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Pervious concrete using brick chips as coarse aggregate: An experimental study

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Abstract

In an effort to find an alternative material in concrete, much work has been focused to use brick aggregate in producing normal strength or even high strength concrete. However, there is hardly any literature of producing pervious concrete using brick chips as coarse aggregate. This paper describes an experimental investigation carried on pervious concrete made of brick chips and also shed lights on the engineering properties of this new product. The properties of pervious concrete such as strength, permeability and void ratio were investigated. Different sizes of aggregate were used here. Stone aggregates were also used here for comparison purposes. Relationships among various parameters i.e. strength, void ratio, aggregate size, permeability for two different pervious concrete are also presented here. It can be seen that pervious concrete made of brick chips performs well in respect of permeability; however, the strength of this concrete is lower than that of the stone aggregate concrete.

Keywords: brick aggregate; permeability; pervious concrete; porosity; void ratio

1. Introduction

Pervious concrete is a special type of concrete obtained by omitting fine aggregates from the mix design. Thus the name no fine concretes is also applied, which is agglomeration of coarse aggregate particles surrounded by a coating of cement paste. Absences of fine particles introduce a high percentage of voids in concrete, which leads to its low compressive strength. However, these voids are large in size resulting in very low capillary movement of water, and high permeability. Comparing to conventional concrete which has a void ratio of about 3-5%, pervious concrete possesses void ratio as high as 15-40% depending on its application. This high percentage of void ratio results of its low unit weight of about 70% that of conventional concrete (Chopra et al., 2007). Low compressive strength of pervious concrete limits its application under low traffic loads and volumes. However, high flow rate of water together with light weight makes pervious concrete an ideal material to be used in pavements. High permeable pavement has a great advantage in reduction of storm water runoff as compared to other conventional non pervious pavements. This property has lead pervious concrete to be increasingly used in urban settings to improve the storm water quality and reducing rainfall runoff (Graham et al., 2004; Bean et al., 2007). This concrete has also been used as a load bearing walls in houses (Ghafoori 1995). Application of pervious concrete in USA is limited to sidewalks, parking lots, and low traffic volume areas. Because this concrete has a high void ratio, the 28-day compressive strength is lower than structural concrete of same water cement ratio. (Kosmatka et al., 2002)

Primary design objective of pervious concrete is to increase its permeability without much compromising of its compressive strength. Type and size of coarse aggregate, water-cement ratio, and cement-aggregate ratio thus requires a careful consideration. Malhotra (1976) provides a detailed study on pervious concrete; the researcher showed that compressive strength of pervious concrete depends on water-cement ratio, and on aggregate-cement ratio. Effect of compaction on compressive strength has also been studied by the researcher. Similar types of experiments and results were also reported by Meininger (1988). Different types of naturally available aggregates i.e. quartzite gravel, flint gravel, limestone, river gravel, crushed granite etc. were used in the past in making pervious concrete and are well documented (Malhota 1976; Kevern et al., 2008). These natural virgin aggregates although readily available in urban settings; however, they are not mined in urban areas and must be shipped. As a result aggregate needs to be carried to the construction sites from remote quarry which is costly on the basis of transportation, handling and, also inconvenience. Scarcity of natural aggregates leads the researcher to find alternative sources. Recycled aggregates from demolished buildings have been used in different parts of the world for many years (Collins and Sherwood 1995; Tavakoli and Soroushian 1996; Khalaf and DeVenny 2004). This is an alternative source of aggregate and also environmental friendly.

Clay is burnt in form of brick, and when crushed, form aggregates which are known as brick aggregate. This type of aggregates has been extensively used in concrete in many places of the world especially in the South Asian country, where source of natural aggregate is limited. However, these aggregates are porous and light weight, and also have high water absorption capacity than virgin natural aggregates. Porosity of brick aggregate leads towards its low compressive strength and high abrasion value. Despite of all these shortcomings, brick aggregate has been used in making concretes for many years. Aktaruzzaman and Hasnat (1983) carried out research on the engineering properties of brick aggregate concrete. They showed that by carefully selecting proportion and quality control, high strength can be achieved in brick aggregate concrete. Khaloo (1994) studied the properties of concrete using crushed clinker brick as coarse aggregate. Mansur et al. (1999) studied the properties of stone aggregate concrete with those of brick aggregate concrete by replacing equal amount of stone with brick. All the above mentioned studies were for normal strength concrete; however, attempts have also been made to produce high strength concrete using brick chips as coarse aggregate (Rashid et al., 2008). Brick aggregate concrete also performs well or even better than natural aggregate concrete under high temperature (Fouad et al., 2004). All these studies justified the use of crushed brick as an alternative source of coarse aggregate in concrete.

