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Experimental Study on Strength and Permeability of Porous Concrete

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Abstract: To make high strength normal concrete we use coarse aggregates; fine aggregates; cement and water. But for making concrete porous it is advisable to use minimum fine aggregate content or even avoid its use because they are used as void filling materials and they make concrete denser and compact, but in porous concrete we need interconnecting voids for water to percolate through it easily. This paper aims at experimentally studying the effect of maximum nominal size of aggregate on the properties of porous concrete and subsequent change in its strength. Concrete test specimens are prepared for different gradation and test for permeability, compressive strength, density, tensile and flexural strength, and workability is carried out on these blocks. Various properties of fresh and hardened concrete is recorded and studied with the help of graphs. The strength of porous concrete is lower than the normal conventional concrete and as the porosity characteristic is enhanced its strength is reduced and this behavior is showed with the help of graphs.
Keywords: Porous concrete as road pavement, density, workability, compressive, water permeability test and tensile/flexural strength, maximum nominal size of aggregate.

I. 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 porous microstructure. The intercommunicating pores in theses porous concrete makes the pavements have good permeable performance. And these would guide to the promotion of sponge city in future.

Experiments and researches on porous concrete as pavement materials is essential in order to use it more frequently in place of conventional pavement materials to reduce the bad environmental effects caused by normal pavements like drainage problems, ground water depletion and flood problems during excessive rain in urban areas where larger area of roads and pavements are covered with impervious non absorbing conventional pavements.

Pavements made with impervious conventional concrete offers greater strength and durability as they are compact in structure with void filling fine aggregates and are more resistant to wear, tear and impact loadings but they are incapable of providing proper drainage of water through them and thus don’t help in flood problem in urban area caused due to excessive rain and poor drainage and don’t help in reducing the load of water treatment plants

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 or no 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 paper presents the results of an investigation to determine the performance characteristics of concrete mixes made with different proportions of coarse aggregates, studies the effect of maximum nominal size of aggregates on the properties of no-fines porous concrete. The concrete mixes of different gradations were prepared and permeability and strength characteristics were tested in laboratory.

In this paper the change in strength for different permeability coefficients which is obtained by adopting different gradations is studied.

The rain water and surface runoff reduces the permeability of these pavements by clogging the open pores of porous concrete reducing the effectiveness of such pavements. This effect of rain water and surface runoff can be studied by preparing plugging material samples. Continuous use of porous concrete reduces the permeability of pavement with time. Only when studied, this problem can be overcome by flushing techniques for washing out these plugging materials with water pressures.

Concrete test specimens are prepared for different gradation and test for permeability, compressive strength, density, tensile and flexural strength, and workability is carried out on these blocks. Various properties of fresh and hardened concrete is recorded and studied with the help of graphs. The strength of porous concrete is lower than the normal conventional concrete and as the porosity characteristic is enhanced its strength is reduced and this behavior is showed with the help of graphs.

II. PROBLEM STATEMENT

The research on the variation of strength and permeability for different gradation provides a better understanding about the possible and suitable mix proportions of pervious concrete as pavement material as well as for various other uses.

The effect of maximum nominal size of coarse aggregate and the water cement ratio for the maximum strength with considerable permeability is a subject of study which can help us to design such pervious pavements which can be used as pavement material for heavy vehicular traffic also. This research can be used as guidance for further studies on the topic for comparison with other different gradations and conditions for lesser clogging characteristics.

III. 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. 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.

IV. METHODOLOGY: EXPERIMENTS

A. Materials and Method of Testing

Concrete mix was prepared with different aggregate ratios and water cement contents. Varying aggregate cement ratio of 7:1 8:1 and 9:1 by weight was adopted and the concrete specimens were prepared with no fine contents using ordinary Portland cement as cementitious material. Two different sizes of Coarse aggregates made up of crushed stones of sizes 10mm and 20mm was used which was provided by local construction material shop. Cubes with a side of 150mm, beams 700 x 150 x 150 mm, slab with side 600 x 600 x 100 mm and cylinders with diameter and length 150mm were prepared by using gentle rodding only. Tests for workability and vibration test were not performed due to very less cohesion between particles. A visual inspection was used to check the even coating of all the particles. Water curing was done of the samples, which becomes very important as there is a very small coating of cement paste around all the aggregate particles.

