Acta Technica Napocensis: Civil Engineering & Architecture
Volume 61, No. 1, (2018)
Journal homepage: http://constructii.utcluj.ro/ActaCivilEng
ISSN 1221-5848

Behavior and Durability Evaluation of Recycled Aggregate Pervious Concrete

Alaa A. Bashandy[1]
Associate Prof., Civil Engineering Department, Faculty of Engineering, Menoufia University, Egypt.

(Received 15 April 2018; Accepted 25 May 2018)

Abstract

Pervious concrete is a special concrete type with no or little fine aggregates and a high porosity. It is used for concrete flat applications allows water from rainfall and extra water from other sources to pass directly through. Also, it is considered as porous and permeable concrete. Nowadays the recycled aggregates become one of the solutions to reduce the bad environmental impacts of demolished wastes. This research studied the use of recycled aggregates to cast the pervious concrete. It is conducted in two stages. The first is achieved to investigate the behavior of pervious concrete when cast using recycled aggregates compared to cast using natural aggregates. The second stage aims to study the durability of this type under the attack of sulfates and chlorides. The main variables in the first stage are the aggregate type and slab reinforcement. The main variables in the second stage are the aggregate type, attack type, attack period. Results show that using coarse recycled aggregate is efficient enough comparing to coarse natural aggregates to cast pervious concrete, especially when using crushed concrete. The use of pervious concrete cast using recycled crushed concrete may be considered as an alternative solution to the use of conventional pervious concrete in infrastructures.

Keywords: *Pervious concrete; Recycled aggregates; Slab; Behavior; Durability; Sulfate attack; Chloride attack.*

1. Introduction

The pervious concrete is one of the special types of concrete with a high proportion of large-sized pores (about 2-8 mm) which allows the water to flow easily through the pervious concrete [1, 2, 3]. The typical porosity of pervious concrete is about 15-25% [1]. Also, Pervious concrete is a type of concretes with little or no fine aggregate concrete. It is used for flat applications of concrete to allow water from rainfall and extra water from different sources to pass through it, so decreasing the excess from a site and permitting recharge of groundwater. Also, it is considered as porous concrete, permeable concrete, no fines concrete, and porous pavement [1, 4].

[1] Corresponding author: Tel./ Fax.: 002 0100 308 0 108
E-mail address: Dr.Alaa.Bashandy@sh-eng.menofia.edu.eg, Eng_alb@yahoo.com

Pervious concrete is traditionally used in pedestrian walkways, parking areas, residential streets, and greenhouses as a significant application for maintaining buildings and as one of several low influence development methods used by constructors to protect water quality [5]. Also, one of its advantages is reducing puddles on the road, enhancing water quality through permeation and heat absorption [4].

The basic ingredients of the pervious concrete mixture are not very changed from the conventional concrete mixture, except in the ingredients proportion of cementations binder, aggregate, water, and admixtures (if necessary).

It may eliminate or reduce the need for underground storm sewer drainage systems. Pervious concrete may also collect the runoff from the roofs to return it to the aquifer. Trees are one of the tools to fight greenhouse effect. Pervious concrete lets oxygen and water enter the soil beneath unlike impervious pavements. This allows the roots of the tree to make their tasks well, such as cooling the nearby air by the evaporation of the collected groundwater. This may help reduce air conditioning cost. The strength parameters and structural performance of pervious concrete vary when compared to conventional concrete, and it mainly depends on porosity [6]. Superior porosity leads to higher permeability with little compressive strength. The usual pervious concrete mix consists of 180-355 kg/m^3 of cement, 1420-1600 kg/m^3 of coarse aggregate, and water to cement ratio ranged from 0.27 to 0.43. The average 28-days compressive strength ranges from 5.6-21 MPa, the coefficient of permeability varies from 0.25 to 6.1 mm/Sec., density in the range of 1600-2000 kg/m^3, and void ratios of about 14-31%. The porosity of pervious concrete is in the range of 15-25% and is dependent on the water-cement ratio and compaction effort [7]. Its compressive strength can vary based on the material properties, its proportioning, porosity and obviously the compaction techniques which are applicable for a wide range of applications. The pervious concrete mixes should achieve the specification requirements for permeable concrete pavements [8]. The durability of pervious concrete and its water absorption are inversely proportional to each other means that, concrete cast using a 1:6 mix proportion has more durability and less water absorption and concrete cast using a 1:10 mix proportion has less durability more and water absorption [9].

Using recycled aggregate "RA" from waste, demolished buildings become a need to reduce its bad impacts on the environment. Many researchers studied the possibility of utilizing recycled aggregates as coarse aggregates for concrete [10, 11, 12]. The good quality recycled aggregate concretes "RAC" may have comparable properties like virgin aggregate [13]. Different recycled aggregates can be used as coarse aggregates for concrete such as crushed concrete, crushed ceramics, crushed bricks, and crushed tiles with sufficient characteristics, especially for non-structural concretes [11, 12, 14, 15]. Recycled coarse aggregates are feasible to be used with several special concrete types such as lightweight concrete, self-curing concrete, high strength concrete as well as conventional concrete [15, 16, 17]. Improving the concrete with recycled aggregates is studied too, and satisfactory results were obtained [18, 19]. The replacement of natural aggregate with recycled aggregate in concrete, partially or totally, reduces compressive strength, tensile strength, and modulus of elasticity and increases the dry shrinkage of concrete [20, 12]. Recycled aggregates can be advised to be used for mid-strength concretes.

Using recycled aggregates with pervious concrete is studied recently [21, 22, 23]. The changes in mix, composition and supplementary cementitious additives (such as fly ash or silica fumes) can easily be used in order to increase the characteristic compressive strength of pervious concrete [24]. The 15% RCA has strength limits nearly similar to control mix [23]. It is suggested that up to 30% replacement of natural aggregates with recycled aggregates is feasible without compromising strength and permeability too much [23]. The use of recycled aggregates with pervious concrete produces desirable results in both strength and infiltration when compared to partially replace RA [21, 22, 25].

In this research, the behavior and the durability of pervious concrete cast using recycled aggregates were studied.

2. Research Significance

This research describes the experimental approach to obtain pervious concrete cast using recycled aggregates and its durability. The experimental program is divided into two stages. In the first stage, this study aims to investigate the performance of pervious concrete cast using recycled aggregates. In the second stage, it aims to study the durability of this type under the attack of sulfates and chlorides. The main variables in this investigation are the aggregate type, type of attack, a period of attack. The importance of this work is based on the need to know the data available addressing the behavior of the pervious concrete cast using recycled aggregates under the aggressive weather. This study provides data concerning the durability of pervious concrete.

