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Properties of pervious concrete made from graded and single size crushed coarse aggregate

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ABSTRACT

The current search is aimed to investigate the properties of the pervious concrete cast from graded and single size coarse aggregate. A total of 18 mixes, nine mixes for each type, were designed, cast and sampled. The properties concerning compressive strength, flexural strength, density and porosity were discussed. The influence of aggregate type, water-cement ratio (w/c) and coarse aggregate to cement content ratio (CA/C) on the characteristics of pervious concrete was tested. Three w/c (0.3, 0.35 and 0.4) were used in each type of pervious concrete. For each w/c, three CA/C (3.5, 4.0 and 4.5) were employed. Besides, relationships between compressive and flexural strength, compressive strength and density, compressive strength and porosity and between density and porosity were developed and discussed. The experimental results prove that both types of pervious concrete have the usual tendency regarding the properties. At the same time, the tests of compressive strength, flexural strength and density reflect the reduced mechanical characteristics of pervious concrete in comparison to normal concrete. The density of the tested specimens decreased with increasing porosity up to 22% and 32% for graded and single size aggregate pervious concrete respectively, and then it continued approximately stable.

Keywords: Pervious concrete, single size aggregate, graded aggregate, CA/C, density and Porosity

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1. Introduction

Pervious concrete which is also recognized as “No-fine Concrete” or “Porous Concrete” is material made with barely graded coarse aggregates, cementations materials, water and admixture and maybe with fibres. For more than a half-century, this material is used in different fields. Recently, the Environmental Protection Agency (EPA) laws encourage owners and designers to re-study fields of this concrete [1]. A No-fine concrete mix essentially made from normal concrete with high porosity between 15% and 30%. So, the resulting concrete has an open and interrelated pore structure with high permeability [2].

The workability of Porous concrete is very low [1][3]. Tennis et. al. [4] advised that the capability of the pervious concrete capability to form into a ball with one’s hands will decide the determination of the w/c. The sensitive workability of pervious concrete imposed firm control on the water quantity. In pervious concrete, the w/c from 0.30 to 0.40. CA/C is 4:1 to 4.5:1 by mass, according to Ghafoori, N., and Dutta, S. [5]. Any chemical additives can be used to modify the concrete properties.

The approximate pervious concrete density is 1900 kg/m^3 with a mean compressive strength of 35.5 MPa [1][3][6]. The compressive strength decreasing with increasing aggregate content [3]. Matasu et. al. [7] report that earlier drying shrinkage will occur in pervious concrete and it remains lesser in contrast to conventional concrete.

Neithalath et. al. stated that although a relationship is predictable, there is no specific connection between porosity and permeability [8]. On the other hand, despite the absence of a typically recommended value, the average permeability of pervious concrete ranged from 5mm/s to 20mm/s. Neithalath et. al. evolved the falling head method that is nominated by ACI using Darcy Law [3].
In contrast to normal concrete, pervious concrete has less compressive strength due to the high porosity. The range of compressive strengths is 3.5 MPa to 28 MPa, with a typical value of 17 MPa [4].
In pavements, the structural behaviour is very sensitive to flexural strength and dynamic modulus of elasticity. The flexural strength of pervious concrete generally ranges between 1.0 MPa and 3.8 MPa [4]. Several factors particularly the compaction degree and voids ratio affect the flexural strength of pervious concrete [9] [10].

2. The objective of research significance

The limited studies relating the pervious concrete lead to the absence of dependent methods to understand and compute its essential properties. The major aim of the current work was to, **1.** estimate the influence of coarse aggregate grading, the ratio of coarse aggregate to cement content (CA/C), and the w/c on the characteristics of pervious concrete. **2.** study compressive and flexural strength, compressive strength and density, compressive strength and porosity, and density and porosity relationships.

3. Experimental program

The pervious concrete is an open pore structure with intrinsic characteristics that differ from conventional concrete. This search aimed to explore the characteristics of pervious concrete made from conventional materials. Eighteen mixes were designed to satisfy previous concrete requirements. Nine mixes for pervious concrete prepared with graded crushed coarse aggregate (GA) and nine mixes for pervious concrete cast with single size crushed coarse aggregate (SSA).

3.1. Samples details

For this work, eighteen mixes were designed to study the pervious concrete characteristics. Nine mixes for each type of aggregate. Within each mix six 150×150 ×150 mm cubes and six 500×150×150 mm prisms were prepared for compressive strength, flexural strength, density and porosity tests on hardened concrete at the 7 and 28 days age. Fig. 1 shows fresh pervious concrete, cubes and prisms specimens.

3.2. Coarse aggregate

Complied with Iraqi standard No. 45-1984 requirements [11], two types of crushed coarse aggregate from the Al-Zubair region, Basrah, Iraq were used in this study: graded crushed coarse aggregate (GA) (20-5 mm) (Fig.2a) and single-sized crushed coarse aggregate (SSA) (20 mm) (Fig.2b). The physical and chemical characteristics of the used aggregate are presented in Table 1. Moreover, Fig.3 depicts the grading curves of these two types of aggregate.

3.3. Preparation of mixed components

Crushed graded or single size aggregate, cement (coincide with the Iraqi standard specification. No. 5-1984) [12], water and a high-efficiency polycarboxyly based superplasticizer (FlowCrete PC-200) (ASTM C494) [13] were mixed to manufacture the required pervious concrete. The details of the compositions of the designed pervious concrete mixes are presented in Table 2. For each type of pervious concrete, the w/c was used at 0.3, 0.35 and 0.4. Within each w/c, CA/C was employed at 3.5, 4.0 and 4.5. So, nine mixes were introduced for each pervious concrete type.

3.4. Test methods

Table 3 presents the laboratory results of the characteristics of both pervious concrete types. The compressive strength was tested based on BSEN 12390-3 [14]. For each mix, six typical 150 mm cubes were cast, cured in water till test, capped from both sides, and tested. The listed compressive strength is the average of the three results.

