STRENGTH AND DURABILITY STUDY OF PERVOIUS CONCRETE

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Abstract* — Concrete is a construction material composed of cement, commonly Portland cement as well as other cementations materials such as fly ash and slag cement, coarse aggregate, fine aggregate such as sand, water, and chemical admixtures. Porous concrete is concrete which is designed to have many voids to trap water and allow it to penetrate through the concrete to the ground below. This concrete does not use fine aggregates in the mixture. Thats why it has more voids than conventional concrete. The materials use is coarse aggregates, cements and water. We totally eliminate the use of fine aggregates in porous concrete. There are a number of alternate names for porous concrete including permeable concrete, porous pavement, and pervious concrete. All of the names basically mean the same thing which is porous concrete is a form of concrete which is permeable, rather than solid. Porous concrete is made by mixing large aggregate material with mortar, creating lots of voids in the cast concrete. When water lands on the concrete, it flows through the voids and go to the ground below.

Porous concrete, no fine aggregate is the term for a mixture of coarse aggregate, Portland cement and water that allow for rapid infiltration of water and overlays a stone aggregate reservoir. It is a unique and effective mean to address important environmental issues and support sustainable growth. Porous concrete has been developing as an environmentally friendly material in Japan since1980s. Since then it has been widely used in various application. The water -permeating, water-draining, and water-retaining performances of this porous concrete have been utilized in road pavement, sidewalks, parks and building extension, as well as for plant bedding and permeable gutters.

Keywords- Porous Concrete, pavement, infiltration

1. INTRODUCTION

Porous concrete pavement can potentially infiltrate storm water at source which will allow the oils from cars and trucks to biodegrade safely, improve driving safety, reduce traffic noise and also reduce urban temperatures. There had been numerous studies throughout others country on porous concrete and their application like road pavement, fishing bank and even for sidewalks. Many researches were conducted to design materials based on requirements within the aspect of economical, availability, recyclability, energy use, cost and environmental considerations. Therefore before the new material can be widely used as a building material, the properties of the material and methods to improve the material are to be studied carefully. The good thing about porous concrete is it very suitable for people who are concerned about the environment because porous concrete traps water, rather than allowing it to drain uselessly into the ocean.

Porous concrete can help route storm runoff and rain directly into the soil where it can nourish gardens and flow down into the water table. It also can be made with recycled materials including recycled concrete rubble and recycling aggregates. This flexibility and potential for recycling makes it an ecologically friendly and aesthetically pleasing building material. The good thing about porous concrete is it very suitable for people who are concerned about the environment because porous concrete traps water, rather than allowing it to drain uselessly into the ocean. Porous concrete can help route storm runoff and rain directly into the soil where it can nourish gardens and flow down into the water table. It also can be made with recycled materials including recycled concrete rubble and recycling aggregates. This flexibility and potential for recycling makes it an ecologically friendly and aesthetically pleasing building material.

Black pavement vs pervious pavement

Black pavements and hot impervious roofs are taking more and more natural planted surfaces out of doing what they do best. Natural surfaces like grass and trees absorb sunlight and through photosynthesis they remove that Global Warming gas, Carbon Dioxide, as well as other pollutants from the air we breathe. Also their roots and foliage help trap storm water and move it to the underground aquifer. If you are concerned about global warming, consider this: Asphalt pavements absorb more of the heat of the sun. This adds to the problem. Because asphalt is so widely used it creates heat islands as its black or grey surface absorbs sunlight. In summer its temperature may climb to 140° F or more. That heat requires more air conditioning thus requiring more electricity. Most electricity is generated using fossil fuels. So not only does this waste money, but in making electricity, power plants create more greenhouse gasses. Even impervious concrete absorbs much heat from the sun. Of the three, pervious concrete is the coolest. When it rains on hot pavements, the rain evaporates more quickly. Less water reaches the aquifer or other runoff receptors. Without Pervious Pavements, what eventually reaches streams, estuaries, the bays, the Intracoastal Waterway and the Gulf of Mexico or ocean is warmer water. It affects everything living in those waters changing the balance of nature.

Fig 1.2 Ordinary concrete and pervious pavement

Pervious Concrete Reduces Problems

It may reduce or eliminate the need for subterranean storm sewer drains. Pervious concrete not only eliminates much of the run off from pavements, but may also catch the runoff from roofs and return it to the aquifer. Trees are great tools in fighting the greenhouse effect. Unlike impervious pavements, Pervious Concrete lets water and oxygen enter the soil below. This allows tree roots to perform their tasks efficiently. Those tasks include cooling the surrounding air by the evaporation of the captured ground water. This helps reduce air conditioning costs.