However, there is hardly any literature on use of brick aggregate in pervious concrete. This absence of documentation together with potential of using brick chips as a viable alternative of coarse aggregate in pervious concrete motivated the authors to do this study. This paper embodied the experimental investigation carried out on pervious concrete made of brick aggregate. Natural aggregate has also been used for purposes of comparison. The paper basically consists of three parts; first part described the properties of both brick and stone aggregates. Second part describes preparation of sample and testing of specimen according to standard procedure. Third part describes results of the experiment, and also trend and comparison between two types of pervious concrete.

2. Research Significance

Much work has been done to find an alternative material to produce concrete to be used for different purposes. Brick aggregate is one of the alternative materials, and has been used extensively in producing lightweight concrete, and even high strength concrete. However, there is hardly any work that has been done to produce pervious concrete using brick aggregates. Brick aggregate pervious concrete performs better in respect of permeability than that of stone aggregate pervious concrete. The authors believe to their best knowledge that this research work dealing with pervious concrete made of brick aggregates is carried out for the first time and will shed light and draws attention of other researchers on this new products.

3. Material Properties

Concrete mix consists of ordinary portland cement and coarse aggregate. No fine materials were used in this study. Two types of aggregate were used; brick aggregate and stone aggregate. Stone aggregate was used to compare its properties with that of brick aggregate. Fig. 1(a) shows typical brick aggregate used in this study and Fig. 1(b) shows stone aggregate that has been used for comparison purposes. Commercially available well burnt bricks were used in this study. It was deemed necessary to investigate strength of bricks as a whole before it was crushed to produce aggregates. Compressive strength of bricks was measured following the standard of ASTM C67. The standards required to test at least ten individual samples of bricks; however in this study five brick specimens were tested. Specimens were dried at a temperature of 110ºC in oven for 24 hours followed by a cooling at a temperature of 25ºC.

(a) (b)

Fig.1 (a) Brick aggregate used in this study (b) Stone aggregate

Individual bricks were then cut into two pieces and depressions (fog marks) were filled with mortar paste consist of one part of cement with two parts of sands. Sulfur capping were used to make the compression face of brick parallel and then compression force was applied through an MTS machine until rupture. Strength of clay bricks used in this study is summarized in Table 1. Same type of brick is then machine crushed and screened to produce coarse aggregate. Commercially available stone aggregate which was a mix of lime stone, sand stone and granite was used in this study. Three single size aggregates were used, ¾" (19mm), ½" (12.5mm) and #4 (4.75mm), thus eliminating the variable of aggregate gradation. Single size aggregate indicates size of sieve on which 100% of aggregate retains and all the aggregates pass through sieve just immediate above the retained sieve. Properties of brick and stone aggregates are summarized in Table 2 and Table 3. Dry rodded unit weight and void ratio were measured following the standard procedure of ASTM C29. In this study the authors found that unit weight of brick aggregate was much lower than that of stone aggregate.

Table 1
Strength of clay bricks used in the study

Sample No.	Crushing strength (MPa)	Average crushing strength of individual bricks (MPa)	Average crushing strength (MPa)	Coefficient of variation (%)
1A	17.6	18.8	16.7	8.65
1B	19.9			
2A	15.5	15.3		
2B	15.1			
3A	15.0	16.1		
3B	17.1			
4A	16.3	16.7		
4B	17.1			
5A	16.7	16.5		
5B	16.3			

*Symbol 'A' and 'B' represents the half size of a single brick. 1 MPa = 145.04 psi

