Periodicals of Engineering and Natural Sciences ISSN 2303-4521
Vol. 9, No. 1, February 2021, pp.147-155

Engineering properties of porous concrete made of sustainable aggregate

Ahmed A. Hassan [1], Abdulkhaliq A. Jaafer [2], Haider H. Haider[2], Hussain K. Hashim[3], and Karrar H. Shwaikh[3]
[1] Southern Technical University, College of Technical Engineering, Maysan, Iraq
[2] University of Misan, College of Engineering, Civil Engineering Department, Maysan, Iraq
[3] Civil Engineer, Amarah, Maysan, Iraq

ABSTRACT

The effect of using different types of aggregate on engineering properties of previous concrete is experimentally evaluated in this study. For this purpose, a total of four concrete mixes are cast and tested. The main parameters studied in this study are the aggregate type (natural and recycled) and aggregate size. The recycled aggregate was provided from damaged pavement roads at Amarah city. The flexural and compressive strength, infiltration, and permeability of pervious concrete are recorded throughout the study. The results of study revealed that the mechanical and physical properties of previous concrete made of recycled aggregate confirms with the international specifications. Furthermore, the conclusions appear the ability of using recycled aggregate from damaged road pavements as aggregate for producing the pervious concrete have an acceptable engineering properties. The utilizing of recycled aggregate contributes to reduce the pollution and represent as a kind of sustainability of this type of concrete materials.

Keywords: recycled aggregate, pervious concrete, infiltration, permeability, sustainable

Corresponding Author:

Ahmed A. Hassan
Southern Technical University
College of Technical Engineering, Maysan -Iraq
ahmed.ajeel@stu.edu.iq

1. Introduction

In some applications, it is required using concrete paving with high porosity. This type of concrete called pervious concrete. Sometimes, it also named no fines concrete, permeable concrete, or porous concrete. It is a concrete with special properties characterized by high porosity which permit water passing directly through during precipitation and other sources to reduce the runoff at the site and providing a recharge for groundwater [1]. This type of concrete made of the same traditional concrete ingredients with so no to little quantity of fine aggregates. Therefore, the cement paste coats the coarse aggregate and the water pass through concrete slab freely. The applications of this type of concrete are in residential streets, parking areas, pedestrian walkways, arena, greenhouses, driveway, sidewalks, parking lots, low water crossings, artificial reefs, slope stabilization, noise barriers, tennis court, swimming pool decks, and zoo areas. The using of previous concrete in these applications represent an important for sustainable construction. Also, it is considered as one of development techniques has low impact for protecting and controlling the quality of water which was used by builders [2]. The studies conducted on concrete which has no fine aggregate were extremely limited and appeared in particular applications in recent years. However, this type of concrete was used as a construction material for buildings extensively for more than seventy years in Middle East, Europe, and Australia [3]. After world war II, it was used in construction of bearing walls of single or multistorey cast in place building as a resultant of shortage of materials. Recently, concrete with no fine aggregate was also used in construction of bearing walls in tall buildings which reached to ten stories [4]. For example, the upper thirteen stories of Stuttgart building in Germany were built using concrete with no fine aggregate [5]. The application appeared at the first time of this concrete kind in construction of two-story houses called Wimpey Houses in England [6]. Then, Wimpey engineers and architects had been used no-fine concrete in parts of wall for reducing the cost.

Sustainable characteristics play a vital role on judged of construction materials increasingly. Moreover, the incorporating of recycled aggregate within the components of pervious concrete lead to obtain extreme ecological benefits [7]. The use of concrete recycling leading to reduce the need for available landfills and it make significant gain by minimizing consume mining of natural aggregate, and hence it led keeps the natural environment [8].

The effects of different ratios of recycled concrete aggregate (RCA) content on properties such as permeability and void ratio beside compressive strength of porous concrete was experimentally investigated by Rizvi et al. [9]. The results appear an increasing in both of permeability, and void ratio and decreasing in compressive strength of porous concrete with increasing of RCA ratios. The properties of previous concrete made of RCA in terms of compressive strength, void ratio, and permeability approximately equal to those of concrete made of natural aggregate when the ratio of RCA not greater than 15%. The recommendation of the study was further investigation should be achieved on porous concrete of different sources of recycled aggregate.