Pervious Concrete because of its Solar Reflectivity Index of about 29 absorbs much less heat than asphalt and with its water retention it reduces the load on air conditioning.

Finally for the developer or engineer, it makes possible maximum land use for parking lots, roads, and structures. With certified engineering it can reduce the size of retention areas. Storm drains may be eliminated and some curbing as well. For watershed and estuary areas it is an environmental tool to keep these waters clean and cooler. These are ecological as well as dollars and cents issues.

Trees thrive as Pervious Concrete allows rain water to reach their roots.As the water is drawn up to the leaves or blades of grass the miracle of transpiration converts it back to vapor which helps create more rain while cooling surrounding air.

MATERIALS USED:

3.1.1 CEMENT

Pozzlona Portland cement was used in casting the specimens. The results of Specific Gravity, Fineness, Initial setting time and Consistency of the cement were given in Table No.3.1

Fig 3.1 Ordinary Portland cement

3.1.2 COARSE AGGREGATE

Hard granite broken stones of less than 20mm size were used as coarse aggregate. The results of Specific Gravity, Fineness modulus, Water absorption and Bulk density of the coarse aggregate were given in Table No.3

3.1.3 WATER

Potable water available in laboratory with pH value of 7.0±1 and conforming to the requirement of IS 456-2000 was used for mixing concrete and curing the specimen as well.

3.1.4 FLY ASH

Fly ash was used as admixture in casting the specimens.20% of cement was replaced by the fly ash in order to increase the strength of pervious concrete. The results of Specific Gravity, Fineness, Initial setting time and Consistency of the fly ash were given in table3.3

3.2 PROPERTIES OF MATERIALS

3.2.1 CEMENT: The type of cement used was Portland Pozzalona Cement.

3.2.1.1Specific Gravity:

The density bottle was used to determine the specific gravity of cement. The bottle was cleaned and dried. The weight of empty bottle with brass cap and washerW_1 was taken. Then bottle was filled by 200 to 400g of dry cement and weighed as W_2.The bottle was filled with kerosene and stirred thoroughly for removing the entrapped air which was weighed as W_3.It was emptied, cleaned well, filled with kerosene and weighed as W_4.

$$\text{Specific gravity of Cement (G)} = \frac{(W_2-W_1)}{(W_2-W_1) - (W_3-W_4)}$$

W_1 = Weight of empty density bottle with brass cap and washer in gm.

W_2 = Mass of the density bottle & cement in gm.

W_3 = Mass of the density bottle, cement & kerosene in gm.

W_4 = Mass of the density bottle filled with kerosene in gm.

3.2.1.2 Fineness (by sieve analysis):

The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat. Finer cement offers a greater surface area for hydration and hence faster development of strength.

100 grams of cement was taken on a standard IS SieveNo.9(90 microns). The air-set lumps in the sample were broken with fingers. The sample was continuously sieved giving circular and vertical motion for 15 minutes. The residue left on the sieve was weighed.

3.2.1.3 Consistency:

The objective of conducting this test is to find out the amount of water to be added to the cement to get a paste of normal consistency. 500 grams of cement was taken and made into a paste with a weighed quantity of water (% by weight of cement) for the first trial. The paste was prepared in a standard manner and filled into the vicat mould plunger, 10mm diameter, 50mm long and was attached and brought down to touch the surface of the paste in the test block and quickly released allowing it to sink into the paste by its own weight. The depth of penetration of the plunger was noted. Similarly trials were conducted with higher water cement ratios till such time the plunger penetrates for a depth of 33-35mm from the top. That particular percentage of water which allows the plunger to penetrate only to a depth of 33-35mm from the top is known as the percentage of water required to produce a cement paste of standard consistency.

3.2.1.4 Initial setting time:

The needle of the Vicat apparatus was lowed gently and brought in contact with the surface of the test block and quickly released. It was allowed to penetrate into the test block. In the beginning, the needle completely pierced through the test block. But after sometime when the paste starts losing its plasticity, the needle penetrated only to a depth of 33-35mm from the top. The period elapsing between the time when water is added to the cement and the time at which the needle penetrates the test block to a depth equal to 33-35mm from the top was taken as the initial setting time.