The following tests were carried out: slump test, compaction factor test, and density test on fresh concrete, flexural strength test on beam specimens, compressive strength test on cube specimens, split tensile strength test on cylindrical specimens and permeability test on slabs.

Plugging sample was prepared by addition of certain amount of clayey material with normal tap water to resemble the approx situation of the clogging water which occurs during rainy seasons for the porous concrete of the locality.

1) *Mixture Proportion and Specimen Preparation:* Cement concrete specimens were prepared of different proportions adopting three different cement-aggregate ratios 6:1, 7:1 and 8:1 with two sizes of coarse aggregates 10mm and 20 mm three batches are prepared for each of two aggregate sizes. Using 10mm aggregates three batches (6:1, 7:1, and 8:1) are prepared and 6 cubes, 6 cylinders 2 beam and 2 slab is made per batch similarly same numbers of cubes, cylinders, beams, and slabs are made using 20mm aggregates. Normal tap water was used for all specimens. Mixing procedure: to increase the bond strength between the aggregates and cement particles for 6:1 A/C ratio 6 parts of aggregate was mixed with 1 part of cement and W/C ratio of 0.45 was adopted to obtain a workable mix, hand mixing was done with shovels in the pan with all the measured amount of ingredients. Same procedure for mixing other batches and another size of aggregate was used. After proper mixing the cement, aggregates, cement and water mixture was placed in the moulds in three layers with 25 times of rodding and left for 24 hours to set in the mould. After 24 hours samples were taken out of the moulds and cured. Half of the samples were tested for seven day strength and other half of the sample was test after 28 days to obtain standard 28 days strength. 150 mm side cubes and 150mm dia. ;300mmlength cylinders were used for compression and split tensile strength test, 750 x 150 x 150 mm beams were used for flexural strength test and constant head permeability test was performed on a cylindrical specimen of size 100 x 200 mm.

B. Experiments Performed and Observation

Various tests which were performed on the concrete test samples are given in details below; one by one test are discussed with their results and comparison is done for different A/C ratio as well as for different size of aggregates. For comparing results for different nominal size and mix proportions graphs are prepared along with the tabular data records.

Various tests are as follows:

1) *Workability Test*: Workability of concrete determines the ease with which it can be mixed and placed at the time of working. Slump cone test is the most suitable and easy test for finding out the workability of fresh concrete mixtures the test is performed for all the three A/C ratios wiz 7:1, 8:1 and 9:1 for both aggregate size 10mm and 20 mm. workability has a much deeper meaning than other words. The value of slump is lower for conventional concrete and it is very high for porous concrete as the porous concrete has very less surface area for binding material in order to hold all particles together.

a) *Procedure*

i) First of all after mixing the concrete, sample was taken into the cleaned and oiled mould in four equal layers with 25 times of rodding each layers.

ii) Excess of concrete was removed with trowel and the surface was leveled.

iii) Then the mould was raised from the concrete immediately and slowly in vertical direction

iv) Slump was measured and recorded as the difference of height of the mould and the height of the sample being tested.

b) *Observation And Calculation:* The slump (vertical settlement) value is recorded in terms of millimeters of subsidence of the sample in the test:

Aggregate / cement ratio	Slump value
6:1	149
7:1	152
8:1	157
9:1	160
10:1	162

Table: slump values for different gradation of porous concrete

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However slump values are meaningless in case of porous concrete there are other methods for checking workability of porous concrete at the sites like balling methods in which a small size ball is prepared in hand and the suitability is assured by judging its shape retention capacity.