The novelty of this research is three points; the comparative study on the using of a suitable recycled aggregate type compared to using natural aggregates to cast pervious concrete, the evaluation of the structural performance of recycled aggregate pervious reinforced concrete slabs reinforced with rebars verses steel meshes, and the evaluation of the behavior of that concrete type under the attack of sulfates or chlorides.

The importance of this research is to provide sufficient data for the researchers and engineers that concerns in using pervious concrete, especially that cast using recycled aggregates and its durability to be used at parking areas, residential streets, and greenhouses or such places where allows water from rainfall and extra water from other sources to pass directly through.

3. Experimental Program

All tests in this investigation are carried out in the Construction Materials Laboratory in Civil Engineering Department, Faculty of Engineering Science, Sinai University.

3.1. Materials

The cement used is the ordinary Portland cement CEM I 32.5 N from Al-Arish Cement Factory. It satisfies the Egyptian Standard specification (E.S.S. 4756-1/2009) [26]. The fine aggregate used is the natural siliceous sand that satisfies the (E.S.S. 1109/2008) [27]. It is clean and nearly free from impurities with a specific gravity 2.5 t/m^3 and a fineness modulus of 2.85. Its mechanical properties are given in Table 1 while its sieve analysis is given in Table 2. Two types of coarse aggregates were used, natural and recycled aggregates. The natural coarse aggregate used was dolomite. Two recycled aggregates were used, crushed concrete and crushed red bricks. The demolished concrete samples are collected from the testing laboratory while the red brick samples are collected from construction sites. Each type has nearly the same range of crushing factor value to ensure the stability of characteristics.

Collected samples are broken into small pieces with the help of a hammer. Crushed materials are then sieved through 12.5 mm and 9.5 mm sieve to get an average size of 10 mm aggregate. Materials retained on 12.5 mm sieve are again broken into smaller pieces so as to get the required size of aggregate. The coarse aggregates used to satisfy the (ASTM C-33) [28]. Their main properties are given in Table 3. The shape of these particles is irregular and angular with a very low percentage of flat particles with a maximum nominal size of 9.5 mm.

Drinkable clean water, fresh and free from impurities is used for mixing and curing the tested samples according to the Egyptian code of practice (E.C.P. 203/2017) [29].

A high-range water-reducing admixture (HRWR) is often referred to as super-plasticizers help in increasing the workability of concrete without an additional amount of water. It is a third-generation superplasticizer for concrete and mortar. Its main properties are given in Table 4. It meets the requirements of (ASTM C-494 Type F) and (E.S.S. 1899-1/2006) [30].

Two types of reinforcement were used in this investigation, steel rebars and steel meshes. Mild steel as a secondary steel of rounded plain rebars of 8 mm diameter and high tensile steel as main reinforcement of 10 mm diameter were used. Steel meshes with an opening size of 40 mm and bar diameter of about 4 mm were used to be nearly equal to the surface area of rebars used. Main mechanical properties of steel reinforcement are shown in Table 5.

Table 1 : Physical properties of the sand.

Property	Value
Specific gravity	2.58
Volumetric weight *(t/m^3)*	1.7
Voids ratio *(%)*	33.8%
Percent of clay, silt and dust *(by weight)*	0.75%

Table 2: Grading of the sand.

Sieve size (mm)	4.5mm	2.36mm	1.18mm	0.6mm	0.3mm	0.15mm
% Passing ASTMC 33- 82	100-90	100-80	85-50	60-25	30-10	10-2
% Passing	92,8	84	63,4	34,7	17,5	8

Table 3: Physical properties of the coarse aggregates used.

Property	dolomite	Crushed Concrete	Crushed red bricks
Specific gravity	2.62	2.24	1.65
Volumetric weight (t/m^3)	1.84	1.6	--
Voids ratio (%)	3%	2%	8%
Crushing factor (%)	19	25	45
Percent of sulfate (by weight)	0.08%	--	--
Percent of chloride (by weight)	0.025%	--	--

Table 4: Technical information of Addicrete BVF. *(As provided by the manufacturer)*

Base	Appearance	Density	Chloride content	Air entrainment	Compatibility
Naphthalene sulphonate	Brown liquid	1.18±0.01 kg/L	Nil	Nil	All types of Portland cement

Table 5: The test result of reinforcing bars (rebars). *(Due to test results)*

Steel type	Yield Stress *(MPa)*	Tensile Strength *(MPa)*	Elongation *(%)*	Modulus of Elasticity *(GPa)*
Mild Steel	295	409	22	210
High Tensile Steel	365	530	13	210

3.2. Concrete and test samples

The flow chart of the experimental program is shown in Fig. 1. A concrete mix casts using dolomite as a natural aggregate as well as two mixes cast using crushed concrete and crushed red bricks as recycled aggregates as coarse aggregates were studied. The chosen proportion of pervious concrete was taken based on previous researchers [21, 22, 3]. The mix proportions of pervious concrete mixes are shown in Table 6. For each concrete mix, main mechanical properties for control mixes as well as main mechanical properties after an attack by sulfates or chlorides for different periods were studied.

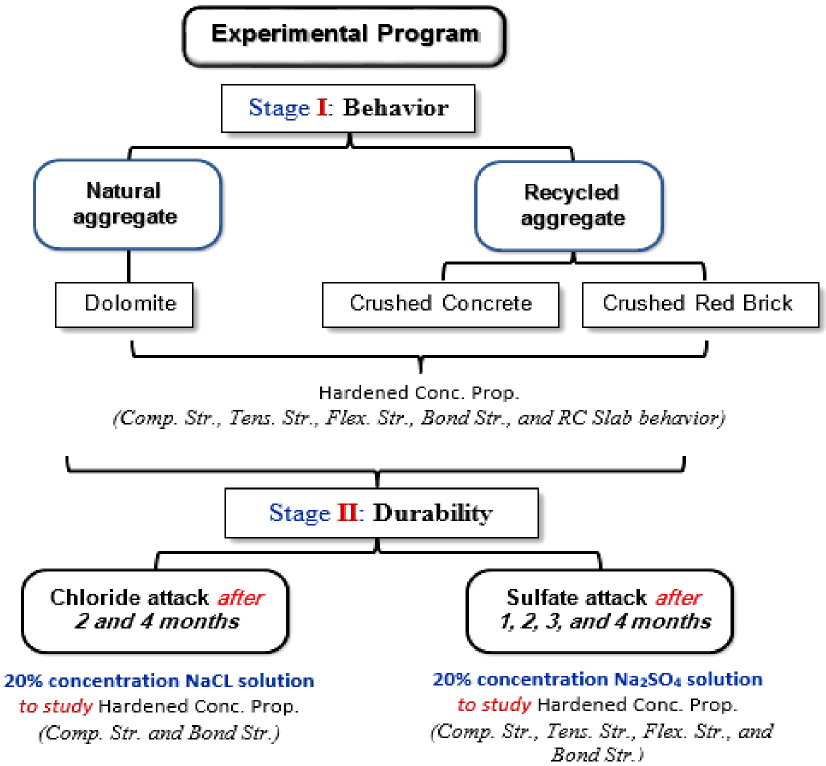


Fig. 1: Flow chart of the experimental program.