3.2.2 COARSE AGGREGATE: 12.5mm down size aggregate was used.

3.2.2.1 Specific Gravity:

A pycnometer was used to find out the specific gravity of coarse aggregate. The empty dry pycnometer was weighed and taken as W_1. Then the pycnometer is filled with 2/3 of coarse aggregate and it was weighed as W_2. Then the pycnometer was filled with part of coarse aggregate and water and it weighed as W_3. The pycnometer was filled up to the top of the bottle with water and weighed it as W_4.

$$\text{Specific gravity of Cement (G)} = \frac{(W_2-W_1)}{(W_2-W_1) - (W_3-W_4)}$$

W_1 = Mass of empty pycnometer in gm.

W_2 = Mass of pycnometer& coarse aggregate in gm.

W_3 = Mass of the pycnometer, coarse aggregate & water in gm.

W_4 = Mass of the pycnometer filled with water in gm.

3.2.2.2Bulk density:

Bulk density is the weight of a material in a given volume. It is expressed in Kg/m^3.A cylindrical measure of nominal diameter 250mm and height 300mm was used. The cylinder has the capacity of 1.5 liters with the thickness of 4mm. The cylindrical measure was filled about 1/3 each time with thoroughly mixed aggregate and tampered with 25 strokes. The measure was carefully struck off level using tamping rod as straight edge. The net weight of aggregate in the measure was determined. Bulk density was calculated as follows.

Bulk density = (Net weight of coarse aggregate in Kg)/(Volume)

3.2.2.3 Surface moisture:

100g of coarse aggregate was taken and their weight was determined, say W_1. The sample was then kept in the oven for 24 hours. It was then taken out and the dry weight is determined, says W_2. The difference between W_1 and W_2 gives the surface moisture of the sample.

3.2.2.4 Water Absorption:

100g of nominal coarse aggregate was taken and their weight was determined, say W_1. The sample was then immersed in water for 24 hours. It was then taken out, drained and its weight was determined, say W_2. The difference between W_1 and W_2 gives the water absorption of the sample.

3.2.2.5 Fineness modulus:

The sample was brought to an air-dry condition by drying at room temperature. The required quantity of the sample was taken (3Kg). Sieving was done for 10 minutes. The material retained on each sieve after shaking, represents the fraction of the aggregate coarser then the sieve considered and finer than the sieve above. The weight of aggregate retained in each sieve was measured and converted to a total sample. Fineness modulus was determined as the ratio of summation of cumulative percentage weight retained (F) to 100.

3.3 TEST RESULTS OF MATERIAL PROPORTIES:

3.3.1CEMENT:

Table 3.1 Test results of cement

Specific gravity	3.15
Fineness (by sieve analysis)	2%
Consistency	31%
Initial setting time	110minutes

3.3.2 COARSE AGGREGATE

Table 3.2 Test results of coarse aggregate

S.NO	**Description**	**Values**
1	Specific gravity	2.65
2	Bulk density	1642.45 Kg/m^3
3	Surface moisture	0.08%
4	Water absorption	1%
5	Fineness modulus	6.98

3.3.3FLY ASH

Table 3.3 Test results of Fly ash

S.NO	**Description**	**Values**
1	Specific gravity	2.15
2	Fineness (by sieve analysis)	7%
3	Setting time	35 min
4	Consistency	29%

MIX DESIGN

(BASED ON **ACI 522R-06)**

PERVIOUS CONCERTE OF STRENGTH 20 MPa

Design average cube strength at 28 days

20/0.75 = 26.66 N/mm^2

a/c = 3

Adopted W/C ratio = 0.31

Density of concrete = 2414 Kg/m^3

Bulk density of cement = 1411 Kg/m^3

Bulk density of coarse aggregate:

12.5 mm = 1675.43 Kg/m^3

For 12.5 mm:

a/c ratio by weight = 3 X 1675.43/1411 = 3.5622

Cement: Aggregate: Water

1 : 3.5622: 0.31

Quantities of materials per m^3 Concrete:

Cement = 372.956 Kg/m^3

C.A = 1660.75 Kg/m^3

Water = 144.52Kg/m^3

Fly ash = 93.239 Kg/m^3

TESTING DETAILS AND RESULTS

Production of good quality concrete requires meticulous care exercised at every stage of manufacture of concrete. It is interesting to note that the ingredients of bad concrete are the same. If meticulous care is not exercised and good rules are not observed, the resultant concrete is going to be of bad quality. With the same material if intense care to exercise control at every stage it will in good concrete. The various stages of manufacture of concrete are in this chapter.