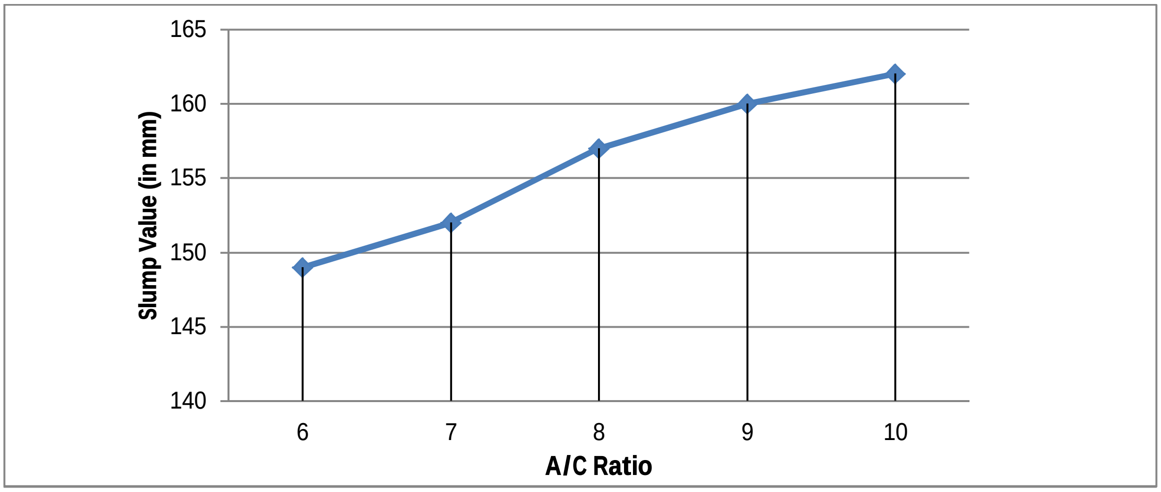

Fig: Variation in slump value for different gradations

2) *Density Test:* Density of concrete is the mass of concrete which is required to fill the container of unit volume. This helps to calculate the yield of concrete per cubic meter. Porous concrete has interconnected voids and more porosity as compare to conventional concrete which results in lower density of the porous concrete. Lower density makes the concrete lighter as compared to traditional high density compact concretes.

a) *Procedure:* Materials and equipments required are, balance, temping rod 38 cm long and cylindrical measure having inner diameter-250mm outer diameter-280mm and capacity 0.01 cum.

b) *Steps*

i) The freshly mixed concrete was filled in the cylindrical measure jar and compacted using tamping rod in the layers of 50mm with 60 strokes and the measure is filled up to the top.

ii) Tamping rod is used for compaction of the concrete and after completing the surface of the concrete is smoothened and leveled.

iii) The jar is measured and weight is noted as '*w*' and the density is calculated by dividing the total weight by the volume of the jar.

$$\gamma = \frac{\mathbf{w}}{\mathbf{volume}}$$

c) *Observational Record:* Density of porous concrete investigated varies approximately between 1800 and 1950 kg/m^3; this is about 22 percent lower than conventional concrete which have density of approximately 2500kg/m^3. Decreased density means lower dead load of structure. As the aggregate cement ratio is increased the lower density concrete is obtained.

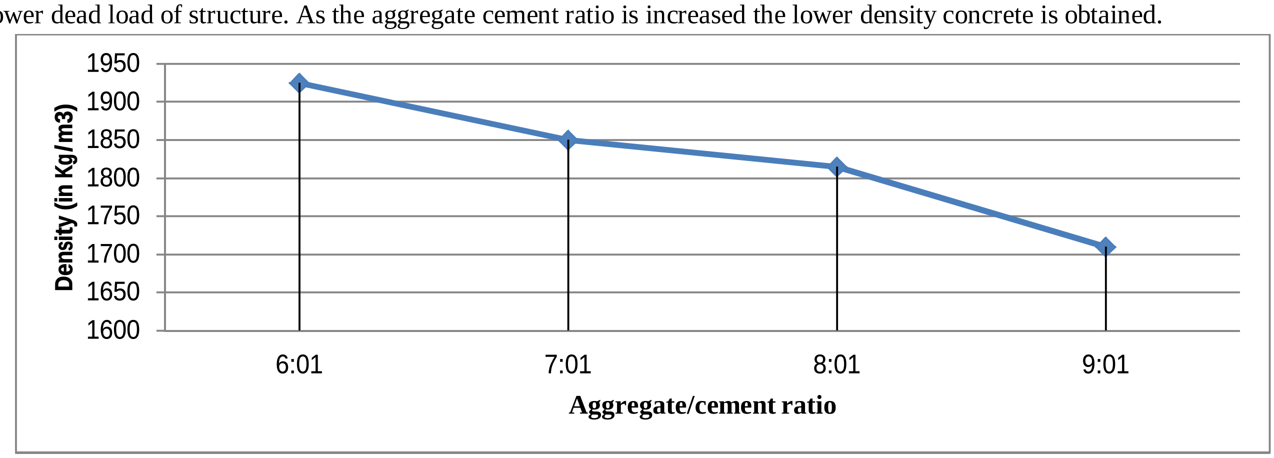

Fig. 1 Variation in density of concrete for different A/C ratio

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3) *Compressive Strength Test*: this test provides information about various parameters of concrete it gives an idea mainly about the strength that the structure is going to achieve in its service life and it gives an idea if the chosen grade of concrete is good for the structure. Compressive strength of concrete is calculated by dividing the load applied by the cross=sectional area of the cube in which load is being applied.