The flexural strength test coincides with ASTM C78/C78-18 [15] was accomplished. For the present work, three standard 500 ×150mm × 150mm prisms were used. After 28 days of curing in 25°C water, all samples were tested. The modulus of rupture was calculated to describe the flexural strength of the previous concrete depending on the initiation of specimens fracture in the tension surface.

The density of the mix based on ASTM C1754/C1754M standard [16] was calculated for hardened pervious concrete as, $\boldsymbol{\rho_c = \frac{K \times A}{D^2 \times L}}$, where: ρ_c = Concrete Density (kg/m^3), A = dry mass of the specimen (g), D = average diameter of the specimen (mm), L = average length of the specimen (mm), and K = 1 273 240 in SI units.

Dependent on ASTM C1754/C1754M standard [16], total porosity was calculated in terms of void content as, $\boldsymbol{e = \left[1 - \frac{K(A-B)}{\rho_w \times D^2 \times L}\right] \times 100}$, where: e = void content, B = submerged mass of the specimen (g), and ρ_w = density of water at the temperature of the water bath, 1000 kg/m³.

Figure 1. Casting and sampling of pervious concrete

Table 1. Physical and chemical characteristics of GA and SSA.

Physical characteristics	GA	SSA	Chemical composition	GA and SSA
S.S.D Bulk density (gr/cm^3)	2.69	2.63	SO_3 (%)	0.05
OD Bulk density (gr/cm^3)	2.65	2.60	Cl (%)	0.014
Apparent density (gr/cm^3)	2.70	2.65	Sio2 (%)	88.0
Loose unit weight (kg/m^3)	1580	1420	Silicon Oxide (%)	2.1
Tamped unit weight (kg/m^3)	1675	1571		
Water absorption (%)	1.1	0.93		

(a) (b)

Figure 2. Graded and single size coarse aggregate, (a) GA, (b) SSA

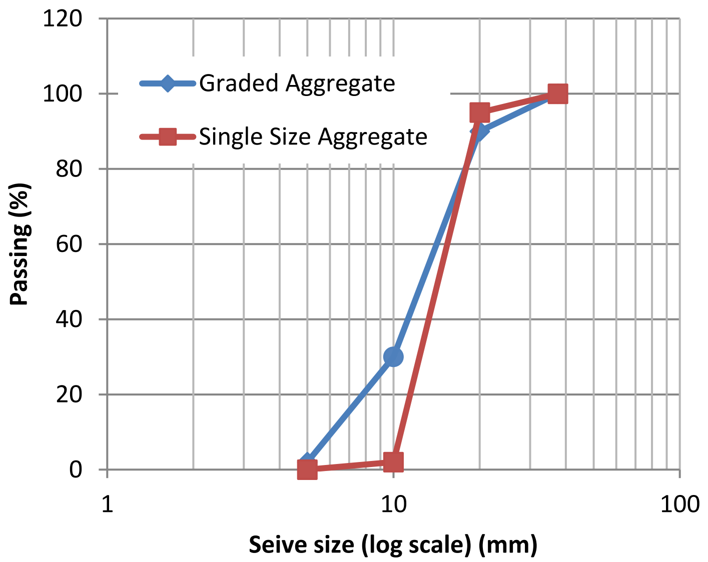


Figure 3. Graded and single size coarse aggregate grading curves

Table 2. Pervious concrete mixtures proportions

Mix	Type of grading of CA	CA/C*	w/c	Cement kg/m3	Gravel kg/m3	Water kg/m3	SP/C** %
MG1	Graded	3.5	0.3	417	1458	125	0.60
MG2		4.0		377	1509	113	0.65
MG3		4.5		344	1551	103	0.68
MG4		3.5	0.35	412	1442	144	0.55
MG5		4.0		373	1492	130	0.60
MG6		4.5		341	1534	119	0.63

Mix	Type of grading of CA	CA/C*	w/c	Cement kg/m3	Gravel kg/m3	Water kg/m3	SP/C** %
MG7		3.5		408	1428	163	0.50
MG8		4.0	0.4	370	1480	148	0.56
MG9		4.5		340	1530	136	0.59
MS1		3.5		417	1458	125	0.59
MS2		4.0	0.3	377	1509	113	0.56
MS3		4.5		344	1551	103	0.54
MS4		3.5		412	1442	144	0.55
MS5	Single Size	4.0	0.35	373	1492	130	0.51
MS6		4.5		341	1534	119	0.48
MS7		3.5		408	1428	163	0.51
MS8		4.0	0.4	370	1480	148	0.47
MS9		4.5		340	1530	136	0.42

* CA/C coarse aggregate to cement by weight
** SP/C superplasticizer to cement by weight

Table 3. The properties of all pervious concrete mixes

Mix	f_c (MPa)		f_r (MPa)		Density (kg/m^3)		Porosity (%)	
	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
MG1	4.57	14.06	0.526	1.316	1901	1982	20	13
MG2	3.89	11.27	0.468	1.21	1892	1971	22	16
MG3	3.56	10.15	0.423	1.112	1881	1966	23	17
MG4	3.34	9.81	0.4	1.112	1861	1932	25	19
MG5	3.33	9.63	0.373	1.013	1801	1881	26	21
MG6	3.27	8.23	0.354	0.934	1799	1878	27	22
MG7	3.23	8.19	0.322	0.922	1778	1858	30	25
MG8	3.06	7.83	0.304	0.922	1774	1852	31	26
MG9	3.04	7.60	0.295	0.895	1759	1850	33	28
MS1	3.01	7.34	0.282	0.828	1723	1802	34	28
MS2	2.93	6.92	0.265	0.827	1698	1774	35	28
MS3	2.77	6.65	0.257	0.763	1688	1764	36	29
MS4	2.74	6.37	0.246	0.732	1680	1758	36	30
MS5	2.64	6.30	0.237	0.684	1674	1752	38	31
MS6	2.49	6.20	0.22	0.678	1654	1733	38	32
MS7	2.21	5.22	0.204	0.618	1605	1681	39	33
MS8	2.21	5.12	0.185	0.579	1605	1667	40	34
MS9	2.05	4.75	0.147	0.473	1534	1600	40	36

4. Test Results and discussion

4.1. Compressive strength

The failure nature in pervious concrete occurs between the aggregate particles through the cement paste due to the bonding fracture failure, therefore, the efficiency of the pervious concrete is highly affected by the cement paste strength [17].

