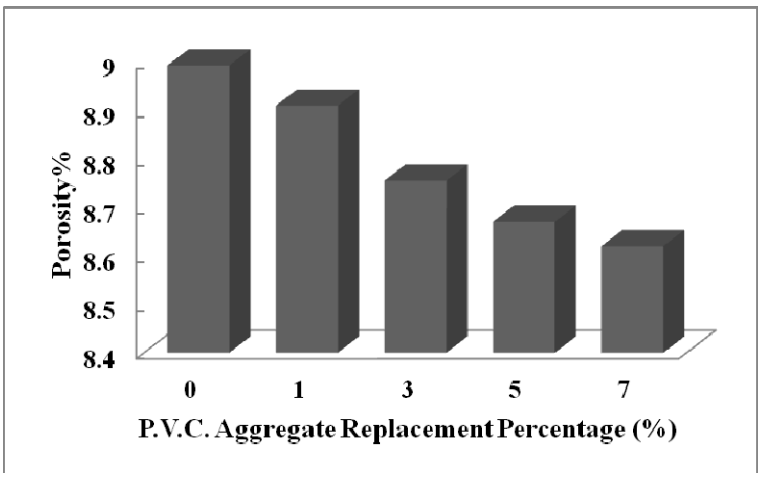

Fig. 16 Porosity of PVC samples.

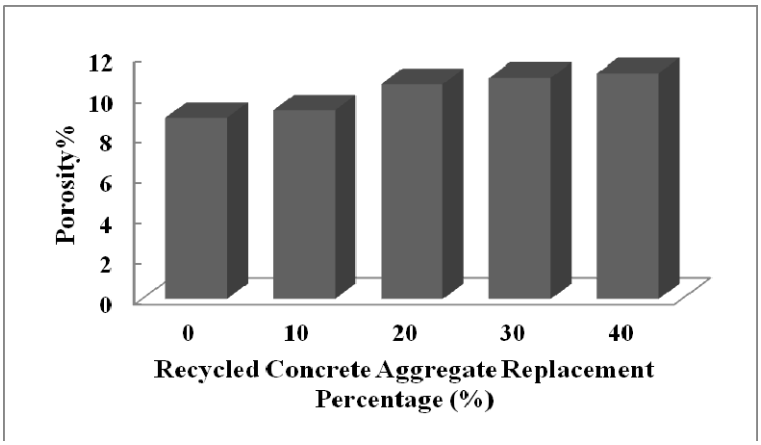

Fig. 17 Porosity of recycled concrete samples.

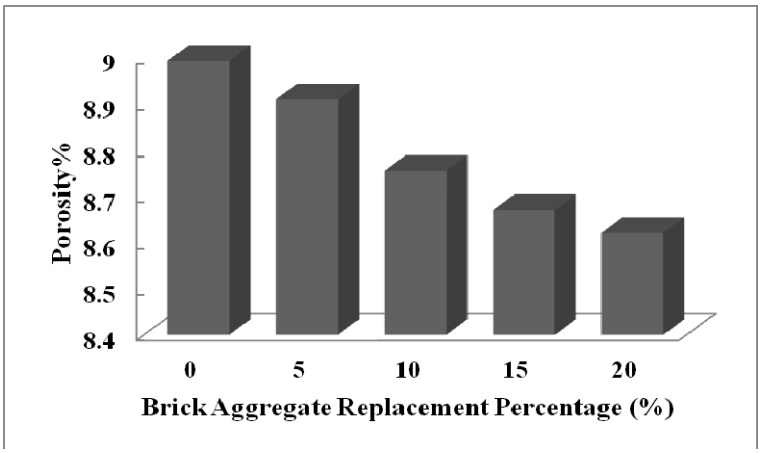

Fig. 18 Porosity of brick aggregate samples.

Fig. 19 Recycled concrete aggregate.

Fig. 20 Recycled PVC aggregate.

Fig. 21 Brick aggregate samples.

Fig. 22 PVC aggregate samples.

5. Conclusions

Using of recycled concrete as a partial coarse aggregate replacement in proportions 10%, 20% and 30% gives a best mechanical and physical properties test results. The results are close to reference concrete samples results but 40% recycled concrete replacement results are slightly differs from reference samples results.

Using of PVC chips as a partial coarse aggregate replacement in proportions 1%, 3% and 5% gives a good mechanical and physical properties test results. The results are slightly differs from reference concrete samples results but 7% PVC replacement results

sharply differ from reference samples results.

PVC chips in proportions 1%, 3% and 5% as a partial coarse aggregate replacement improve porosity and water absorption properties of concrete samples. It decreases the porosity and water absorption of concrete samples in proportions 4.19%-22.09% and 0.125%-0.377% compared to reference samples respectively.

Regardless using of clay brick as a partial coarse aggregate replacement in proportions 5%, 10%, 15% and 20% gives a bad mechanical and physical properties test results. The results sharply differ from reference concrete samples results. These results due to the amount of w/c ratio which reaches 0.64.

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