Table 2
Brick chips aggregate characteristics

Aggregate size (mm)	19	12.5	4.75
Dry roodded unit weight (kg/m^3)	1007.58	970.74	933.89
Voids (%)	50.12	49.23	48.67
Specific gravity	1.91	1.91	1.91
Absorption (%)	11.79	11.79	11.79

1 mm = 0.0394 inch (Approximately) ; 1 kg/m^3 = 0.06247 lb/ft^3

Table 3
Stone chips aggregate characteristics

Aggregate size (mm)	19	12.5	4.75
Dry roodded unit weight (kg/m^3)	1528.19	1483.33	1459.31
Voids (%)	33.82	32.85	31.50
Bulk specific gravity	2.21	2.21	2.21
Absorption (%)	0.53	0.53	0.53

1 mm = 0.0394 inch (Approximately); 1 kg/m^3 = 0.06247 lb/ft^3

As aggregate size become smaller, unit weight also becomes smaller. Void ratio of brick aggregate was much higher than that of stone aggregate. ASTM C127 standard procedure was used to measure the bulk specific gravity and absorption of aggregates. Specific gravity of brick aggregate was found much lower than specific gravity of stone aggregate. Absorption capacity of brick aggregate was found to be 11.79% as compared to 0.53% of stone aggregate. Porosity of brick aggregate plays a dominant role in producing its high absorption properties. Inclusion of this porosity in brick aggregate comes during its making process. Clay was dried in shape of brick before it was burnt in kiln. However, some of water entrapped inside the brick, and when burnt, water evaporated leaving brick porous. Since pervious concrete does not contain any fine aggregates, strength of concrete comes from bonding of cement paste coated on aggregates and also from interlocking friction of aggregate themselves. Thus it was deemed necessary to determine the angularity number which is a measure of absence of roundness of aggregate. Basic idea is that if a single size spherical aggregate is compacted in its dense form then total volume of solid will be 67 percent and volume of voids will be 33 percent of total volume (BS 812). However, if aggregates are angular or irregular then total volume of solid will be decrease, consequently an increase in volume of voids. Measured angularity number for brick aggregate was found to be 8.0 and those for stone aggregate was 5.0. Brick was machine crushed to produce aggregate resulting sharp edge of particles as can be seen from Fig. 1(a) which may have also resulted for its high angularity number. Strength of aggregates plays a dominant role on the overall strength of concrete, thus it was necessary to determine strength characteristics of aggregates as a whole. Los Angeles abrasion test was carried out on both types of aggregate to find out its resistance against abrasion and impact loading following the procedure stated in ASTM C131 standard. It was found that abrasion value for brick aggregate was 39.2 and for stone aggregate it was 27.5. The ability of an aggregate to resist crushing is determined through the aggregate crushing value (ACV) test (BS 812). The ACV of brick aggregate was found to be 27.9 and that of stone aggregate was 28.2, it is to be noted here that the crushing strength of both aggregates were almost same. The shape and strength characteristics of brick and stone aggregate are summarized in Table 4.

Table 4
Shape and strength characteristics of the aggregates

Parameters	Stone chips	Brick chips
Los Angeles Abrasion Value (%)	27.5	39.2
Aggregate Crushing Value (%)	28.2	27.9
Angularity Number	5.0	8.0

4. Specimen preparation and testing

Specimens were prepared with an aim to investigate strength, void ratio and permeability. The mix was prepared with cement, coarse aggregate and water keeping water cement ratio of 0.3 for all mixes. Thus the variable of water cement ratio on strength was eliminated. Aggregate cement ratio for both aggregate was kept as 6:1. For pervious concrete, aggregates were bonded together with help of cement coating. Thus aggregate cement ratio plays an important role. However, since aggregate to cement ratio was same for both type of concretes, influence of aggregate on strength, void ratio, and permeability were easily investigated. Mixing of concrete was performed following the ASTM C192 standard using a concrete mixing machine. To improve bond between aggregate and cement paste, aggregate was first mixed with dry cement for one minute and then half of water was added and mixed for another one minutes. Next remaining cement and water was added and mixed for five more minutes before casting. Cylindrical mould was 6" (150 mm) in diameter and 12" (300 mm) in height. Wet concrete was placed inside mould in three layers with each layers compacted with help of a standard tamping rod 25 times and then placed in the mould for 24 hours, after that cylinder specimens were demoulded and placed inside water tank in room temperature and cured according to the ASTM C192 standard. Specimens were tested on different days to determine the compressive strength according to ASTM C39 standard procedure. Before that specimens were sulfur capped following the ASTM 617 standard. Three 6×12 inch (150×300 mm) cylindrical specimens were tested for compression for each of aggregate size and also for different days for both stone and brick aggregate concrete.