Tables 4 and 5 introduce the reduction in compressive strength due to the type of aggregate grading and CA/C respectively. Figure 4 depicts the relationship of w/c verse the compressive strength of both pervious concrete types which approaches linear relationship as the CA/C increases for graded mixes but it has an approximately linear relationship regardless of CA/C for single graded mixes.

From Table 3 and Fig. 4, it can be noticed that the compressive strength of the specimens manufactured with graded aggregate is greater than that of the specimens cast with single size aggregate due to the reduced void content in previous concrete made with well-graded aggregate and hence increase its density which leads to enhance its compressive strength. For this reason, the wide graded aggregate is to be avoided in pervious concrete [18].

Table 5 and Fig. 5 show that all concrete mixes have a reduction (of approximately linear shape) in compressive strength with increasing CA/C regardless of the w/c. The reduction in compressive strength for all mixes increases with the age of the test (as mentioned in Tables 4 & 5) from 7 to 28 days. Due to the age effect, the least reduction of 4.8% and 6.8% occurred at the 0.4 w/c for 3.5 and 4.0 CA/C, while it was 0.8% for 4.5 CA/C at 0.35 w/c as can be concluded from Table 4. At the same time, the age of the test had less influence on pervious concrete with single size aggregate as can be drawn from Table 5, while increasing in CA/C accompanied with w/c of 0.35 gives least reduction in 7 and 28 days compressive strength for both pervious concrete types.

Table 4. Ratio of compressive strength reduction due to the type of aggregate grading

CA/C	w/c	Specimens	Reduction in Compressive Strength (%)	
			7 days	28 days
3.5	0.3	MG1, MS1	34.1	47.8
	0.35	MG4, MS4	18.0	35.1
	0.4	MG7, MS7	31.6	36.3
4.0	0.3	MG2, MS2	24.7	38.6
	0.35	MG5, MS5	20.7	34.6
	0.4	MG8, MS8	27.8	34.6
4.5	0.3	MG3, MS3	22.2	34.5
	0.35	MG6, MS6	23.9	24.7
	0.4	MG9, MS9	32.6	37.5

Table 5. Ratio of compressive strength reduction due to CA/C.

Aggregate Type	w/c	Specimens	Reduction in Compressive	
			7 days	28 days
Graded	0.3	MG1, MG2	14.9	19.8
		MG1, MG3	22.1	27.8
	0.35	MG4, MG5	0.3	1.8
		MG4, MG6	2.1	16.1
	0.4	MG7, MG8	5.3	4.4
		MG7, MG9	5.9	7.2
Single Size	0.3	MS1, MS2	2.7	5.7
		MS1, MS3	8.0	9.4
	0.35	MS4, MS5	3.6	1.1
		MS4, MS6	9.1	2.7
	0.4	MS7, MS8	0.0	1.9
		MS7, MS9	7.2	9.0

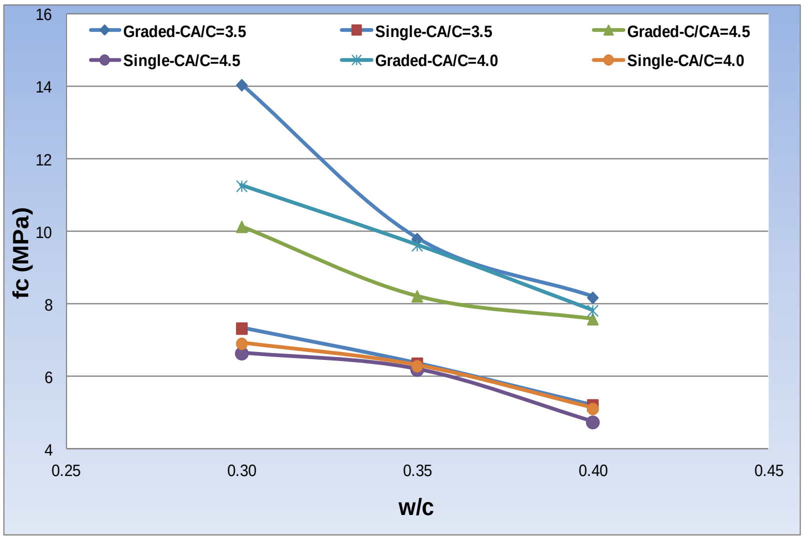


Figure 4. w/c - compressive strength relationship of pervious concrete (Effect of aggregate grading type)