2. Research significance

Based on the knowledge obtained from previous studies, this research focuses on using different aggregate types specially of damaged road pavements to produce a porous concrete. That is due to not enough information available about this type of aggregate. Therefore, to find out the possibility use of recycled aggregate as a kind of sustainability of concrete materials insightful be the main goal of the current study.

3. Experimental program

3.1 Materials and Instruments

3.1.1 Materials

The materials used in this investigation were commercially available, which include cement, water, gravel, silica fume and superplasticizer. Ordinary Portland cement was used throughout this investigation. The setting time and compressive strength are confirmed to ASTM C191[10] and ASTM C109 [11], respectively. In all the mix, 7.5% silica fume was replaced from cement weight. Superplasticizer type (BETONAC®-1030) was used as high range water reducer. The amount of superplasticizer was 0.2 % by total weight of cementitious materials. Its specific gravity was 1.10. Superplasticizer complies to ASTM-C494 [12]. For both mixing and curing purposes, drinking water was used in the experimental work. Four concrete mixes were designed to product a previous concrete. The mixes were A, B, C, and D. Two types of aggregates were used in concrete mixes as listed below:

1) Natural crushed aggregate: The size of natural aggregate used in concrete mixes were ranged (12-4.75) mm, (19-12) mm, and (19-4.75) mm, for mix A, B, and C, respectively.

2) Recycled aggregate: The aggregate of damaged asphalt pavement of road was used in this exploration. This type of aggregate was scraped from damaged pavements at Amarah City by a special truck as can be shown in Figs. (1) and (2). The size of recycle aggregate ranged between (12-4.75) mm. The amount of this type of aggregate used in this study represents 50% of natural aggregate. The absorption and specific gravity of aggregate used were 1.06 % and 2.58, respectively. This type of aggregate was used only in concrete mix D.

Figure 1. Scraper truck for damaged roads.

Figure 2. Recycled aggregate.

3.1.2 Concrete mix

Four concrete mixes were used through the whole investigation as shown in Table (1). In four mixes, the superplasticizer and silica fume to cement ratio kept constant and were 0.2% and 7.5%, respectively. No fine sand was used in all mixes. For mix A, the proportions of the ingredients, by dry weights were (1 cement: 4 gravel). The water cementitious ratio (w/c) was 32%. The natural gravel of small size ranged (12-4.75) mm was used in this mix. The materials of Mix B were (1 cement: 5 gravel). The water cementitious ratio (w/c) was 31%. The natural gravel of large size ranged (19-12) mm was used in this mix. While, in Mix C, were (1 cement: 4.5 gravel). The water cementitious ratio (w/c) was 32%. The natural gravel of size ranged (19-4.75) mm was used in this mix. The materials quantities of Mix D were (1 cement: 5 gravel) and water cementitious ratio (w/c) was 33%. The coarse aggregate of small particles size ranged between (12-4.75) mm with (50% natural aggregate) and (50% recycled aggregate) was used in this mix.

During casting of each mixture, six (150 × 150 × 150) mm cubes for pervious concrete were made to predict the compressive strength of each mix at seven and twenty-eight days, three at each age. To determine the permeability characteristics of each mix, two (100 × 200) mm cylinders were made. Three prisms (100 × 100 × 500) mm was casting to determine the flexural strength of concrete of each mix at 28 days. Also, three slabs of dimensions (350 × 350 × 150) mm was cast to conclude the infiltration rate of pervious concrete for each batch.

Table 1. Materials quantities in concrete mixes.

Mix	Cement to Gravel ratio	Water to cement ratio	Silica fume (%)	Superplasticizer (%)	Aggregate type
A	1:4	0.32	7.5	0.2	natural
B	1:5	0.31	7.5	0.2	natural
C	1:4.5	0.32	7.5	0.2	natural
D	1:4	0.33	7.5	0.2	Recycled and natural

3.1.3 Instruments

For determining the permeability of pervious concrete, permeability device was manually manufactured as shown in Fig. (3). This device satisfies the test requirements of specifications. It consists of two parts of rubber tubes and a bulge at the bottom. The upper part is fixed with plastic pipe. The concrete cylinder (specimen) of dimensions (100 × 200) mm is located between the rubber tubes. Then it covered with the nylon to prevent exit water. The plastic tube is filled with known quantity of water. The time requires of water discharge is recorded. Then the permeability of concrete may be calculated. The device fixed in timber table as can be shown in Fig. (3).

