Experimental Study of Strength and Permeability of Porous Concrete for Different Gradations: a Literature Review

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Abstract - This review paper provides the information on the various researches that have been performed by many researchers and engineers so far for understanding the characteristics of porous concrete, starting from its first recorded use by Europeans in 1800s for pavement surfacing and load bearing walls. It has been in use in United States since 1970s (Malhotra 1976), in India, it became popular in 2000. Its popularity has increased significantly since last 10 years since its usefulness in managing storm water runoff is realized. Various papers have been published on its structural designs and properties; on specification and test methods; on its mix designs; and on its impact on environment etc. researchers now a days working on the comparison of strength and permeability of conventional and porous concrete also for suitable and acceptable mix design for pervious concrete. The intention of this review paper is to provide necessary information, which will be helpful for designers and engineers for adopting the suitable mix design and gradation for different projects according to required strength and permeability characteristics of porous concrete.

Key words: *permeable concrete as a road pavement, density, compressive and tensile strength, gradation nominal mix design.*

1. INTRODUCTION:

Porous concrete are being used in many parts of the world as a green solution to overcome various environmental problems like decreasing ground water level and subsequent flooding due to lack of absorbing surface in the city. These porous concrete pavements can be useful in managing quality and quantity of urban storm water.

Ordinary concrete pavement consists mainly of conventional cementitious materials (organic inorganic and organic-inorganic combination), granular aggregate, water, chemical admixtures and mineral admixtures. This type of concretes are impervious and surface flow is hard to penetrate, causing flooding in cities, moreover the air permeability of normal concrete is poor, which is not convenient for heat exchange. When sun irradiates the ground, the temperature of the earth increases, this will lead to urban heat island effect and urban environment deterioration.

As compared to conventional concrete, the porous concrete reduces or avoids the use of fine aggregates, which forms interconnecting voids or pore-microstructure. The intercommunicating pores in theses porous concrete makes the pavements have good permeable performance. In addition, these would guide to the promotion of sponge city in future.

Though the strength of permeable concrete pavements is not as high as conventional concretes initially this porous concrete pavements were being used only for light traffic of foot and for house yard surfacing but with experiments on porous concrete and wide awareness about its advantages over conventional concrete on environment its use is made possible for further using it as traffic pavement materials and further experiments are going on to increase its strength.

The advantages of this type of porous concrete are lower density, lower cost due to lower cement content and very low sand content, lower thermal conductivity (intrinsic gaps in these concrete provide reduced thermal conductivity as compared to the dense conventional concrete.) relatively low drying shrinkage, less or no capillary movement of water, better insulating characteristics than conventional concrete because of the presence of large voids according to Fulton's concrete technology (1994) and Neville (1981).

This review paper consists of analysis and outcomes of some research papers, which gives information about the strength and permeability characteristics of permeable concrete as road pavement also gives information on appropriate mix designs for various types of projects according to required characteristics for particular projects.

2. LITERATURE REVIEW:

Many research works have been done on pervious concrete since 18th century. These researches have been proved to be helpful in understanding the behavior of pervious concrete. Some of the research works are discussed as follows:

1) Literature Review of researches on strength and permeability characteristics of pervious concrete:

Malhotra (1976) found the density of permeable concrete is only 70 percent of conventional concrete most of the time when casted using similar constituents. Malhotra suggested that using light rodding is adequate for the pervious concrete to reach all sections of the formwork. Malhotra Also stresses that if the normal conditions are not achieved the formwork should not be removed after 24 hours.

Ghafoori et al (1995) undertook a considerable amount of laboratory investigations for determining the suitability of permeable concrete to be used as a paving material. The comparison between different curing types was investigated to determine if there is any change in its strength and permeability characteristics by adopting wet and sealed curing and conclusion came out that curing type didn't affected the strength development of porous concrete. The greater tensile strength was achieved by lower aggregate cement ratio by choosing aggregate-cement ratio of 4:1; Strength was produced in excess of 20 MPa.

Abadjieva et al (1997) examined that the compressive strength of permeable concrete and the conventional concrete increases at same rate with age. The permeable concrete specimens were prepared with varying aggregate-cement ratio from 6:1 to 10:1 in which 6:1 proved to be strongest amongst all and concluded that this strength is sufficient for some load bearing walls and some other associated uses.

Kingsten Banh, Benjamin Rehder and Narayanan Neithalath (2014) studied the fractural response of permeable concrete specimens that they proportioned for different porosities, as a function of the fiber volume fraction and pore structure features. The experiments show that the fracture toughness depends on the porosity of permeable concrete.
For a similar porosity, as the pore size is increased it shows a reduction in fracture toughness.