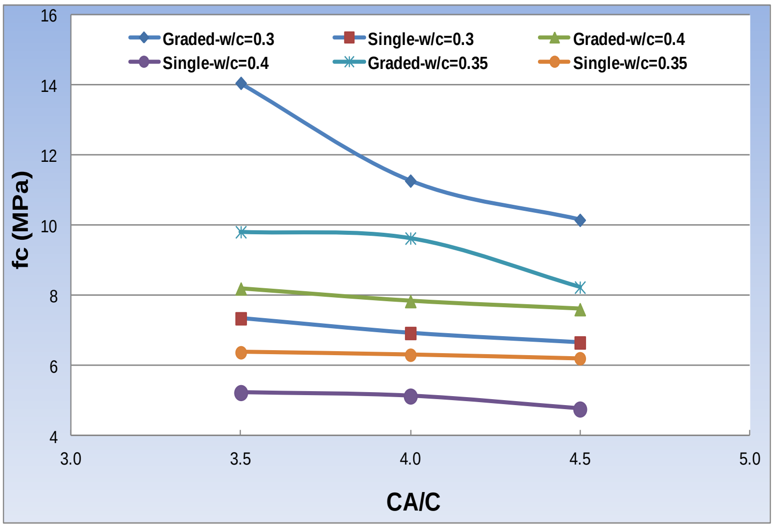


Figure 5. CA/C - compressive strength relationship of pervious concrete

From Tables 4 & 5 and Figs. 4 & 5, it is clear that the w/c affects the compressive strength for pervious concrete made from both aggregate types. The increasing w/c inversely affects the cement paste properties and hence reduced the bond at the cement paste interface between aggregate particles. Therefore, the compressive strength decreased as the w/c increased despite the aggregate type and CA/C.

4.2. Flexural strength

The results demonstrate that the flexural strength of pervious concrete made with graded aggregate is greater than that of the pervious concrete cast with single size aggregate. This is also because of reduced voids content of the graded pervious concrete. Table 6 reported the ratio of flexural strength reduction due to the type of aggregate grading. Fig. 6 illustrates the influence of the w/c on the flexural strength of previous concrete.

For both types of pervious concrete, increasing the CA/C decreased the flexural strength. Table 7 contains the ratios of reduction in flexural strength due to an increase in the CA/C. Fig. 7 graphs the effect of the CA/C on the flexural strength of pervious concrete. The effect of the age of the test can be found in Tables 6 and 7. It can be noted that the decrease in flexural strength reduced with the development of the age of specimens despite the type of aggregate, CA/C and w/c.

Table 6. Ratio of flexural strength reduction due to the type of aggregate grading

CA/A	w/c	Specimens	Reduction in Flexural Strength (%) 7 days	28 days
3.5	0.3	MG1, MS1	46.4	37.1
	0.35	MG4, MS4	38.5	34.2
	0.4	MG7, MS7	36.6	33.0
4.0	0.3	MG2, MS2	43.4	31.7
	0.35	MG5, MS5	36.5	32.5
	0.4	MG8, MS8	39.1	37.2
4.5	0.3	MG3, MS3	39.2	31.4
	0.35	MG6, MS6	37.9	27.4
	0.4	MG9, MS9	50.2	47.2

Table 7. Ratio of flexural strength reduction due to CA/C

Aggregate Type	w/c	Specimens	Reduction in Flexural Strength (%) 7 days	28 days
Graded	0.3	MG1. MG2	11.0	19.8
		MG1, MG3	9.6	27.8
	0.35	MG4. MG5	5.4	1.8
		MG4, MG6	6.8	16.1
	0.4	MG7. MG8	5.1	4.4
		MG7, MG9	9.0	7.2
Single Size	0.3	MS1. MS2	5.6	5.7
		MS1, MS3	3.0	9.4
	0.35	MS4. MS5	4.4	1.1
		MS4, MS6	6.0	2.7
	0.4	MS7. MS8	3.0	1.9
		MS7, MS9	4.3	9.0

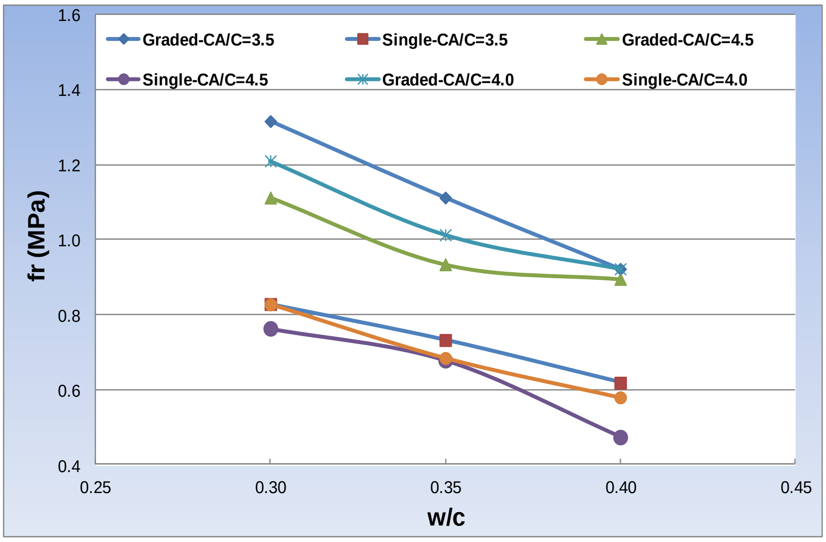


Figure 6. w/c - flexural strength relationship of pervious concrete (Effect of aggregate grading type)