Table 6: Pervious concrete mixtures.

Mix.	Mix proportions *(kg/m³)*					*Properties*	
	Cement	Water	Fine aggregates	Coarse aggregates	Super-plasticizer	Density *(kg/m³)*	Voids *(%)*
D	338	114.8	*Sand* → 114.8	*Dolomite* → 1530	3.3 *(1%C)*	1820	18%
Cr.C				*Crushed concrete* → 1310		1800	21%
Cr.RB				*Crushed red brick* → 965		1720	24%

For each mix, cube specimens, 100x100x100 mm, were prepared for evaluating the compressive strength. Cylindrical concrete specimens, 100 mm in diameter and 200 mm high, were prepared to evaluate the split tensile strength. They were tested for split tensile strength according to (E.C.P. 203/2017) [29]. The flexural strength was determined according to (ASTM C-293) using a midpoint loading method utilizing using 100x100x500 mm prismatic concrete specimens. Samples are shown in Figs. 2 to 4. To obtain bond strength, push-down tests were conducted on the reinforcing bar embedded in concrete cubes, as shown in Fig. 5, at various testing ages of concrete. Steel rebars (St.52) of 12 mm diameter were cut into 16 cm length specimens then they embedded in 150x150x150 mm standard concrete cubes during the casting process.

The bond properties of reinforcing bars in pervious concrete were studied by conducting a direct push-down test of reinforcing bars embedded in pervious concrete specimens and also in recycled aggregate pervious concrete specimens and the results are compared. The concrete-rebar bond strength is formulated according to (E.C.P. 203/2017) [29] as $F_{bu}= f_s .\varphi / (4.L_d)$. Where L_d (mm) is the bond length of steel; φ (mm) is the diameter of the steel, and f_s (N/mm^2) is the steel tensile stress. If in the previous equation $f_s= F / (\pi.\varphi^2 /4)$, where F (N) is the applied force on the reinforcing bar, it then drives out as $F_{bu} = F / (L_d .\pi. \varphi)$.

Fig. 2: Compressive strength test.

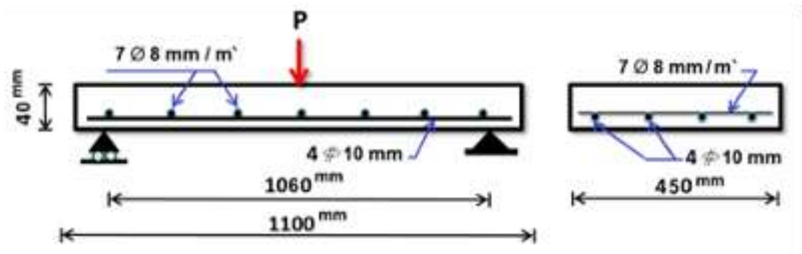
Fig. 3: Splitting tensile strength test.

Fig. 4: Pervious concrete samples.

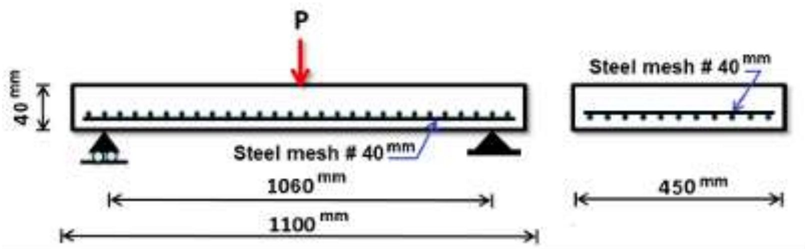
Fig. 5: Pervious concrete cube samples.

Fig. 6: Pervious concrete slab samples.

Fig. 7: Preparing the supports at the lower surface of slab samples.



(a) Slabs reinforced with rebars.



(b) Slabs reinforced with steel meshes.

Fig. 8: Details and reinforcement of tested slab samples.

Main mechanical properties, as well as durability after exposing to sulfates and chlorides, were obtained. The samples of each mix were tested to determine the main mechanical properties for each mix, including the compressive strength (fcu), tensile strength (ft), and modulus of rupture (fr) as well as bond strength. Three specimens representing the same constituent were used for each test throughout this investigation and the average values were reported.

To study the performance of reinforced recycled aggregate pervious concrete slabs, two reinforcement types were used, rebars and steel meshes. In most cases, the pervious concrete slabs rest on the ground and all surfaces are supported. Sometimes, the slabs may simply supported on the sides of the underground channel. To achieve that case, simply supported slabs of dimensions 40x450x1100 mm were used as shown in Fig. 6. Supported area of each slab (at the lower surface of the slab) was flattened at each edge by using cement mortar to ensure smooth contact with supports during loading stages as shown in Fig. 7. Details and reinforcement of slab samples are shown in Fig. 8. The slab flexure test was performed on slabs by using 3-point load system. The load is applied by using a hydraulic jack (capacity of 500 KN). Dial gauges of 0.01 mm accuracy and maximum capacity of 20 mm were used for deflection measurements at the middle point of the bottom surface as shown in Fig. 9. The abbreviations for the tested samples are shown in Table 7.

Fig. 9: Hydraulic jack and the loading frame of slab samples.

Fig. 10: Permeability of a pervious slab sample.

Table 7: Abbreviations for the samples.

Sample code	Coarse Aggregate	Attack type	Attack periods	Remarks
D	Dolomite	--	--	Control Samples
Cr.C	Crushed concrete	--	--	
Cr.RB	Crushed red bricks	--	--	
S-D-R	Dolomite	--	--	Slabs reinforced with rebars
S-Cr.C-R	Crushed concrete	--	--	
S-Cr.RB-R	Crushed red bricks	--	--	
S-D-M	Dolomite	--	--	Slabs reinforced with steel meshes
S-Cr.C-M	Crushed concrete	--	--	
S-Cr.RB-M	Crushed red bricks	--	--	
D-CL	Dolomite	Chlorides	2 and 4 months	Under chlorides attack
Cr.C-CL	Crushed concrete			
Cr.RB-CL	Crushed red bricks			
D-Sl	Dolomite	Sulfates	1, 2, 3, and 4 months	Under sulfates attack
Cr.C-Sl	Crushed concrete			
Cr.RB-Sl	Crushed red bricks			

3.3. Durability simulation

To investigate the durability of this concrete type, the performance of the samples is measured over different periods of immersion in sulfate or chloride solution. Percentage change in strength and weight is tested out. The schedule for casting and testing is as shown in Fig. 1.