(a) (b)

(c)

Fig 2. (a) A typical cylindrical specimen of pervious concrete (b) Specimen under loading (c) Failure pattern of specimen

Fig. 2(a) shows typical cylindrical specimen of pervious concrete made of brick aggregate, Fig. 2(b) shows specimen under loading and Fig. 2(c) shows specimen after crushing. Void ratio of specimen was tested using a 3 × 6 inch (75 × 150 mm) cylindrical sample. The sample was first oven dried and weight was recorded, then it was immersed under water and submersed weight was recorded. The void ratio was then computed using the following expression (Equation 1) (Park 2004)

$$Void\ ratio = \left[1 - \frac{w_2 - w_1}{\rho_w V}\right] \times 100, \tag{1}$$

where

$w_1 =$ weight of specimen under water (lbs) or (kg)

$w_2 =$ oven dry weight of specimen (lbs) or (kg)

$V =$ volume of specimen (in^3) or (m^3)

ρ_w =density of water (lb/in^3) of (kg/m^3)

Permeability of specimen was determined by constant head permeameter shown in Fig. 3. However, permeability can also be measured by falling head permeameter (Montes et al., 2006). The permeameter consist of 3" (75 mm) inner diameter PVC pipe with sufficient drainage facilities. Sample for permeability test was 3" (75 mm) in diameter and 3" (75 mm) in height. Flexible sealing tape was used around perimeter of sample to prevent water leakage between perimeter of sample and inner surface of permeameter. Constant time ranged between 30 and 60 seconds. Co-efficient of permeability was determined using the following equation (Equation 2) (Das 2002).

$$k = \frac{QL}{AHt}, \tag{2}$$

where

$k =$ co-efficient of permeability (in/sec) or (mm/sec)

$Q =$ volume of water collected in time t (sec)

$H =$ head causing the flow (in) or (mm)

$A =$ cross-sectional area of sample (in^2) or (mm^2)

$L =$ height of sample (in) or (mm)

$t =$ time in sec.

5. Results and discussion

The test results are presented graphically in category of strength, void ratio, permeability and age of concrete. Keeping water-cement ratio and aggregate-cement ratio constant for both of the brick and stone chips, the sizes of aggregates was varied. Three single size aggregate was used for both of brick and stone chips. The stone chips concrete was used as for comparison purposes. Fig. 4 represents strength of pervious concrete for different sizes of brick aggregates. It is clear that as age of concrete increases, strength also increases. However, strength is higher for smaller size of aggregate, and lower for larger size of aggregate. This is true because for smaller size aggregates, inter-aggregate void is much lower than that of larger size aggregate, and as the void reduces, strength increases. There is another factor behind the higher strength of smaller size aggregate. As aggregate size reduces, its surface area increases, and since for pervious concrete the bonding between aggregates largely depends on cement paste coating around the aggregates, there is more bonding for smaller size aggregate than bigger size aggregates which eventually increase the compressive strength of concrete. Fig. 5 represents the strength of pervious concrete for different size of stone aggregates.

The authors found that for same size, stone aggregate produces higher strength than that of brick aggregate. Lower strength of brick aggregate is due to its porosity. However, it is also evident that for stone aggregate pervious concrete, smaller size aggregate produces higher strength than that of larger size aggregate. Fig. 6 represents the relation between void ratio and size of aggregate for brick and stone chips. From the figure it is clear that for brick aggregate void ratio is higher than stone aggregate for same sieve opening. This extra void for brick chips is due to its porosity. When entrapped water evaporated during burning of bricks it leaves the place empty and this void place on the surface of the aggregate was filled with cement paste, therefore intra-aggregate voids become more in brick aggregate pervious concrete.