Figure 3. Parts of permeability test.

4 Results and discussions

The density, compressive strength, flexural strength, permeability, and filtration of each previous concrete mix are present in the following section.

4.1 Density results

The average density of porous concrete of mixes (A, B, C, and D) that tested in this study are (1807, 1735, 1796, and 1602) Kg/m^3, respectively. The density of tested samples is ranged between (1600-1800) Kg/m^3, this indicates the previous concrete can be considered as lightweight concrete type. The results indicted, the concrete mix A, has higher density compared with the other mixes. This is due to the aggregate size used in this mix is smaller than that of the other mixes and it make voids between the particles are smaller leading to increase of density. The concrete contains 50% recycled aggregate provided from damaged flexible pavements is lighter than other types of previous concrete contain natural aggregate only. The reason returns to the other materials adhere to the aggregate grains such as asphalt and the unit weight of these materials are lower than of aggregate. Therefore, the previous concrete with recycled aggregate of damaged pavements seem lower density.

4.2 Compression strength

The compressive strength of previous concrete of all mixes are presented in Fig. (4). The results obtained are of cubes specimens at 28-days of concrete age. The average concrete compressive strength of the four mixes A, B, C and D are (16.25, 5.1, 6.8 and 6.5) MPa, respectively. From these results, it can be noticing that the difference between the values of compressive strength is wide. The conclusion of these results, the compressive strength of concrete mix A has higher value compared with the other mixes. The aggregate size of mix A is smaller than the other caused an increase in the density of the concrete and thus leading to a decrease in the proportion of spaces and thus increase the coherence of the concrete structure which caused high compression resistance. On the other hand, the concrete mix B appears lower compressive strength obtained. The aggregate size of this mix is larger particles type, and it makes the concrete has high voids and thus leading to construct concrete in weak structure. Therefore, it has lower strength for compression test. The effect of aggregate type (recycled and natural) on compressive strength can be obtained by comparing the results of A and D mixes. As mentioned in the previous section, the mix A and D are made of the same aggregate size with different aggregate type. The previous concrete mix D shows lower compressive strength than in the first mixture A. The reason is that 50% of coarse aggregate of mix D is a rubble and it is covered with asphalt and thus causes a weak link between the particles of the aggregates and cement paste leading reduce in the compressive resistance. Fig. (5) shows modes of failure under compression load of A, B and D specimens.