Compressive strength = load applied / c-s area

This value determines the capacity of the concrete to bear compressive stress coming over it due to applied loads.

a) *PROCEDURE:* The compressive strength test was done on 150mm cubes in the laboratory after 7 and 28 days of curing. The concrete achieves its maximum strength at 28 day after casting however due to restriction of time available and cost involved in each working day the strength of concrete is calculated at lesser interval of time as 7 days and 3 days. Procedure for test involves following steps:

i) The concrete is filled in the cleaned and oiled cube mould and temped to achieve desirable compaction.
ii) Sample is left for setting for one day and then the cubes are removed carefully out of the moulds for curing.
iii) Curing of concrete cube sample is done with water for next 7 days of three cube samples and three cube specimens of each batch was kept for 28 days curing.
iv) Cubes are tested on the compressive strength testing machine
v) And the compressive strength for different cubes was recorded in MPa.

b) *Observation And Calculation:* Graph shows the variation of compressive strength for different aggregate/cement ratio at different ages. The compressive strength of porous concrete for given duration increases with same rate as that for conventional concrete. Compressive strength was highest for aggregate/cement ratio 6:1 and lowest for aggregate/cement ratio of 10:1. The overall average compressive strength however was lesser for porous concrete as compared to conventional concrete because of higher porosity present in porous concrete. The compressive strength values for load bearing walls are recommended as minimum of 2.76MPa at 28 days for load bearing walls. The strength of tested sample was however enough for drainage and walling materials.

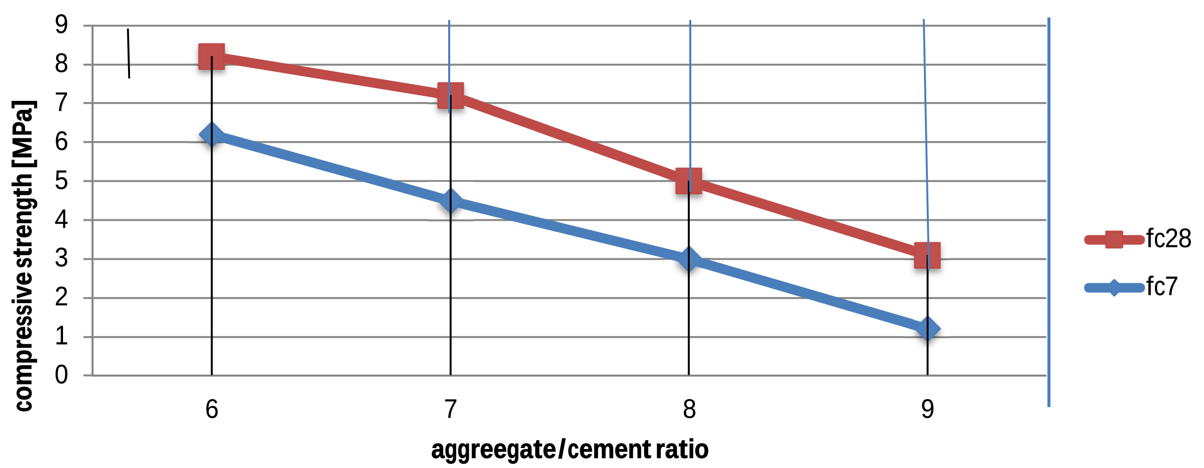

FIGURE: 4.2 effect in compressive strength for different A/C ratio

4) *Split Tensile Strength Test*: tensile strength test is done to calculate the tensile strength of the cylindrical test specimens of porous concrete prepared for different gradations. It is the standard test for calculating tensile strength of concrete indirectly. Tensile strength of concrete is generally very low as compared to its compressive strength.

a) *Procedure:* for tensile strength test standard cylindrical specimens of size 150mm diameter and 300mm of length was used for different gradations 3 specimens were prepared for each batch wiz. 6:1, 7:1, 8:1 and 9:1. Tensile strength test was performed using compression testing machine the cylindrical specimen was placed horizontally between the loading surfaces of the machine diametrically the compression load is applied uniformly along the length of the cylinder till the cylinder fails along the vertical diameter. To reduce the load concentration at the point of loading and to distribute the loads uniformly all over the surface the plywood strips were used between the loading platens of the testing machine and the test specimen. The specimen cylinder splits into two halves due to the tensile stress developed.