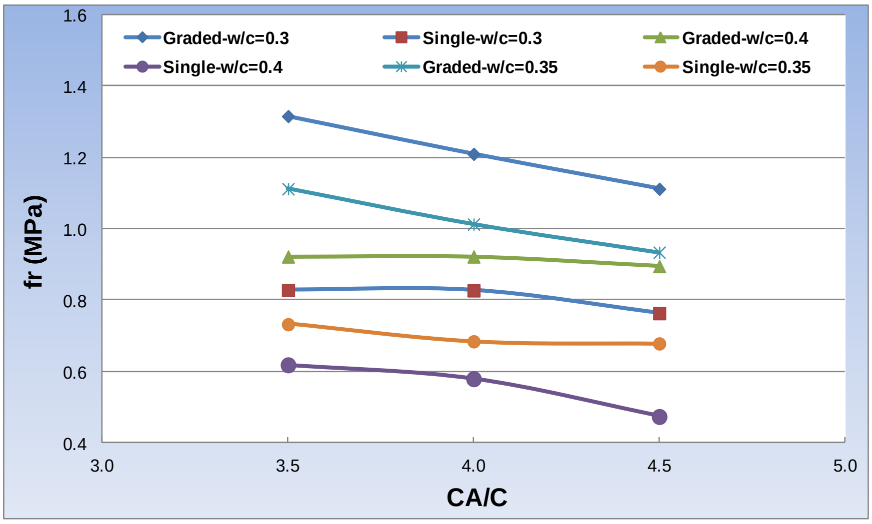


Figure 7. CA/C - flexural strength relationship of pervious concrete

The w/c inversely affects the pervious concrete flexural strength for both aggregate types. Referring to Tables 6 & 7 and Figs. 6 & 7, it can be concluded that when the type of aggregate is governed, the w/c of 0.4 gives the least reduction in 7 and 28 days flexural strength for pervious concrete with 3.5 CA/C, while for CA/A of 4.0 and 4.5, the least reduction in 7 and 28 days flexural strength of pervious concrete can be guaranteed with w/c of 0.35. Alternatively, when the CA/C governs, the least reduction in 7 and 28 days flexural strength can be achieved with 0.4 and 0.3 w/c for graded and single size aggregate respectively.

4.3. Density

The limited studies relating to the previous concrete lead to the absence of a dependent method to compute unit weight. Between many procedures, Density is the most excellent way to manage the pervious concrete features. [20].

Table 8 and Fig. 8 show the ratio of reduction in density due to the type of aggregate grading. It can be noticed that for any ratio of CA/A, the least reduction in density due to the type of aggregate can be attained with a w/c of 0.35 regardless of the aggregate grading. Furthermore, the density of pervious concrete reduced with increasing CA/C, regardless of aggregate grading type and w/c. Table 9 and Fig. 9 explain the influence of the CA/C on the pervious concrete density. For previous concrete cast with GA, less reduction in density can be achieved with 0.4 w/c regardless of CA/C, while for pervious concrete made with SSA, a w/c of 0.35 gives the least reduction in density. At the same time, the density decreased with increasing w/c despite the aggregate grading type and CA/C. This is related to the increased void content in the previous concrete structure.

Table 8. Ratio of reduction in density due to the type of aggregate grading

CA/A	w/c	Specimens	Reduction in Density (%)	
			7 days	28 days
3.5	0.3	MG1. MS1	9.4	9.1
	0.35	MG4. MS4	9.7	9.0
	0.4	MG7, MS7	9.7	9.5
4.0	0.3	MG2. MS2	10.3	10.0
	0.35	MG5. MS5	7.1	6.9
	0.4	MG8, MS8	9.5	10.0
4.5	0.3	MG3. MS3	10.3	10.3
	0.35	MG6. MS6	8.1	7.7
	0.4	MG9, MS9	12.8	13.5

Table 9. Ratio of reduction in density due to CA/C.

Aggregate Type	w/c	Specimens	Reduction in Density (%) 7 days	Reduction in Density (%) 28 days
Graded	0.3	MG1. MG2	0.5	0.6
		MG1, MG3	0.6	0.3
	0.35	MG4. MG5	1.1	1.7
		MG4, MG6	3.2	2.6
	0.4	MG7. MG8	0.1	0.2
		MG7, MG9	1.2	1.1
Single Size	0.3	MS1. MS2	0.2	0.3
		MS1, MS3	0.8	0.1
	0.35	MS4. MS5	2.0	2.6
		MS4, MS6	1.5	1.6
	0.4	MS7. MS8	0.6	0.6
		MS7, MS9	0.5	0.3

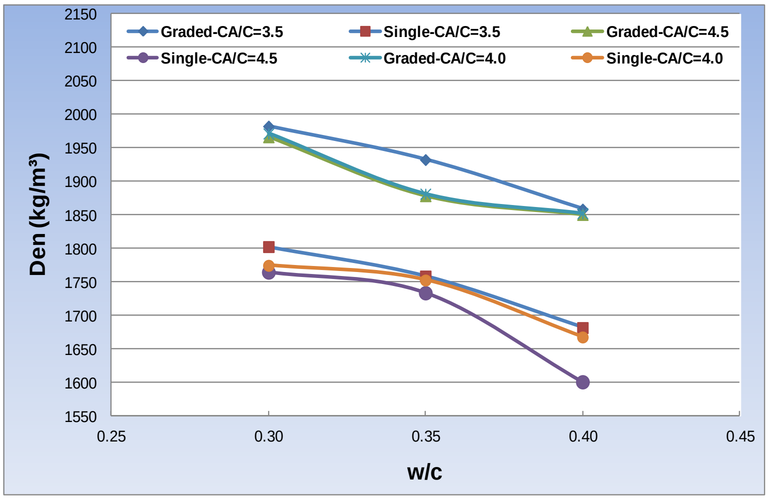


Figure 8. w/c - density relationship of pervious concrete (Effect of aggregate grading type)