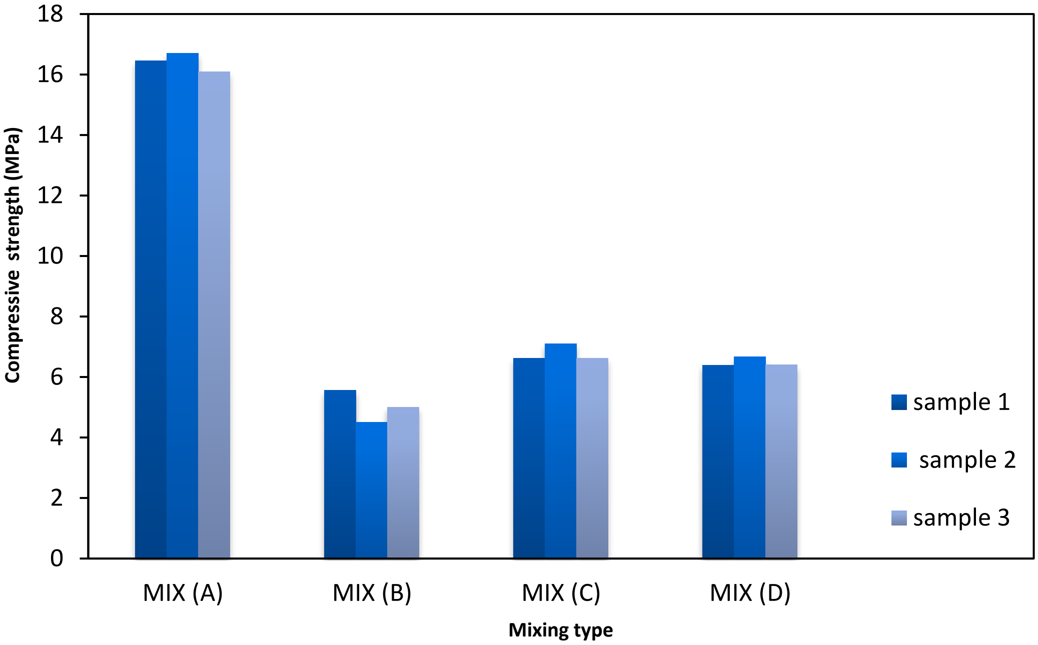

Figure 4. Compression strength for various concrete mixtures at 28-days.

Figure 5. Modes of failure of A, B and D mixes.

4.3 Flexural strength

The flexural strength of previous concrete tested in this study are (2.1, 1.3, 0.8, and 1.4) MPa, for mix A, B, C and D, respectively. These values represent an average strength of three prisms in each batch tested at the age of 28 days. Fig. (6) shows histogram of tested specimens. The results of the bending test show bending strength of mix Ais higher than that of other concrete mixtures. That due to in mix A, small aggregates was used caused an increase in the density of the concrete and thus caused a decrease in the percentage of the spaces between particles and thus leading an increase in the cohesion of the concrete structure which caused high flextural resistance. The concrete mixes B and C show that the value of the flexural resistance are less than the first mix and the reason return to size of aggregates of these mixes are large and it makes the concrete more porous and thus weak in the structure of concrete. On the other hand, the last concrete mixture D has been used as a small rubble but did not show high flexural resistance as in the mix A. The reason is that 50% of the aggregate is a recycled and that is covered with asphalt and thus causes a weak interconnect between the aggregate grains and thus reduces bending resistance.

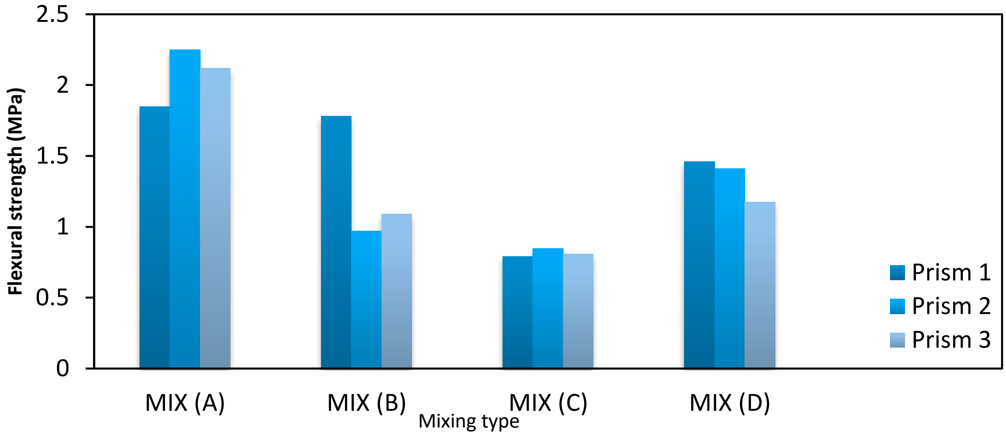

Figure 6. Flexural strength for various concrete mixtures at age of 28-days.

4.4 Infiltration of previous concrete

The infiltration test for different mixes of previous concrete is conducted on three specimens with dimensions (350 × 350 × 150) mm. The procedure of test includes fixing a ring of dimensions (300 ± 10) mm on the concrete surface as shown in Fig. (7). Two signs on the inner surface of the ring are marking, the first sign at 10 mm and the second mark at 20 mm from the bottom of the ring. Then pouring (3.60 ± 0.05) kg of the water and maintain the water level between the two signs and measure the time necessary to discharge all quantity of water, as shown in Fig. (8). Then, the rate of infiltration of previous concrete can be determined by the following equation.