2) Review on effects of Different Mix Proportions and incorporation of different materials in Pervious Concrete:

Jing Yang, Guoliang Jiang (2002) experimentally studied the increase in strength properties of pervious concrete by adding some additives and fine materials like SF(silica fumes) and SP(super plasticizers) adjusting the cement quantity use of smaller size aggregates can enhance the strength of pervious concrete. Strength can also be greatly improved by adding SF SP and by adding organic polymer but due to polymer-filling property, it reduces the permeability of concrete. The compressive strength and flexural strength can reach up to 50MPa and 6MPa respectively.

Wang, K. Schaefer, V. R. Kevern, J. T. and Suleiman, M.T. (2006) Designed PCPC mixes with varying amounts of aggregate cementitious materials and incorporating different materials such as chemical admixtures, latex and fibers, study showed that when properly designed and constructed porous concrete can perform excellent under cold weather conditions and also produces good strength and F-T durability by using small amount of sand (7% weight of total aggregate) and microfibers.

Cheng; Sao-Jeng Chao; Hui-Mi Hsu and Kae-Long Lin (2011) investigated the properties of pervious concrete made using the recycled aggregate. Experiments were done to reveal the mechanical and permeability performance for different volume of binder, type of binder (cement paste and styrene-butadiene latex modified paste), aggregate cement ratio and the size of aggregate. Their experiments showed that the mechanical performance becomes poor with the increase in the permeability. Their experiments showed that for a reasonable use of this porous concrete having 28 days compressive strength 12.6 and permeability of 0.33cm/sec can be obtained by using a water binder ratio of 0.35, 11.1mm diameter of recycled aggregates and A/C ratio of 3.9

R. Sri Ravindrarajah, Y. Aoki & H. Khabbaz (2012) incorporated fly ash in the permeable concrete as cementitious material subsequently partially reducing the use of ordinary Portland cement. They tested the specimens for different properties such as density, compressive strength, porosity, drying shrinkage and water permeability. No significant change was to be seen in the density and porosity of porous concrete by using fly ash in place of OPC however, compressive strength could be reduced by an amount of 40% if fly ash is used more than 50% in place of OPC, but an increase in its drying shrinkage was observed by using fly ash. Overall, the properties of permeable concrete with fly ash were acceptable for limited uses.

Tun Chi Fu, Jiang Jhy Chang, Weichung Yeih, and Ran Huang (2014) have studied the changes in strength and permeability properties of the porous concrete for different binder material, amount of binder material and for different aggregate sizes. Specimens tested for mechanical strength permeability, porous and soundness. The results showed that the water permeability and the porosity decreases as the amount of binding materials is increased and increased with the increase of aggregate size. Compressive strength, permeability and sulfate resistance improved when highly viscous binder materials were used.

J. T. Kevern; D. Biddle; and Q. Cao (2014) studied the effects of using macro synthetic fibers on properties and durability of pervious concrete. Two lengths of fibers 38mm and 56mm were incorporated in three different dosage levels it was seen that the use of macro synthetic fibers reduced both the permeability and infiltration capacity of porous concrete and the decreases were higher for higher dosages of longer fibers. Change in compressive and tensile strength was not significant but abrasion resistance and freeze-thaw durability was improved. If permeability is more important than a dosage of 1.5 Kg/m3 is adopted and if durability, freeze-thaw and abrasion resistance are more essential than dosage level of 3Kg/m3 is recommended.

X Xiao, X Zhang (2018) introduced a new method of making porous concrete named as CAVF (coarse aggregate void filling) method. They also suggested a method for selecting temperature at which the maximum specific gravity can be achieved which was proposed to be the best compaction temperature. Stability of the mix remained good even at high temperature (70℃). The skid resistance, water stability and the high temperature stability of permeable concrete exceeded than the standard required qualities.

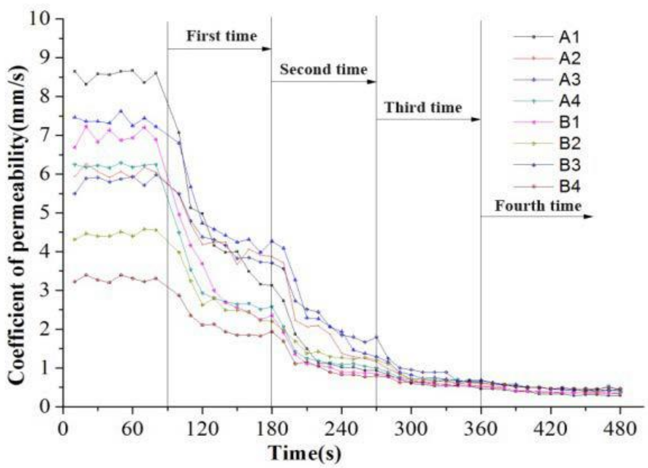
Narayanan Neithalath, Adam Marolf, Eric Sell, Kristy Wegner, Jan Olek and Jason Weiss (2004) investigated whether the enhanced porosity concrete has some sound absorption capacity or not. They also measured the influence of silica fume and sand content on the acoustic properties and mechanical characteristics of EPC.