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b) *Observation And Calculation*: Tensile strength for different aggregate/cement ratio is shown in the figure 4.3. It is estimated that the tensile stress due to loading acts 5/6th part of the lower cylinder and the upper only 1/5th part of the specimen was under compression. Concrete specimen is assumed behave as an elastic material the uniform laterally acting tensile strength can be calculated using formula given below:

$$\mathbf{ft} = \frac{\mathbf{2P}}{\boldsymbol{\pi}\mathbf{DL}}$$

Where,
P = Compressive load at the failure
D= diameter of the cylindrical specimen
L= length of the cylindrical specimen
From the tests it is clear that the maximum tensile strength is achieved for A/C of 7:1 and it decreases for higher aggregate/cement ratios. However tensile strength of porous concrete is less than the tensile strength of conventional concrete.

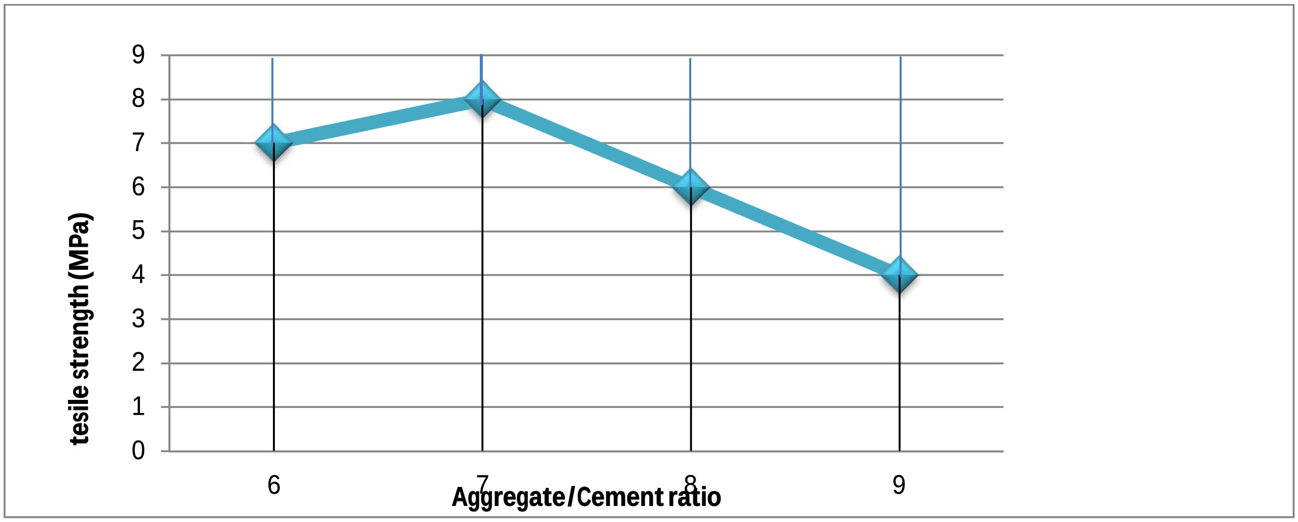
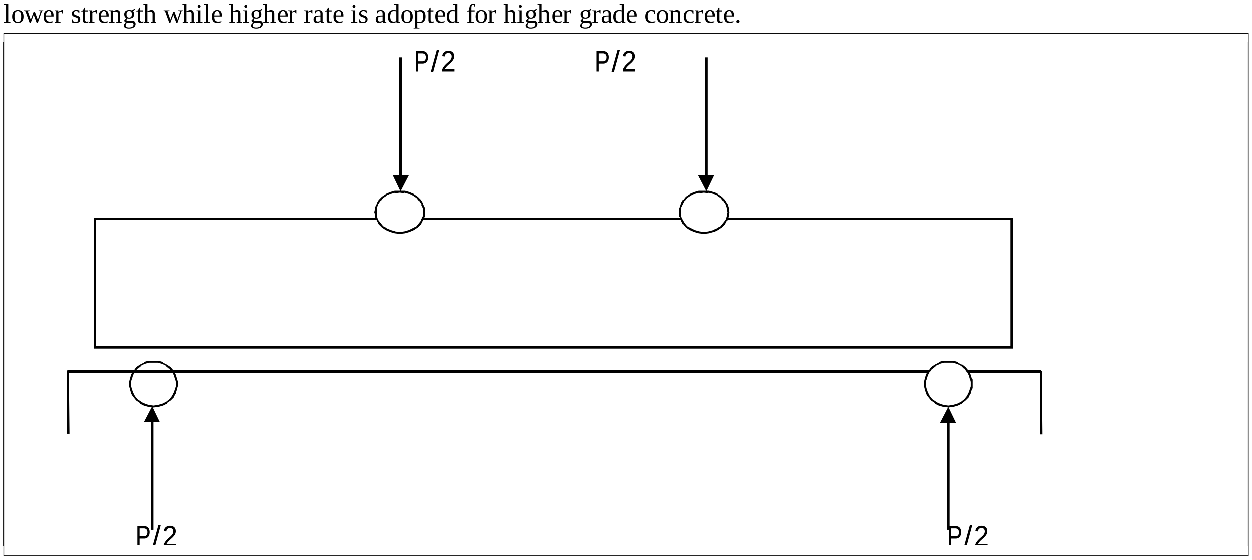