Fig 3. A typical setup for permeability test

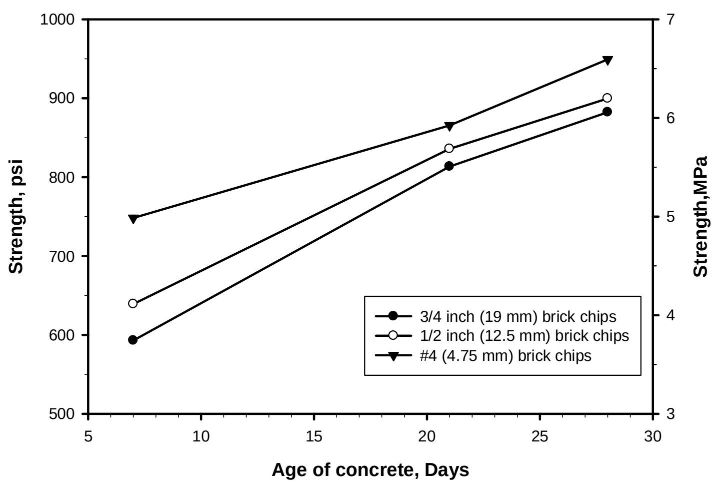

Fig. 4. Strength of pervious concrete made of brick chips for different size of aggregates

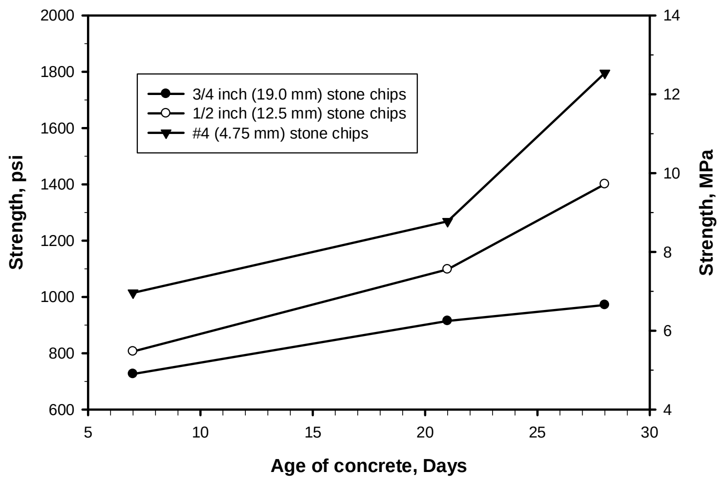

Fig. 5. Strength of pervious concrete made of stone chips for different size of aggregates

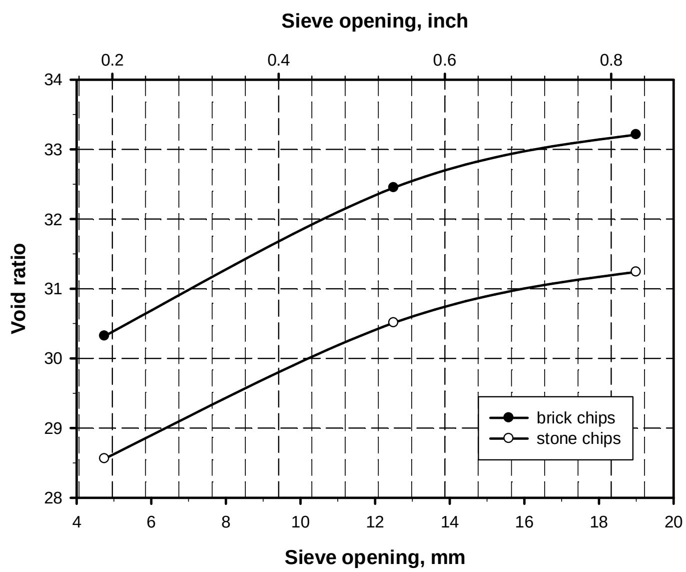

Fig. 6. Void ratio for brick and stone chips pervious concrete for different size of aggregates

These internal voids of the brick chips are also responsible for its lower compressive strength. Fig. 7 represents the relationship between permeability and aggregate size. The permeability of brick aggregate concrete is higher than that of stone aggregate concrete. The permeability of brick aggregate concrete is also appeared to increase proportionately with aggregate size. The relationship between void ratio and permeability for brick and stone aggregate pervious concrete is represented by Fig. 8. The authors found in this study that for same void ratio, stone aggregate concrete produce higher permeability than that of brick aggregate concrete, however, from Fig. 6, it can be seen that for same size, brick aggregate concrete possess higher void ratio than that of stone aggregate concrete.