The samples were immersed in a sodium chloride, NaCl solution to simulate the chloride attack. Its attack was studied in terms of bond strength to judge the corrosion rate to evaluate its effect on flexure performance. To simulate the sulfate attack, the samples were immersed in a sodium sulfate Na_2SO_4 solution. The amounts of the added chloride or sulfates were computed to provide total dissolving ions of about 20% concentration solution. It is worth mentioning that the selected concentration of chloride ions was about 50 times higher than that allowed by the (E.C.P. 203/2017) [29] in order to accelerate the attack rate. The samples were immersed in that solution for periods from 1 to 5 months then tested. Results of samples immersed in chloride solution to simulate chloride attack were compared to control specimens.

Crystals of salt were seen on the surface of samples due to evaporation of the solution. During this test, both temperature and relative humidity were measured once a week. Statistical results showed that the temperature varied in the range 24-32 ^{o}C with an average of 28 ^{o}C, while the relative humidity varied in the range 60-74 % with an average of 67 %.

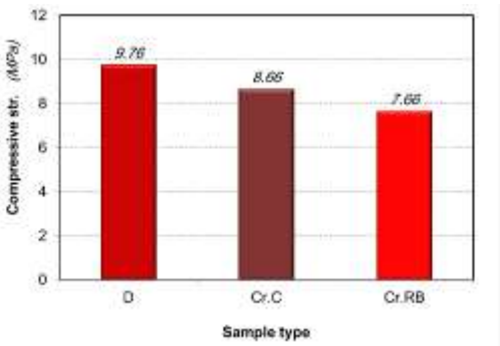


Fig. 11: Compressive strength of control samples.

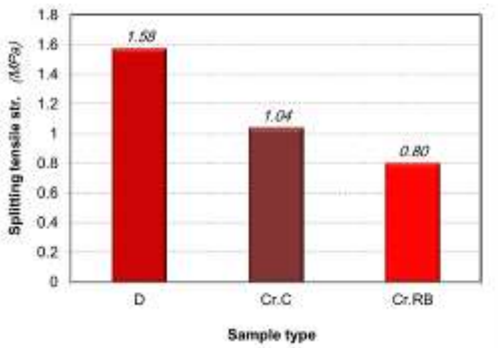


Fig. 12: Splitting tensile strength of control samples.

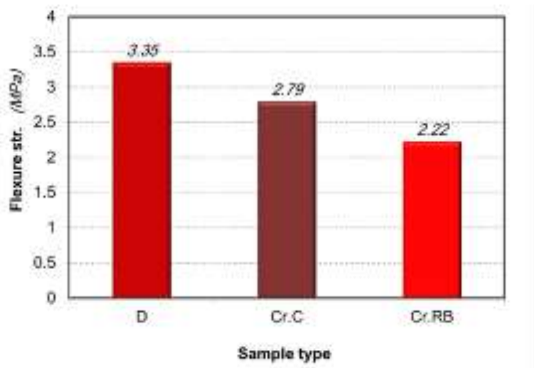


Fig. 13: Flexure strength of control samples.

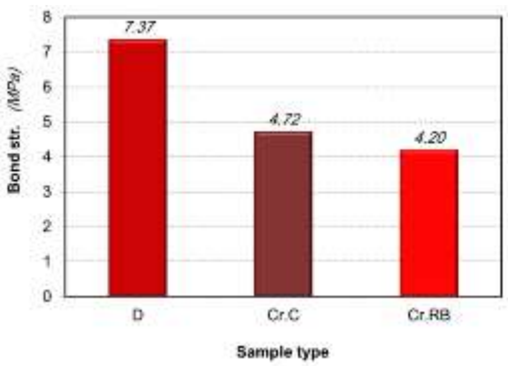


Fig. 14: Bond strength of control samples.

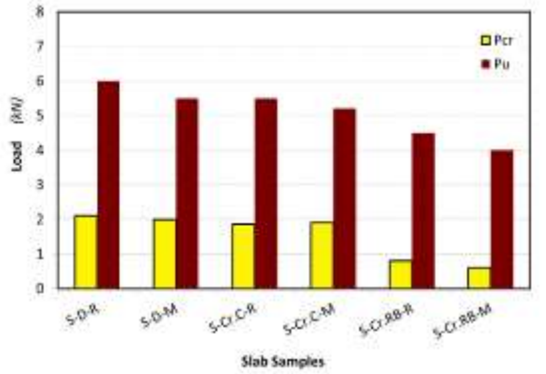


Fig. 15: Initial cracking load and ultimate loads for tested slabs.

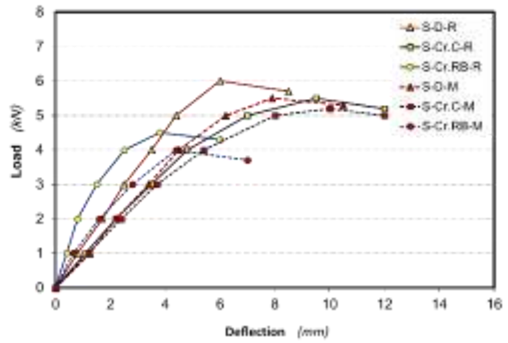


Fig. 16: Load-deflection relationships for tested slabs reinforced with rebars or with meshes.

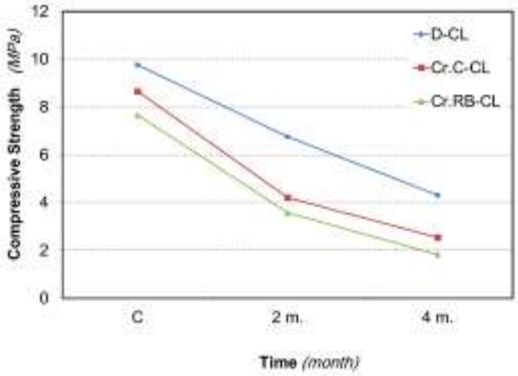


Fig. 17: Effect of chlorides on compressive strength.