Figure 4.3 Variation in tensile strength for different gradations

5) *Flexural Strength Test:* It's another indirect test for calculating the tensile strength of concrete just as the split tensile strength test. It evaluates the strength of slabs and beams against failure in bending.

a) *Procedure And Calculation:* The flexural strength test was conducted on beam specimen of standard size of 150mm x 150mm x 750mm. the beam was loaded at 1/3rd of the span points with equal loadings at equal distances from both the supports it generates equal reaction at both the supports at the same time its value is same as that of loading itself gradually the load is increased at such a rate that the rate of increase in stress in bottom fiber lies within the range of 0.02 to 0.01 MPa. Lower rate is for lower strength while higher rate is adopted for higher grade concrete.



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In above loading condition, it is clear that the portion of the beam between the two loading contains only pure bending moment and no shear stress hence it can be said that the middle 1/3rd portion of the beam is subjected to maximum pure bending moment with zero shear stress.

As gradually the loading is increased the beams starts showing fractures within the middle 1/3rd portion at the maximum tensile stress the flexural tensile strength is obtained and which is known "as modulus of rupture" denoted as f_{bt} it is calculated from the formula given below:

$$f_{bt} = \frac{PL}{bd^2}$$

Where,

P = load at failure

L = beam span between supports

d = depth of beam

b = width of beam

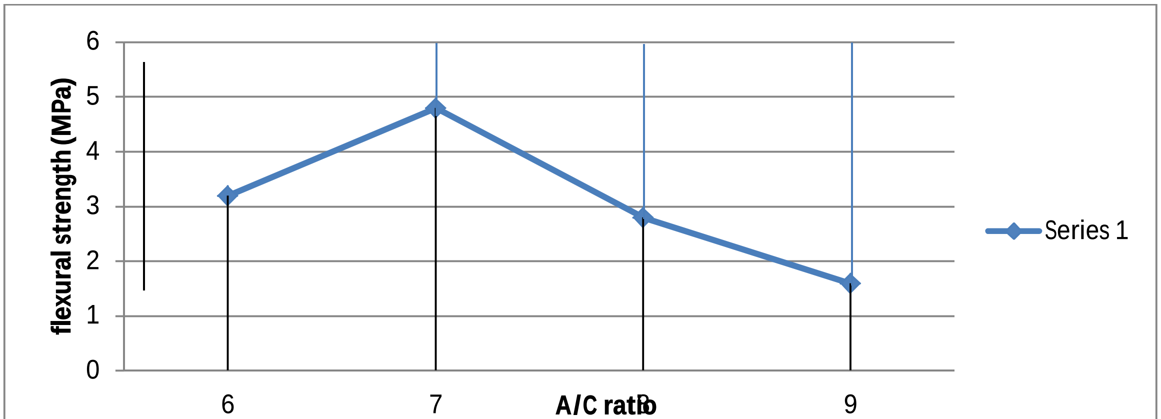

Fig : variation in flexural strength for different gradations

6) *Water Permeability Test:* The main property of a porous concrete is its permeability that is its ability to percolate water through it. This ability decides the suitability and usefulness of the pavement so constructed at any location. Permeability test can be of two types one is constant head test and the other one is the falling head method. These two methods provide the value of permeability coefficient *k*.