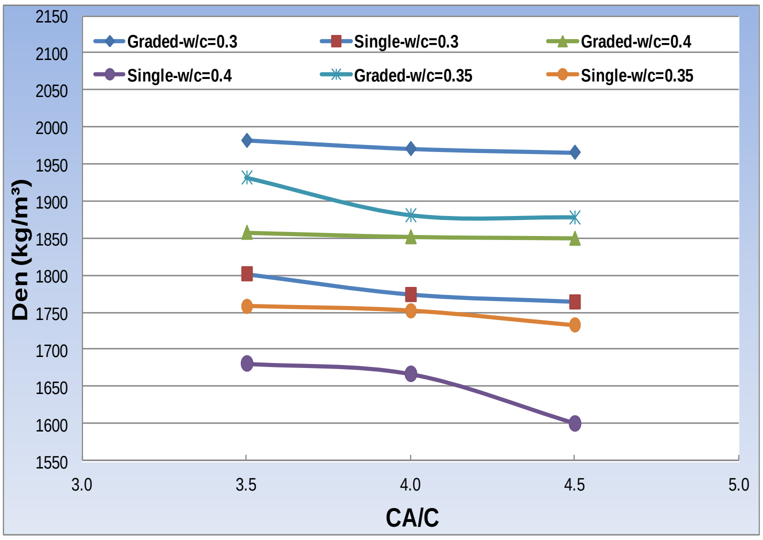


Figure 9. CA/C - density relationship of pervious concrete

4.4. Porosity

Porosity is a very significant parameter in the present work. Porosity is the measure of the void content. Table 3 shows that the porosity of single size aggregate pervious concrete is larger than that of the pervious concrete cast with graded aggregate. This is because the structure of single size aggregate pervious concrete contains more voids compared with that made from the graded aggregate. Table 10 and Fig.10 explain the effect of the type of aggregate grading on the porosity of pervious concrete.

Porosity increased with increasing CA/C despite the type of aggregate grading. Table 11 and Fig. 11 demonstrate the effect of the CA/C on the Porosity of pervious concrete. Also, regardless of aggregate grading type, porosity increase with increasing w/c in a way that approaches the linear relationship with increasing CA/C. Similar behaviour can be noticed between porosity and CA/C regardless of aggregate grading type and w/c. This is because the increasing w/c creates more voids in the structure of pervious concrete.

It can be drawn from Tables 10 & 11, that regardless of the CA/C, the increase in porosity increase with the development of the age of the test. At the same time, for 7 and 28 days porosity test, this increase decrease with increasing CA/C regardless of w/c. Furthermore, for graded aggregate pervious concrete, the porosity increasing ratio increased with the development of the age of test as can be concluded from Table 11, and this increasing ratio decreased with increasing w/c. While an inverse relationship can be noticed for single size aggregate pervious concrete especially for 0.3 and 0.35 w/c. This result may be related to the formation of more voids in the concrete mixture which inversely affect the development of the hydration process.

Table 10. Aggregate grading type effect on the porosity of pervious concrete

CA/A	w/c	Specimens	Increasing in Porosity (%)	
			7 days	28 days
3.5	0.3	MG1. MS1	70	115
	0.35	MG4. MS4	44	58
	0.4	MG7, MS7	30	32
4.0	0.3	MG2. MS2	59	75
	0.35	MG5. MS5	46	48
	0.4	MG8, MS8	29	31
4.5	0.3	MG3. MS3	57	71
	0.35	MG6. MS6	41	45
	0.4	MG9, MS9	21	29

Table 11. Effect of CA/C on porosity of pervious concrete

Aggregate Type	w/c	Specimens	Increasing in Porosity (%)	
			7 days	28 days
Graded	0.3	MG2. MG1	10.0	23.1
		MG3, MG1	4.5	6.3
	0.35	MG5. MG4	8.7	11.8
		MG6, MG4	4.0	10.5
	0.4	MG8. MG7	3.8	4.8
		MG9, MG7	11.1	13.6
Single Size	0.3	MS1. MS2	3.3	4.0
		MS1, MS3	6.5	7.7
	0.35	MS4. MS5	3.0	0.0
		MS4, MS6	2.9	0.0
	0.4	MS7. MS8	2.9	3.6
		MS7, MS9	0.0	3.4

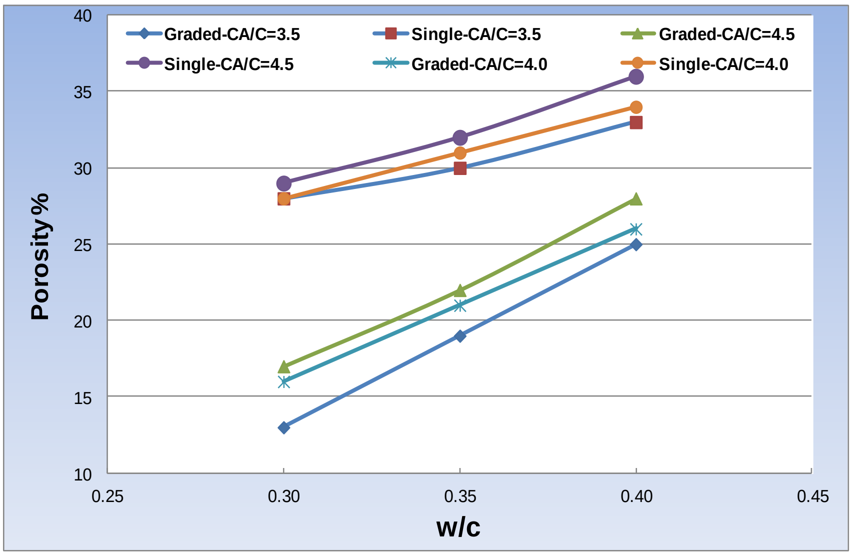


Figure 10. w/c - porosity relationship of pervious concrete (Effect of aggregate grading type)