3) Review on Infiltration Capacity and Clogging behavior of permeable concrete pavements:

Coughlin, J.P., Campbell, C.D. and Mays, D.C., (2011) studied the clogging problem of pervious concrete which is major problem when it is used as pavement material. Laboratory study was carried out for measuring clogging effects of sand and clay. Clay causes ten times more clogging than sand per mass. Even after clogging, the permeability was reduced because of Sub grade condition, which is the limiting factor for the infiltration capacity of pervious pavements. Head loss mainly occurs at the sub grade layers.

Mary E. Vancura, Kevin MacDonald, and Lev Khazanovic (2012): studied about different methods of void maintenance using different municipal vehicles- vacuum truck with flexible hose, vacuum type street sweeper and a regenerative air type street sweeper. These vehicles were used for removing clogging materials from the preexisting permeable concrete pavements in use. It was concluded that all these three methods were effective equally in removing clogging materials from pavements to a depth of 3.18mm. After removal of clogging materials, the permeability is restored significantly but a good permeable sub grade conditions and proper drainage system is required for best performance of permeable pavements.

Xia Liu, Dong Liu, Jing Chen and Weiwei Han (2013) studied the law of attenuation of permeability coefficient of permeable concrete under plugging conditions. Slow plugging and quickly plugging tests were carried out they also studied the recovery rates by high-pressure water guns. The main conclusion of the project work was to achieve idea for designing a permeable concrete with anti plugging properties. A thickness of 15mm for the upper layer of the pervious concrete postpones the plugging increasing the life of pavement without maintenance. Attenuation takes place slowly in slow plugging test whereas permeability decreases faster for quickly plugging tests. Initial value of permeability of the samples depends upon the thickness of upper layer, which was higher for thinner layer and lower for thick upper layer.



Attenuation graph

4) Review on Field Surveys of Some Pre-existing Permeable Concrete Pavements in use:

William F. Hunt, Eban Z. Bean, and David A. Bidelspach (2007) studied the permeability of the 40 permeable pavement sites in North Carolina, Virginia, Maryland, and Delaware. They tested the area both before and after maintenance and discussed the different conclusions. The main conclusion that came out was that the proper maintenance, sandy sub grade and placing permeable pavement away from disturbed soil is the key to sustain its high permeability for a longer period.

Srinivas Valavala, Liv M. Haselbach and Felipe Montes (2006) developed a theoretical relationship between the effective permeability of the sand, permeability of a sand-clogged pervious concrete block, and the permeability of the unclogged pervious concrete pavement blocks, and then they measured the permeability of the PCPC(Portland cement pervious concrete) covered with extra fine sand and simulating a rain. The permeable concrete clogged with the same sand as was used in the sub base showed negligible runoff.

Daniel I. Miller, Aleksandar Mrkajic, and Norbert Delatte (2009) inspected the pervious pavements in the fields and researched on the cores that were removed from the in-service PCPC (Portland cement pervious concrete) pavements and their properties in the laboratory. Fields investigated showed good performance in freeze-thaw environments. Although the sites visited were only four, years old and they did not require maintenance at all and showing very good permeability performance. The sites can be revisited in future for more reliable results for comparing the performances periodically.

5) BRIEF OUTCOME OF LITERATURE REVIEW:

From these papers, this can be summarized that Europeans first used the porous concrete in 1800s for pavement surfacing and load bearing walls. It has been in use in United States since 1970s (Malhotra 1976), in India, it became popular in 2000. Its popularity has increased significantly since last 10 years since its usefulness in managing storm water runoff is realized. Various papers have been published on its structural designs and properties; on specification and test methods; on its mix designs; and on its impact on environment etc.

At present research works are going on comparison of pervious concrete and porous asphalt; pervious concrete mix design for wearing coarse applications; and performance of pervious concrete pavement in cold weather climate; serviceability of pervious concrete pavements; and increasing exfiltration from pervious concrete into the underlying clay soil etc.

Future research needs on porous concrete are: research on more applications and case studies of porous concrete such as on low volume streets, highway shoulders, medians and swales; research on construction techniques to standardize the most effective placement technique (plate compactor, vibratory screed, roller, high density paver); methods to reduce ground water pollution; durability and maintenance; adsorption of grease and oil in porous concrete pores and its long term effects, aerobic digestion and growth and decomposition of biomass in a porous concrete, leaching of concrete materials; byproduct research; development of observation wells for water quality testing; and structural design and properties etc.

I. OBJECTIVES OF THE PROPOSED WORK:

The objective of this project would be:

1) Study the change in strength parameters of porous concrete for different gradation.
2) Study the variation in permeability of porous concrete for different gradation.
3) Study the change in permeability of porous concrete with the change in its strength.

II. FUTURE SCOPE:

Other sizes of aggregates can be use for further studies in place of nominal aggregate size, which have been used in this project. Porous concrete can be studied for the durability criteria under different weather conditions. Some more possible applications for porous concrete like for footpaths, sidewalks, walls etc needs to be checked.

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