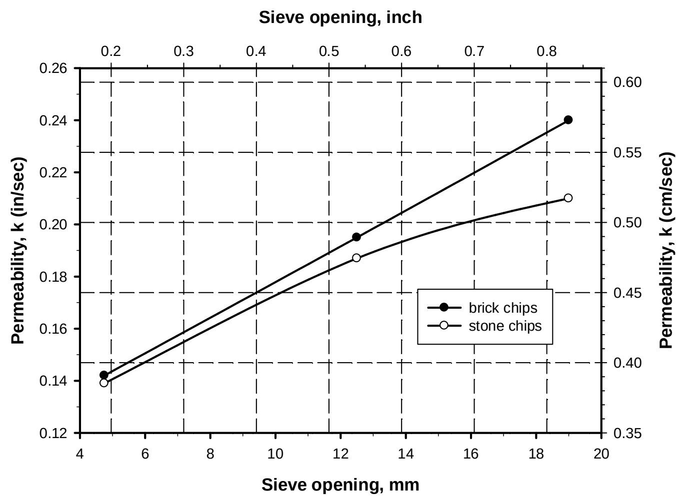

Fig. 7. Relationship between permeability and different size of aggregates for brick and stone chips

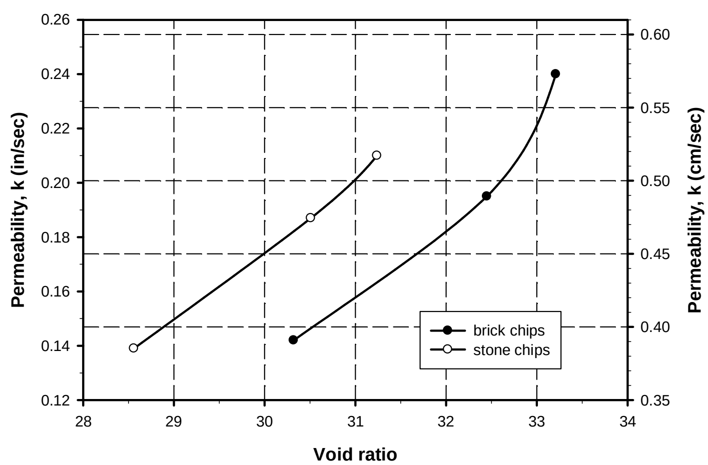

Fig. 8. Void ratio vs. permeability for brick and stone aggregate pervious concrete

From Fig. 8 it can be seen that permeability and void ratio relationship for stone aggregate concrete follows almost a straight line, i.e. permeability increases at the same rate as void ratio. However, the permeability and void ratio for brick aggregate concrete follows somewhat a nonlinear trend. This nonlinearity may have been related with porosity of brick aggregate. This porosity of brick comes during its making process, when clay is dried in the form of brick shape, some part of water trapped inside the brick.

At time this brick is burnt inside the kiln that water evaporated leaving brick porous. When this brick is crushed into aggregate and mixed with cement paste to make pervious concrete, cement paste enter into porous space therefore less cement paste is available to fill intra-aggregate voids. In this way void ratio of brick aggregate pervious concrete increases than that of stone aggregate pervious concrete. Therefore void ratio and permeability relationship for brick aggregate does not follow the same trend as of stone aggregate concrete. However, in this study only three sizes of aggregates were used and tests were conducted on limited number of specimens.