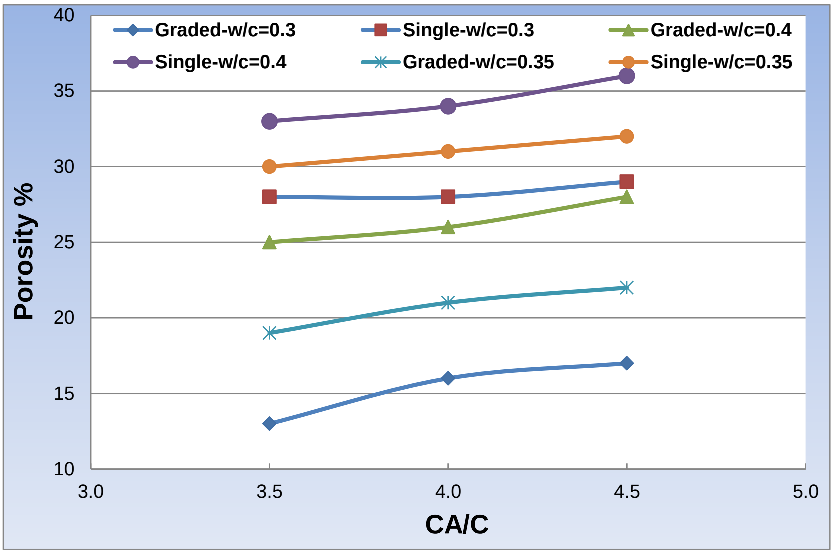


Figure 11. CA/C - porosity relationship of pervious concrete

4.5. Compressive strength and flexural strength relationship

Material has a relationship between its compressive and flexural strength. The importance of this relationship appears in the flexural strength evaluation, particularly in the case when merely cylinders are presented for compression testing [20]. The usual tendency of flexural strength growing as compressive strength increased was recognized in the results.

Fig.12 depicts the compressive and flexural strengths relationships of the samples manufactured from graded and single size aggregates. These relationships were revealed from the regression analysis of the experimental results. It can be seen that these relationships were logarithmic equations.

In Fig.12a, a graph was constructed for single and graded previous concrete individually, with determination factors of 0.9404 and 0.9643 respectively. Since the behaviour of the single and graded pervious concrete was quite identical, a general and stronger relationship was developed for both types as shown in Fig.12b and Eq. (1). This relationship was obtained with R^2= 0.9817 and it was:

fr = 0.7691 $ln(fc)$ - 0.68599 (1)

This relationship explains the reduced mechanical properties of previous concrete when compared with ordinary concrete in which the flexural strength proportional to the square root of compressive strength ($f_r = 0.62\lambda\sqrt{f_c'}$) [ACI318-19] [21]. The value of f_r obtained by Eq. (1) was always less than that of the conventional concrete for the same value of f'_c.

4.6. Relation between compressive strength and density

Fig. 13 depicts the relation between 28-day compressive strength and density. The laboratory compressive strength ranged between 7.60 to 14.06 MPa for specimens cast with graded aggregate while it ranged between 4.75 to 7.34 MPa for single size aggregate specimens. The CA/C of 3.5 and w/c of 0.3 give the largest 28 days compressive strength in both graded and single size pervious concrete (i.e. MG1 and MS1 mixes) and they were 14.06 MPa and 7.34 MPa respectively. This can be related to the fact that these specimens (MG1 and MS1) had the largest 28 days densities of 1982 kg/m^3 and 1802 kg/m^3 respectively. Figure 13 shows the usual trend of compressive strength increased with increasing density. Also, since the behaviour of single and graded pervious concrete was identical, a single and strong relationship was obtained by the regression analysis with a determination factor (R^2= 0.9436) as shown in Fig.13 and Eq. (2) and this relationship was:

D = 371.93 $ln(f'_c)$ + 1064.4 (2)

4.7. Relation between compressive strength and porosity

Fig. 14 shows the relationships between compressive strength and porosity for pervious concrete made with graded and single size aggregate. This relationship was developed using the nature of the scatter graph (regression analysis). As expected, it can be noted that for both types of previous concrete the compressive strength decreased with increasing void content, accordingly, the oneness in behaviour was represented by a single curve for both types of previous concrete as shown in Fig. 14.

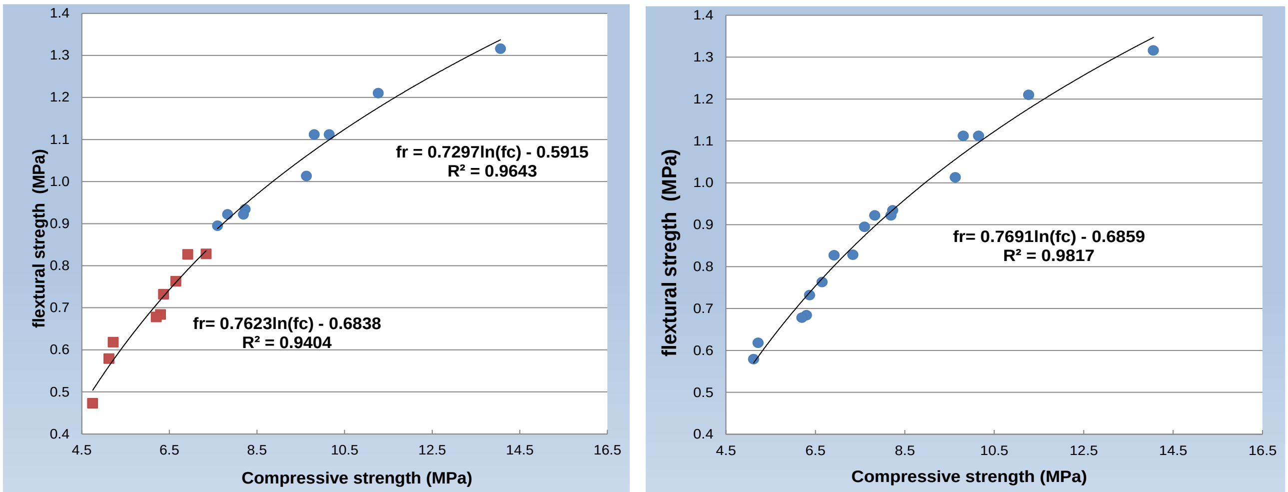
This behaviour can be related to the fact that the density of the specimens decreased with increasing porosity which inversely affects their compressive strength. On the other hand, the high ratio of air voids in previous concrete reduced the support of the surrounding particle which results in a reduction in compressive strength compared to normal concrete [19] [20]. The following relationship was obtained with R^2= 0.9645 as shown in figure 14 and Eq. (3):