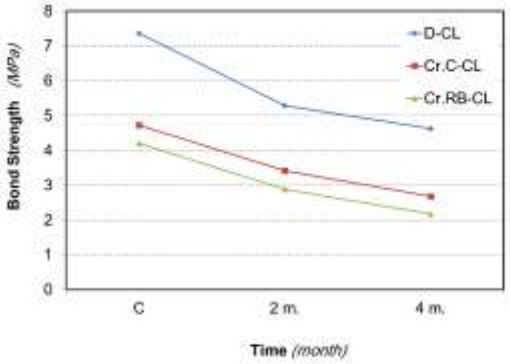


Fig. 18: Effect of chlorides on bond strength.

4. Results and Discussion

The results of the first stage in this research derived in terms of compressive, splitting tensile, bond, and flexure strengths and the behavior of slabs cast using this concrete type is evaluated in terms of initial cracking loads, ultimate loads, and deflection values. At the second stage, the durability of recycled pervious concrete samples under sulfates and chlorides derived in terms of compressive, splitting tensile, bond, and flexure strengths.

4.1. Main mechanical properties of recycled aggregate pervious concrete

The main mechanical properties of the pervious concrete cast using recycled aggregates compared to those cast using natural aggregates are evaluated. Also, the behavior of reinforced pervious concrete slabs casts using natural and recycled aggregates was studied. Table 8 and Figs. 11 to 14 showed the main mechanical properties of the pervious concrete cast using recycled aggregate. When using crushed concrete and crushed red bricks the compressive strength decreased by about 11.2% and 21.5%, respectively compared to using dolomite as coarse aggregates. The splitting tensile, flexure and bond strengths decreased by a range of 34-36% and 43-47% for crushed concrete and crushed red brick, respectively compared to pervious concrete cast using dolomite. So, crushed concrete may be used as recycled aggregate for pervious concrete. The loss of strength may because of the decrease in crushing factor of red bricks compared to crushed concrete that the voids in crushed red bricks which led to a leak in the strength of the pervious concrete cast using crushed red bricks. The results were within the typical range of previous researchers [22, 23, 25, and 31].

Table 8: Percentage of strength loss as functions of control sample strength due to using suggested recycled aggregates.

Samples	% Loss of strength compared to control samples			
	Compressive str.	Tensile str.	Flexure str.	Bond str.
D	0.0	0.0	0.0	0.0
Cr.C	-11.2	-34.0	-35.2	-35.9
Cr.RB	-21.5	-49.1	-47.0	-43.0

4.2. The behavior of recycled aggregate pervious concrete slabs

Initial cracking loads, failure load, and deflection values of recycled aggregate pervious concrete slabs were evaluated.

4.2.1. The initial cracking and ultimate loads.

Initial cracking loads and failure load are shown in Table 9 and Fig. 15. The initial cracking loads of reinforced recycled pervious concrete slabs are nearly behaving in the same manner when using natural and recycled aggregates with a decrease up to 60 and 70% when reinforced with rebars and steel meshes, respectively when using crushed red bricks compared to cast using dolomite.

Table 9: Displacement ductility ratios of the recycled aggregate pervious concrete slab samples.

Slabs	Load (*kN*)		Pcr / Pu	Displacement (*mm*)		Displacement Ductility Ratio ($\Delta u/\Delta y$)
	Initial Cracking Load (P_{cr})	Ultimate Load (P_u)		Δ y	Δ u	
S-D-R	2.1	6	0.35	4.5	6	1.33
S-D-M	2	5.5	0.36	6	7.8	1.30
S-Cr.C-R	1.85	5.5	0.34	5.8	9.5	1.64
S-Cr.C-M	1.9	5.2	0.37	6.4	10	1.56
S-Cr.RB-R	0.8	4.5	0.18	2.55	3.8	1.49
S-Cr.RB-M	0.6	4	0.15	2.9	4.4	1.52

The ultimate loads of reinforced recycled pervious concrete slabs reinforced with rebars decreased by about 8.3% and 25% for samples cast using crushed concrete and crushed red bricks, respectively compared to those cast using dolomite as control samples. When using steel meshes as reinforcement, ultimate loads decreased by about 5% and 27% for samples cast using crushed concrete and crushed red bricks, respectively compared to control samples. Generally, using recycled aggregates reduces the initial cracking loads and ultimate loads of pervious concrete. That may because of the lower crushing factor of suggested recycled aggregates compared to dolomite.

4.2.2. Displacement ductility ratio

The displacement ductility/ductility index can be defined as the ratio of the curvature at the ultimate moment to the curvature at yield. The ductility can be expressed based on the deflection of the slab through that index, $\mu = \Delta u/\Delta y$ where; Δu is slab deflection when a slab collapsed and Δy is slab deflection when longitudinal reinforcement yielded, according to ACI Committee 363 [32].

The ductility indexes of all slabs were listed in Table 9. In the case of reinforcing using rebars, the ductility index of slabs cast using crushed concrete and crushed red bricks increased by about 23.2% and 12%, respectively compared to that cast using dolomite. In the case of reinforcing using steel meshes, the ductility index of slabs cast using crushed concrete and crushed red bricks increased by about 20.2% and 16.7%, respectively.

From the Table, the experimental deflection ductility index ranges from 1.3 to 1.64. Generally, a small ductility index indicates that a structural member is less able to deform prior to failure that a ductility index up to 2 lacked adequate ductility and cannot redistribute moment [33, 34].

4.2.3. Deflection Values

The load-deflection relationships of the different pervious slabs are shown in Fig. 16. It indicated that the load is proportional to the deflection values at the center of the lower surface of the tested slab up to the appearance of the first crack. For slab samples, the load-deflection relationships can be classified into three distinct zones; the post-cracking zone up to the cracking point which continued up to the yielding point, and the post-yield zone, up to failure. The recorded deflection values for slabs reinforced with rebars show that the maximum-recorded deflection value was obtained when using crushed red brick, then when using crushed concrete as recycled aggregates for pervious concrete compared to control slabs. That may refer to their lower stiffness and ductility ratios. The same behavior, but with larger deflection values can be noticed for slabs reinforced with steel meshes.

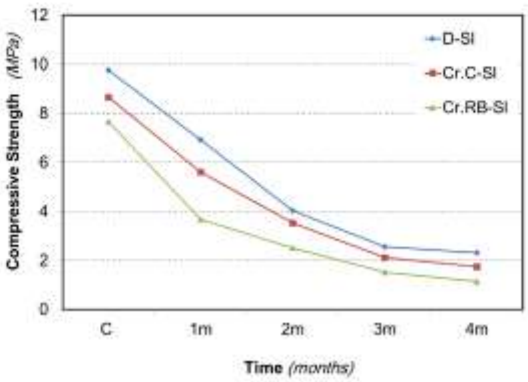


Fig. 19: Effect of sulfate on compressive strength.