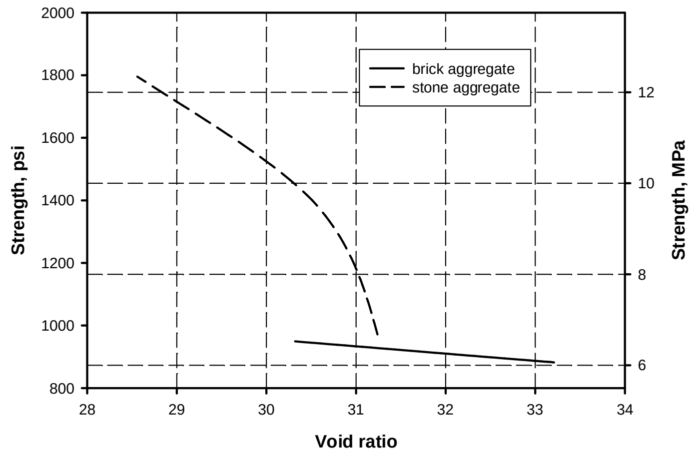

Fig. 9. Relationship between void ratio and 28-day compressive strength of stone and brick aggregate concrete

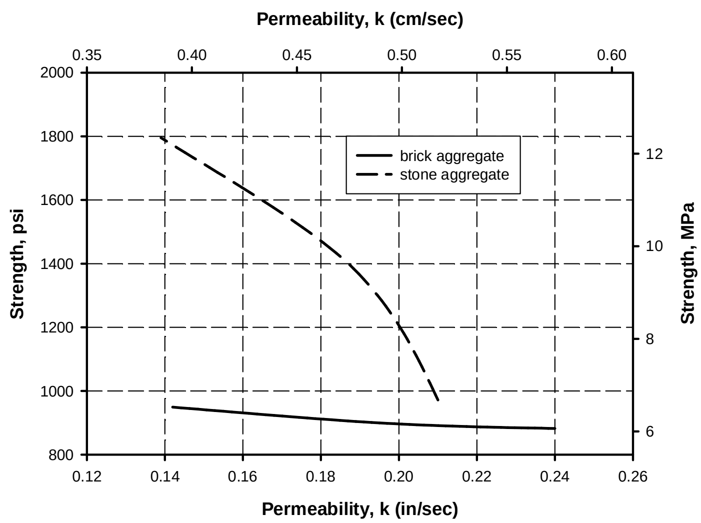

Fig. 10. Relationship between permeability and 28-day compressive strength of stone and brick aggregate concrete

Thus void ratio and permeability of brick aggregate pervious concrete will follow a nonlinear trend is not guaranteed. Relationship between void ratio and 28-day compressive strength for stone aggregate and brick aggregate pervious concrete can be seen in Fig. 9. Strength of stone aggregate pervious concrete decreases more than that of brick aggregate pervious concrete with the same increase of void ratio. It can also be seen that with same void ratio stone aggregate concrete offer more strength than brick aggregate concrete. Relationship between permeability and 28-day compressive strength of stone aggregate and brick aggregate pervious concrete is depicted in Fig. 10. It can be seen here that for brick aggregate concrete, permeability can be increase without much compromising strength. However, for stone aggregate pervious concrete this is not true. Increase of permeability has to be associated with substantial decrease of strength.

6. Conclusions

Brick aggregate can effectively be used as a coarse aggregate in pervious concrete. From experiments the authors found that strength of brick aggregate pervious concrete is less than that of stone aggregate concrete for same aggregate size. However, permeability of brick aggregate pervious concrete is higher than stone aggregate pervious concrete. The purpose of pervious concrete is to drain off rainfall runoff quickly; therefore, permeability is of important characteristics. Brick aggregate performs better in this regard. Thus brick aggregate can be used in pervious concrete in places where load is comparatively less and more permeability is required. Mixture of different size of brick aggregate may produce higher strength concrete therefore; will increase its suitability and scope of applications. Again where availability of natural aggregate is limited brick aggregate, which can be obtain easily by crushing bricks made from landfills, can safely, be used as a viable alternative in making pervious concrete. In this study single size of aggregate was used in making pervious concrete to eliminate aggregate size as a variable; however, in actual practice use of single size aggregate is limited. Therefore use of aggregate gradation is recommended for future study.

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