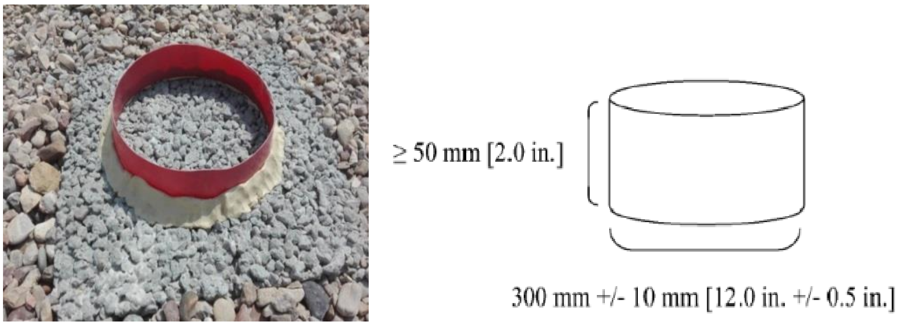

Figure 7. Infiltration device dimensions.

Figure 8. Infiltration test

$$I = \frac{K\,M}{(D^2\ \ t)} \tag{1}$$

Where, I is rate of infiltration (cm/sec); M is infiltration water mass (kg); D is inside diameter of infiltration ring, (mm); t is measured time required for infiltrating concrete specimens by amount of water, (sec); and k is a constant equal to (4583666000) in SI unit.

The results obtained of this test for various porous concrete mixtures are illustrated in Table (2).

Table 2. Infiltration rate of concrete mixtures.

Mix	Prewetting time (sec)	Infiltration (cm/sec)
A	11	1.04
B	6	2.20
C	5	2.12
D	5	1.60

From the above table, it is possible to observe that the difference between the results of the infiltration concrete mixtures due to the different porosity of the concrete mixtures where the relation between porosity and infiltration is higher. The higher the porosity value, the higher the infiltration rate. Also, it can be drawn that previous concrete made of recycled aggregate has good infiltration rate compared with the other casted from natural aggregate.

4.5 Permeability of previous concrete

The permeability test of various concrete mixes tested is shown in Fig. (9). Also, the values of permeability can be determined by divided the head of water by the time required to drain the water head. The results of permeability of various concrete mixes A, B, C and D are (1.6, 1.9, 1.2, and 1.8) mm/sec respectively.

Figure 9. Permeability test.

It can be observed that the permeability of pervious concrete is different according to a concrete mix. It depends on the porosity of the concrete mixtures where the relation between porosity and permeability is positive. The higher porosity value gives greater permeability value. The concrete mix made of a small aggregate size has a lower porosity compared with that of larger aggregate size. Therefore, the higher value of permeability of pervious concrete obtained in mix B that has larger aggregate size. Also, the values of permeability for mixtures A, C and D that have a smaller size of aggregate compared to mix B. The concrete of smaller aggregate size means denser concrete and the less porosity, which characterized by lower permeability. The permeability is therefore greatly affected by porosity, which in turn is affected by the size of the aggregates. Otherwise, the influence of aggregate type on the porous concrete permeability can be observed from the mixes A and D which have the same aggregate size. The values of permeability are (1.6 and 1.8) mm/sec for mix A and D, respectively. It is clear notice that; the previous concrete contain 50% recycled aggregate has higher permeability. Therefore, this type of aggregate can be used in design of previous concrete because the permeability rate of previous concrete considered one of important of engineering properties of this type of concrete.

5 Conclusions

The main conclusion can be drawn from the experimental test results of this investigated as follows

1. The flexural and compressive strength of porous concrete depending significantly on the voids in the specimens. The compressive strengths decrease with increase of voids. Therefore, the pervious concrete made of large aggregate size has a higher void ratio and lower compressive strength.
2. The infiltration and permeability of porous concrete are increase with increase the void ratio. The specimens made of larger aggregate size have high permeability and infiltration rate.
3. The recycled aggregate of damaged road pavements can be used as aggregate for producing the porous concrete with acceptable engineering properties.
4. The using of recycled aggregate contributes to reduce the pollution and represent as a kind of sustainability of concrete materials.

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