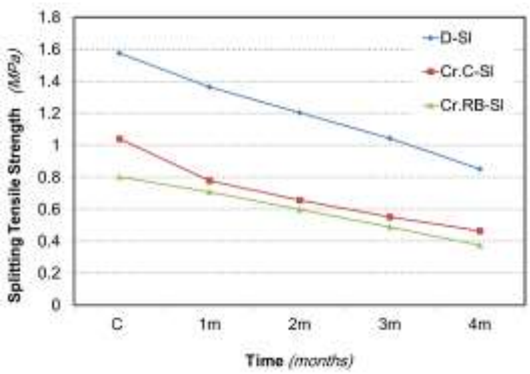


Fig. 20: Effect of sulfate on splitting tensile strength.

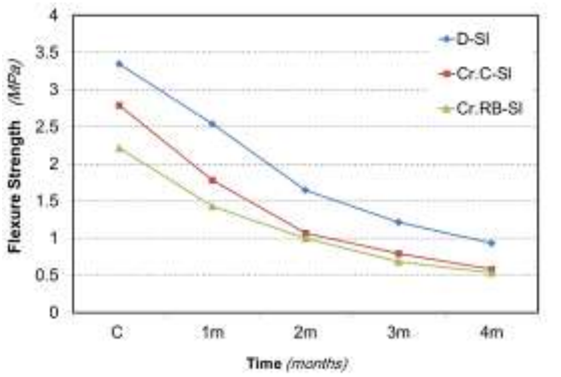


Fig. 21: Effect of sulfate on flexure strength.

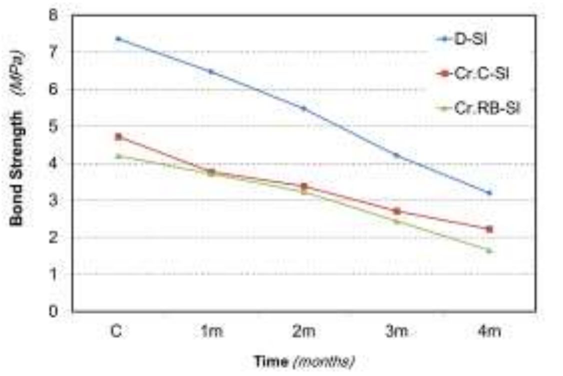


Fig. 22: Effect of sulfate on bond strength.

Based on the obtained results, using crushed concrete is more efficient than using crushed red bricks as a coarse recycled aggregate with pervious concrete slabs. That may because crushed concrete has a higher compressive strength and higher crushing factor compared to crushed red bricks.

4.3. The durability of recycled aggregate pervious concrete

4.3.1. Effects of chlorides

The bond was studied due to the bad effects of chlorides on the steel reinforcement and hence on the bond between it and the concrete which may affect on the behavior of reinforced elements. The compressive strength and bond strength results are shown in Table 10 and Figs. 17 to 18 as a function of exposure time to chloride attack. It shows the variation in the strength with time for recycled aggregate pervious concrete specimens, which were immersed in a 0.2 g/ml NaCl solution (20% concentration) for 2 and 4 months compared to pervious concrete cast using dolomite as a natural aggregate at the same conditions. It is observed that the compressive strength of the pervious concrete cast using dolomite is highest among other types of recycled aggregates followed by crushed concrete.

Table 10: Percentage of strength loss after chloride attack as functions of control sample strength.

Samples	% Loss of compressive strength compared to control		% Loss of bond strength compared to control	
period →	*2 m.*	*4 m.*	*2 m.*	*4 m.*
D-CL	-30.8	-55.9	-28.2	-37.2
Cr.C-CL	-51.4	-70.7	-27.7	-43.4
Cr.RB-CL	-53.3	-76.2	-31.3	-48.5

When considering the effect of an aggregate type, The compressive strength values of a pervious concrete cast using crushed concrete "Cr.C-CL" and crushed red bricks "Cr.RB-CL" decreased by about 37.6% and 47% at 2 months and 41.1 and 57.8 at 4 months, respectively compared to pervious concrete cast using dolomite at the same age of each. The decrease in bond strength values nearly in the same range.

When considering the exposure time effect, the compressive strength of "D-CL", "Cr.C-CL", and "Cr.RB-CL" decreased after 2-4 months with a range of about 30.8-55.9%, 51.4-70.7%, and 53.3-76.2%, respectively compared to their control samples before the attack. The bond strength values of "D-CL", "Cr.C-CL", and "Cr.RB-CL" decreased after 2-4 months with a range of about 28.2-37.2%, 27.7-43.4%, and 31.3-48.5%, respectively compared to their control samples before the attack. That may because of the forming of corrosion on the rebars surface due to the presence of high concentrations chlorides. Using dolomite is recommended, followed by using crushed concrete, then using crushed red bricks with average strength loss of 42% and 57%, respectively compared to using dolomite.

4.3.2. Effects of sulfates

Table 11 and Figs. 19 to 22 shows the variation in the recycled aggregate pervious concrete strength values with time. The attack was simulated by the immersion in a 0.2 g/ml Na_2SO_4 solution (20% concentration) for 1, 2, 3, and 4 months compared to pervious concrete cast using dolomite at the same conditions. The highest concentration is to accelerate the attack effects.

Table 11: Percentage of strength loss after sulfate attack as functions of control sample strength.

Samples	% Loss of compressive strength compared to control				% Loss of splitting tensile strength compared to control				% Loss of flexure strength compared to control				% Loss of bond strength compared to control			
period →	*1m*	*2m*	*3m*	*4m*	*1m*	*2m*	*3m*	*4m*	*1m*	*2m*	*3m*	*4m*	*1m*	*2m*	*3m*	*4m*
D-Sl	-29.1	-58.8	-73.8	-76.2	-13.6	-23.8	-33.9	-46.2	-24.1	-50.7	-63.6	-72.1	-12.2	-25.7	-42.8	-56.6
Cr.C-Sl	-35.3	-59.2	-75.6	-79.9	-25.3	-36.9	-46.9	-55.4	-35.9	-61.6	-71.6	-79.1	-20.1	-28.5	-42.5	-52.9
Cr.RB-Sl	-52.0	-67.2	-80.1	-85.0	-11.7	-25.1	-38.9	-53.3	-35.4	-54.9	-69.2	-75.9	-11.5	-23.0	-42.0	-60.8

Samples with crushed red bricks followed by that with crushed concrete are more sensitive to sulfate effect comparing to that with dolomite. That can be attributed to the presence of voids in recycled aggregates compared to natural aggregates. Also, the loss of strength may because of expansion movements due to the presence of Gypsum and Ettringite which may form when sodium sulfate reacts with CSH and they have expansive characteristics with little damages and microcracks [35].