In this paper the permeability of prepared porous concrete was tested by constant head permeability test method.

a) *Procedure And Calculation:* type of standard permeability test procedure adopted is constant head permeability test: the schematic diagram is shown in below figure.

i) Cylindrical specimen of standard size of 100 x 200 mm was prepared by using standard mould.

ii) The water pipe was filled with water for a certain head which will remain constant throughout the experiment by using the releasing pipe.

iii) The test specimen was inserted in its place and water is allowed to flow through it to find the water flowing capacity of the prepared concrete.

iv) The head is kept constant and the permeability coefficient was calculated by using following formula given in various text books:

$$k = \frac{QL}{AH\Delta T}$$

Where:

K = water permeability coefficient (cm/s),

Q = flow volume (ml),

L = length of specimen in (cm)

A = pervious surface area of specimens (cm^2)

H = water head height (cm)

$T = \Delta t_1 - t_2$ time interval of measurement (s)

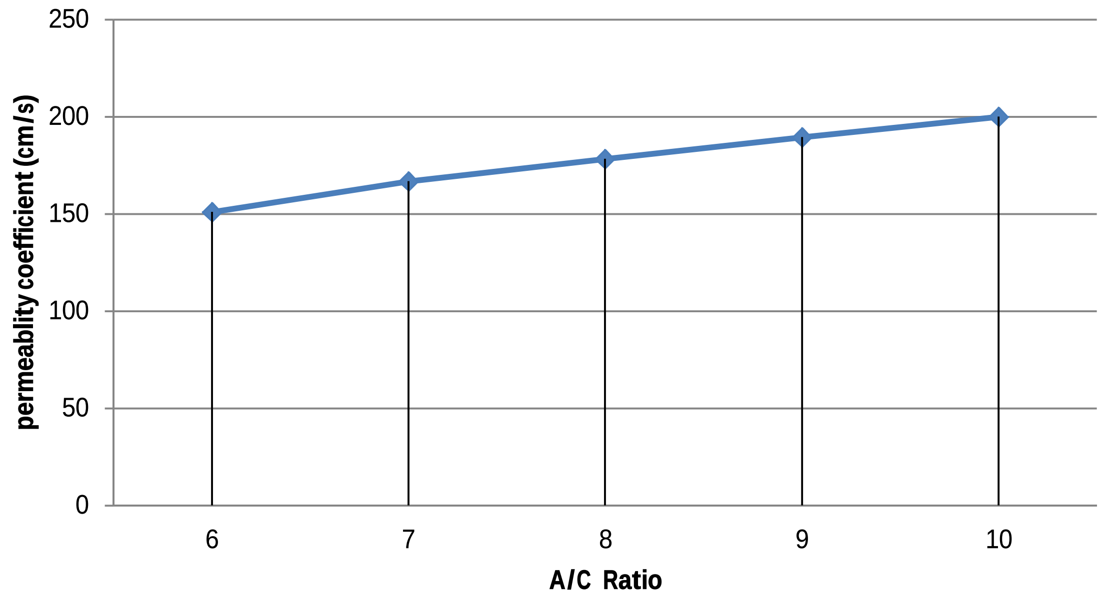

fig: variation in permeability coeffients for different gradations

Aggregate/ cement ratio	Permeability coefficient (cm/s)
6:1	150.80
7:1	166.66
8:1	178.20
9:1	189.30
10:1	199.90

V. RESULT AND DISSCUSSION

The experiment performed shows that the compressive strength and other strength are comparatively lower for porous concrete and the permeability coefficient of porous concrete is relatively higher than that of conventional less porous concrete. The permeability characteristics of the porous concrete increases with the increase in its aggregate cement ratio and simultaneously its strength increases with increasing aggregate cement ratio.

VI. CONCLUSION

A. The permeability of porous concrete increases with increasing aggregate cement ratio.

B. The compressive strength, flexural strength, and tensile strength decreases with increasing porosity or say increasing aggregate cement ratio.

C. This porous concrete so prepared can be used for low traffic areas like parking and where only foot traffic is allowed.