P = -22.72 $ln(fc)$ + 71.967 (3)

4.8. Relation between porosity and density

The relationship between void content and density is represented in Fig. 15. In graded and single size aggregate pervious concrete, the density decreased with increasing porosity up to 22% and 32% respectively, then it continued approximately stable. Furthermore, to simulate this resemblance in the behaviour of both previous concrete types, a single relationship with a determination factor R^2 of 0.9481 was developed using a regression analysis for the experimental results as shown in Fig.15 and Eq. (4), and it was:

$D = - 0.1902P^2 - 4.8405P + 2086.5$ (4)



(a) (b)

Figure 12. Compressive strength and flexure strength relationship of previous concrete: (a) Two relationships, (b) one relationship

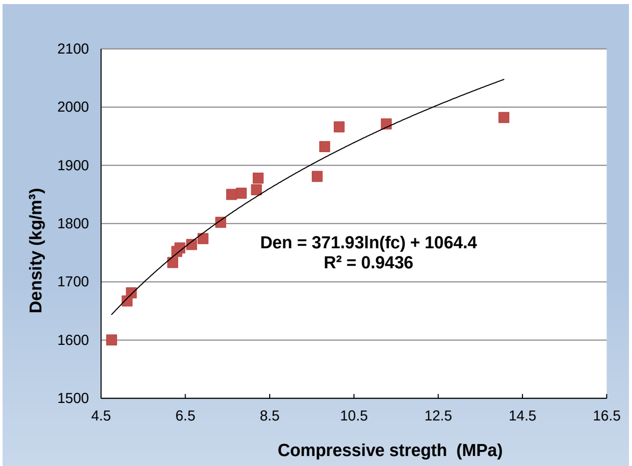


Figure 13. Compressive strength and density relationship of previous concrete

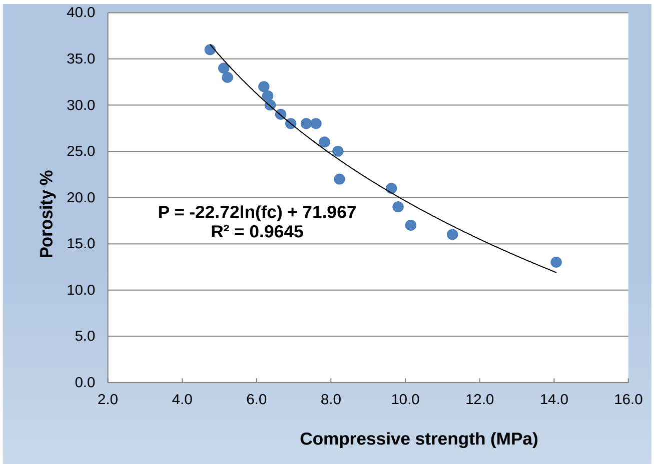


Figure 14: Compressive strength and porosity relationship of previous concrete

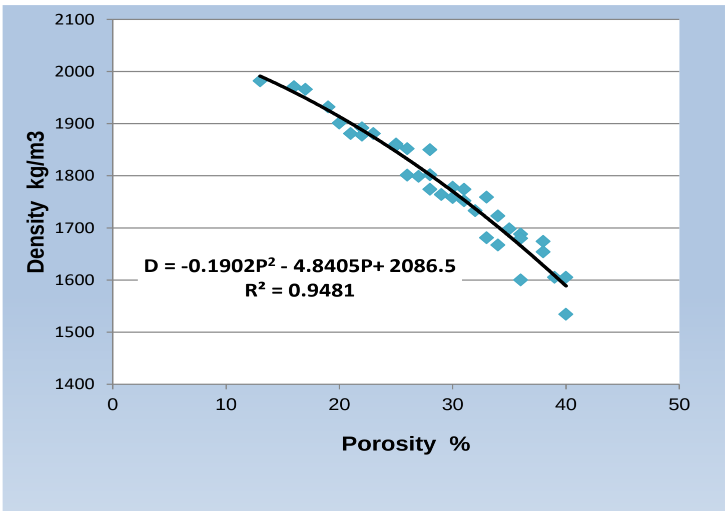


Figure 15. Density and porosity relationship of previous concrete.

5. Conclusions

Depend on the results of the present work, the following conclusions can be drawn:

- The properties of pervious concrete show the usual tendencies in behaviour and relationships.
- The 7 and 28 days compressive strength, flexural strength and density of pervious concrete made with graded aggregate is greater than those of single size aggregate pervious concrete despite CA/C and w/c ratios.
- The porosity of single size aggregate pervious concrete is more than that of graded aggregate pervious concrete regardless of the age of test, CA/C and w/c.
- Despite the type of aggregate grading, compressive strength, flexural strength and density decreased with increasing CA/C and w/c ratios. The porosity showed a reverse tendency with the same parameters.
- Relative to compressive strength, flexural strength, density and porosity, both types of previous concrete showed identical behaviour.
- The flexural and compressive strength relationship for both types of pervious concrete is $fr = 0.7691 ln(fc) - 0.68599$ with $R^2=0.9817$ obtained by regression analysis, reflects the reduced mechanical properties of previous concrete in contrast to normal concrete.
- A logarithm relationship $D= 371.93\ ln(fc) + 1064.4$ with $R^2=0.9436$ represents the compressive strength and density relationship for the single size and graded aggregate pervious concrete.
- The void ratio in pervious concrete inversely affect the compressive strength and this effect was represented by $P= -22.72\ ln(fc)+71.967$ with $R^2= 0.9645$.
- For both types of pervious concrete, the density decreased with increasing porosity up to 22% and 32% for the single size and graded pervious concrete respectively, then it remained approximately constant. The present study showed that the relation $D = -0.1902P^2 - 4.8405P+ 2086.5$ with $R^2= 0.9481$ between density and porosity.

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