When considering the aggregate type effect, compressive strength values decreased by a range of 11.2-25% and 21.5-50.5% along exposure time for "Cr.C-S" and "Cr.RB-S", respectively compared to "D-S" at the same each age. Splitting tensile strength decreased by a range of 43-45% and 48-56% along exposure time for "Cr.C-S" and "Cr.RB-S", respectively compared to "D-S". Flexure strength decreased by a range of 16.7-37.5% and 33.8-44% along exposure time for "Cr.C-S" and "Cr.RB-S", respectively compared to "D-S". Also, bond strength decreased by a range of 35-41.8% and 40.9-48.6% along exposure time for "Cr.C-S" and "Cr.RB-S", respectively compared to "D-S". Generally, the loss of strength in crushed red bricks is larger than crushed concrete. The strength loss was increased as the exposure time increased. After 3 months, a small loading caused extrusion of the pervious concrete samples. However, when a load is applied to specimens cracks have been observed, as the increase of the channels for sulfate diffusion into concrete increases the sulfate diffusion rate. This behavior may refer to the transport of sulfate ions into the pores of concrete where they reacted with hydration products to produce expansive materials that blocked the pores, causing the development of micro-cracks. However, when the concrete pores cannot provide the material expansion, the concrete characteristics are negatively impacted. In particular, if the pore volume is smaller than the expansive material volume produced by the sulfate ions, internal expansion stresses can create a macro-cracks. So, the strength decreased in the later times of the specimen immersion in the Na_2SO_4 solution. These results are in an agreement with the comments of previous researchers [9, 22, 23].

When considering the exposure time effects, the values of compressive strength decreased up to 76.2%, 79.9%, and 85% for "D-S", "Cr.C-S", and "Cr.RB-S", respectively compared to their control samples. The values of splitting tensile strength decreased up to 46%, 55.4%, and 53.4% for "D-S", "Cr.C-S", and "Cr.RB-S", respectively compared to their control samples. The values of flexure strength decreased up to 72.1%, 79.1%, and 75.9% for "D-S", "Cr.C-S", and "Cr.RB-S", respectively compared to their control samples. The values of bond strength decreased up to 56.6%, 52.9%, and 60.8% for "D-S", "Cr.C-S", and "Cr.RB-S", respectively compared to control samples. The lower strength loss is observed for pervious concrete cast using dolomite then that cast using crushed concrete and finally for that cast using crushed red bricks. That meaning casts using dolomite is the best while cast using crushed concrete produces satisfied performance compared to cast using crushed red brick. When considering the variation in concrete mass, no significant visible damage was detected at early exposure time. Damages with higher exposure time were a little more severe but it is related to the specimen voids and aggregate type. The detected damage by visual observation deals, if any, with the outer skin of the specimens and then cause only negligible changes in main mechanical properties related to the whole mass of the specimens.

5. Conclusions

In this study, a series of experiments have been performed to investigate the durability of the pervious concrete cast using recycled aggregates compared to the using of natural aggregates. Based on the experimental results, presented the following conclusions can be drawn:

1. Pervious concrete cast using dolomite is the best in compressive, tensile, flexure, and bond strengths, compared to that cast using crushed concrete and crushed red bricks as recycled coarse aggregate.
2. Using crushed concrete as a recycled aggregate is more efficient than using crushed red bricks for pervious concrete.
3. Recycled aggregate pervios concrete "RA-PC" can be effectively used as a special concrete type, especially when cast using crushed concrete with average strength loss in the range of 12-35% compared to those cast using dolomite. So, it is recommended for slabs with light to medium loads.
4. Steel meshes can be used as a reinforcement for pervious concrete slabs with comparable behavior to those reinforced with conventional rebars. Steel meshes achieve about 85-90% of the recorded values of those reinforced with rebars, especially in initial cracking load, failure load, and stiffness values.
5. Under chloride attack, the best values were recorded for pervious concrete cast using dolomite then that cast using crushed concrete as coarse aggregates. Using crushed concrete is better than using crushed red bricks.
6. Under sulfate attack, recycled crushed concrete can be used as coarse aggregate effectively compared to crushed red bricks.

Finally, it can be concluded that one can use pervious concrete cast using RA, especially which cast using crushed concrete as concrete for slabs in the same applications of the pervious concrete cast using natural aggregates. Steel meshes can be used instead of rebars as pervious concrete slabs reinforcement in case of medium loads with about 85-90% of the performance of those reinforced with rebars. It can be used on sides of parking places and fuel stations to collect the extra used water to re-use it even under sulfates and chlorides attacks. The use of pervious concrete cast using recycled crushed concrete may be considered as an alternative solution to the use of conventional pervious concrete in infrastructures.

6. Future Work

Further research should be aimed at filling the above-mentioned research gap on using different types of RCA to produce pervious concrete. Also, to study the effect of using different mesh types with different opening sizes compared to rebars to investigate the various responses (such as the initial cracking loads, ultimate loads, and flexural strength). Furthermore, research should be conducted to produce guidelines for how to processing recycled aggregates with sufficient quality. This research was done only in a laboratory and there is a need to establish its validity in the field.

7. Acknowledgment

The author avail this opportunity to express his deep sense of gratitude and wholehearted thanks to the laboratory of Construction Materials at the Faculty of Engineering, Sinai University to present and complete this work. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

8. References

[1] ACI.522R-06, "Pervious Concrete," American Concrete Institute, Detroit, USA, 2006.

[2] ACI.555R-01, "Removal and Reuse of Hardened Concrete," Farmington Hills, Michigan, 2001.

[3] NRMCA, "What, Why, and How? Pervious Concrete," National Ready Mixed Concrete Association (NRMCA), Silver Spring, Maryland, 2004.

[4] S. B. Park and M. Tia, "An Experimental Study on the Water-purification Properties of Porous Concrete," *Cement and Concrete Research*, vol. 34, pp. 177-184, 2004.

[5] S. Sri Ravindrarajah and Y. Aoki, "Environmentally Friendly Porous Concrete," in *2nd International Conference on Advances in Concrete and Construction,* Hyderabad, India, 2008.