D. If one wants to achieve more compressive strength as well as significant porosity for good permeability than admixtures can be used in the concrete mix.

E. Slump value for porous concrete is higher as compared to conventional concrete and is of meaning in case of porous concrete. Other method for finding out workability is adopted for porous concrete such as balling method.

F. Density of porous concrete is less in comparison with the conventional concrete because of fewer voids present in porous concrete. Hence it is good for light weight concrete works.

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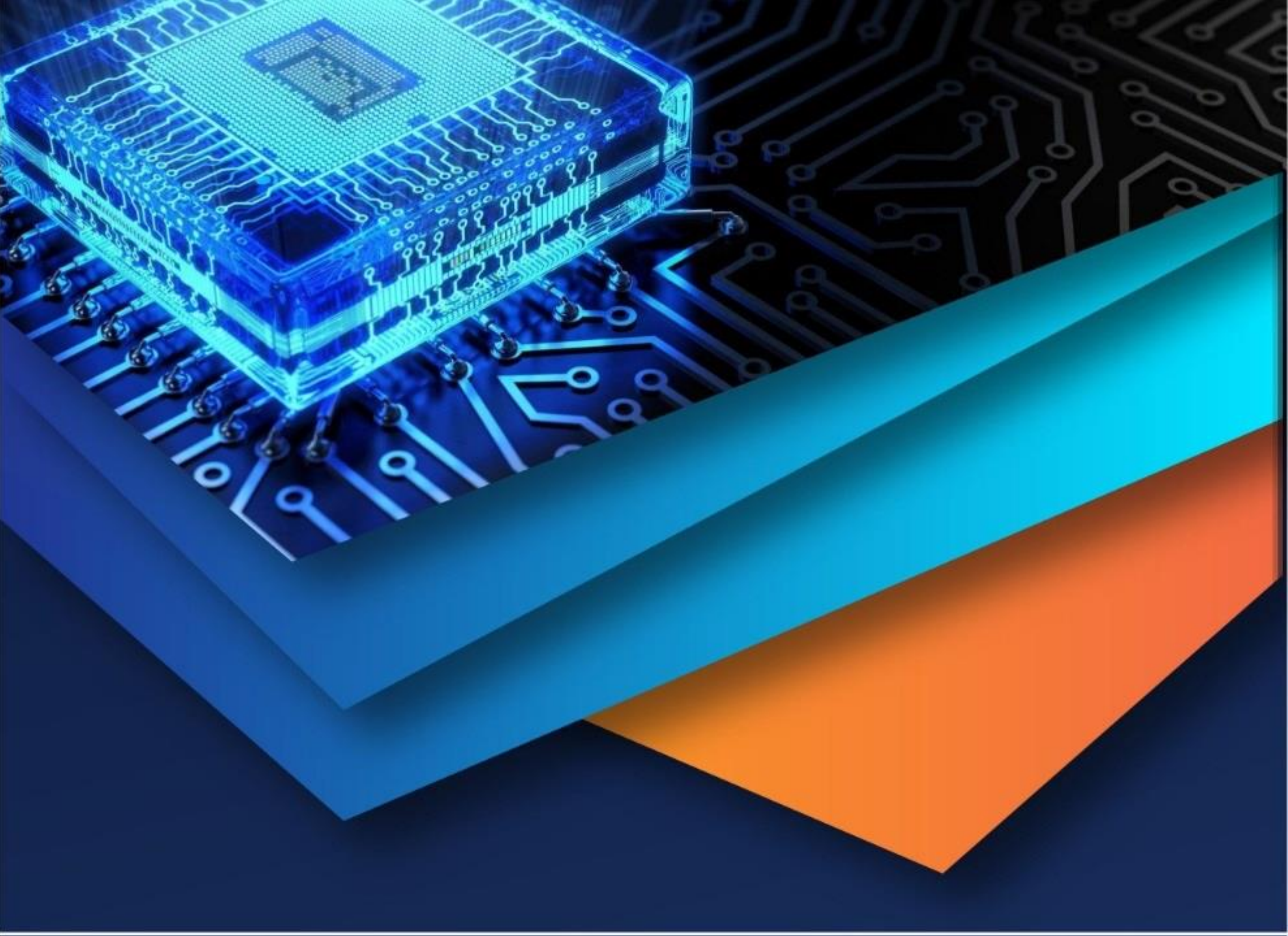

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