[6] L. K. Crouch, J. Pitt and R. Hewitt, "Aggregate Effects on Pervious Portland Cement Concrete Static Modulus of Elasticity," *Journal of Materials in Civil Engineering ASCE,* vol. 19, no. 7, pp. 561-568, 2007.

[7] P. D. Tennis, M. L. Leming and D. J. Akers, "Pervious Concrete Pavements," Special publication from the Portland Cement Association and the National Ready Mixed Concrete Association, USA, 2004.

[8] V. R. Schaefer, K. Wang, M. T. Suleiman and J. T. Kevern, "Mix Design Development for Pervious Concrete in Cold Weather Climates," Center for Transportation Research and Education, Iowa State University, Ames, Iowa, 2006.

[9] D. S. Shah and J. Pitroda, "An Experimental Study on Durability and Water Absorption Properties of Pervious Concrete," *International Journal of Research in Engineering and Technology,* vol. 3, no. 3, pp. 439-444, 2014.

[10] C. C. a. A. Australia, "Use of Recycled Aggregates in Construction," 2008.

[11] M. Batayneh, I. Marie and I. Asi, "Use of Selected Waste Materials In Concrete Mixes," *Waste Management Journal,* vol. 27, no. 12, pp. 1870-1876, 2006.

[12] A. A. Bashandy and Z. A. Etman, "Recycling of Demolished Building Materials as Concrete Coarse Aggregates in Egypt," in *The 8th Alexandria International Conference on Structural and Geotechnical Engineering AICSGE-8*, Alexandria, Egypt, 2014.

[13] M. Etxeberria, E. Vazquez, A. Mari and M. Barra, "Influence of Amount of Recycled Coarse Aggregates

and Production Process on Properties of Recycled Aggregate Concrete," *Cement and Concrete Research,* vol. 37, no. 5, pp. 735-742, 2007.

[14] N. D. Oikonomou, "Recycled Concrete Aggregates," *Cement and Concrete Composites*, vol. 27, no. 2, pp. 315-318, 2005.

[15] A. A. Bashandy, F. M. Eid and E. H. Abdou, "Lightweight Concrete Cast Using Recycled Aggregates," *International Journal of Construction Engineering and Management,* vol. 6, no. 2, pp. 35-45, 2017.

[16] A. A. Bashandy, M. A. Safan and M. M. Ellyien, "Feasibility of using Recycled-Aggregates in Self-Curing Concrete," in *The 9th Alexandria International Conference on Structural and Geotechnical Engineering*, Alexandria, 2016.

[17] A. A. Bashandy, N. M. Soliman and M. Hamdy, "Recycled Aggregate Self-curing High-strength Concrete," *Civil Engineering Journal "CEJ",* vol. 3, no. 6, pp. 427-441, 2017.

[18] J. S. Ryu, "Improvement on Strength and Impermeability of Recycled Concrete Made from Crushed Concrete Coarse Aggregate," *Journal of Materials Science Letters,* vol. 21, pp. 1565-1567, 2002.

[19] A. A. Bashandy, N. M. Soliman and S. S. Khadash, "Enhancing the Durability of Self-Compacted Concrete Cast Using Recycled Aggregates," *International Journal of Scientific and Engineering Research (ISSN 2229-5518),* vol. 8, no. 6, pp. 1161-1189, 2017.

[20] R. S. Ravindrarajah and C. Tam, "Properties of Concrete Made with Crushed Concrete as Coarse Aggregate," *Magazine of Concrete Research,* vol. 37, no. 130, pp. 29-38, 1985.

[21] S. Deepika, K. Lalithanjali, M. Ponmalar, B. Vinushitha and T. Manju, "Influence of Recycled Aggregate based Pervious Concrete with Flyash," *International Journal of ChemTech Research,* vol. 7, no. 6, pp. 2648-2653, 2014-2015.

[22] P. Pal, S. Shukla and A. Ranjan, "Performance of Pervious Concrete with Recycled Concrete Aggregate," *The Indian Concrete Journal,* pp. 86-92, 2017.

[23] R. Rizvi, S. Tighe, V. Henderson and J. Norris, "Evaluating the Use of Recycled Concrete Aggregate in Pervious Concrete Pavement," *Journal of the Transportation Research Board,* vol. 2164, pp. 132-140, 2010.

[24] R. S. Ravindrarajah and C. T. Tam, "Methods of Improving the Quality of Recycled Aggregate Concrete, Demolition and Reuse of Concrete and Masonry: Reuse of Demolition Waste," Chapman and Hall, London, UK, 1988.

[25] B. M. Berry, M. J. Suozzo, J. A. Anderson and M. M. Dewoolkar, "Using Recycled Concrete in Pervious Concrete Pavements," in *TRB 2012 Annual Meeting*, 2012.

[26] E.S.S.4756-1/2009, "Portland Cement, Ordinary and Rapid Hardening," Ministry of Industry, Cairo, Egypt, 2009.

[27] E.S.S.1109/2008, "Aggregates for Concrete," Ministry of Industry, Cairo, Egypt, 2008.

[28] ASTM.C-33, "Aggregates," American Society for Testing and Materials ASTM International, Philadelphia, USA, 2003.

[29] E.C.P.203/2017, "Egyptian Code of Practice: Design and Construction for Reinforced Concrete Structures: 4th Ed.," Research Centre for Houses Building and Physical Planning, Cairo, Egypt, 2017.

[30] ASTM.C-494, "Chemical Admixtures for Concrete," American Society for Testing and Materials ASTM International, Philadelphia, USA, 2015.

[31] J. Yang and G. Jiang, "Experimental Study on Properties of Pervious Concrete Pavement Materials," *Cement and Concrete Research,* vol. 33, pp. 381-386, 2003.

[32] ACI-363-07, "Guide to Quality Control and Testing of High-Strength Concrete," American Concrete Institute (ACI Committee), Detroit, USA, 2007.

[33] S. Iffat, K. Maina and M. A. Noor, "Member Ductility Experiment with High Strength Steel and Concrete," in *4th Annual Paper Meet and 1st Civil Engineering Congress*, Dhaka, Bangladesh, 2011.

[34] M. Rakhshanimehr, M. R. Esfahani, B. A. Mohammadzadeh, M. R. Kianoush and S. R. Mousavi, "Flexural ductility of reinforced concrete beams with lap-spliced bars," *Canadian Journal Civil Engineering,* vol. 41, p. 594–604, 2014.

[35] IS417-PCA, "Concrete Information: Ettringite Formation and the Performance of Concrete", Portland Cement Association, Illinois, USA, 2001.