5.2 CASTING OF TEST SPECIMENS

5.2.1 BATCHING

The measurement of materials for making concrete is known as batching. Here, we have adopted weigh-batching method, and it is the concrete method too. Use of weigh system batching, facilitates accuracy, flexibility and simplicity. Different types of weigh batchers are available; the particular type to be used depends up on the nature of the job. When weigh batching is adopted, the measurement of water must be done accurately. Addition of water in terms of liter will not be accurate enough for the reasons of spillage of water etc.

5.2.2 PREPARATION OF THE MOULD

The compressive strength of the concrete was determined by cubes of size 150mmx150mmx150mm.Flexural strength of the concrete was determined by the beams of size 100mmx100mmx500mm.The percentage of wear for pervious concrete was determined by mould of size 700mmx700mmx350mm.The impact strength of pervious concrete was determined by moulds of size 145mm diameter and 60mm height. The permeability of pervious concrete was determined by the specimen of 90mm diameter and 150mm height .

Fig 5.1 Moulding of specimens

All the faces of the moulds are assembled by using nuts and bolts and are clamped to the base plate. It is also to be noted that, all the internal angle of the moulds must be 90.The faces must be thinly coated with mould oil to prevent leakage during filling.

5.2.3 MIXING

Thorough mixing of materials is essential for the production of uniform course. The mixing should ensure that the mass becomes homogeneous, uniform in colour and consistency. As the mixing cannot be thorough, it is desirable to add 10% more materials.

The mixing was done by concrete mixer machine first pour little amount of water inside the drum. Rotate the drum, add coarse aggregate and cement. Add remaining water inside. Rotate the drum continuously till the mix become homogeneous.

5.2.4 POURING OF CONCRETE

After mixing, the moulds are filled immediately by pouring the concrete inside. Concrete is filled in three layers, each layer is compacted well by using needle vibrator of standard size (25mm), so as to avoid entrapped air inside the concrete cubes and honey combing effects on the sides. During pouring of concrete, is better to avoid wasting of concrete for effective and economical usage.

5.2.5 COMPACTION OF CONCRETE

Compaction of concrete is process adopted for expelling the entrapped air from the concrete. In the process of mixing, transporting and placing of concrete air is likely to get entrapped. Machine compaction was done using a needle vibrator of 25mm diameter. When machine compaction is adopted, the consistency of concrete is maintained at higher.

Concrete is filled in layers of 15 to 20mm, and each layer is compacted using needle vibrator. During compaction the strokes should be distributed in a surface of concrete, and should not forcibly strike the bottom of the mould. After the top layer has been compacted, a strike off bar is used to strike out the excess concrete.

5.2.6 DEMOULDING

The cube specimens are demoulded after 24 hours from the process of moulding. If the concrete has not achieved sufficient strength to enable demoulding the beam specimens, then the process must be delayed for another 24 hours care should be taken not to damage the specimen during the process because, if any damage is caused, the strength of the concrete may get reduced. After demoulding, specimen is marked with a legible identification, on any of the faces by using paint.

Fig 5.2 Demoulded specimens

5.3 TESTING OF SPECIMEN

5.3.1 MECHANICAL PROPERTIES

5.3.1.1 UNIT WEIGHT

Unit weight of pervious concrete is achieved as 2115.5Kg/m^3.

5.3.1.2 COMPRESSIVE STRENGTH

The Compressive strength of the concrete was determined by cubes of size 150mm x 150mm x 150mm. The compressive strength of pervious concrete is strongly affected by the matrix proportion and compaction effort during placement.

Although the water cement ratio of a pervious concrete mixture is important for the development of compressive strength and void structure, the relationship between the water cement and compressive strength of conventional concrete is not significant.

A high water cement ratio can result in the paste flowing from the aggregate and filling the void structure. A low water cement ratio can result in reduced adhesion between particles and placement problems.

Experience has shown that a water cement ratio of 0.26 to 0.45 provides good aggregate coating and paste stability.

The total cementitious material content of a pervious concrete mixture is important for the development of compressive strength and void structure. A high paste content will result in a filled void structure and consequently, reduced porosity. An insufficient cementitious content can result in reduced paste coating of the aggregate and reduced compressive strength. The optimum cementitious material content is strongly dependent on aggregate size and gradation.

Pervious concrete mixtures can develop compressive strengths in range of 3.5Mpa to 28Mpa which is suitable for a wide range of applications. Typical values are about 17Mpa.Compressive strength is obtained with compressive testing machine.

Table 5.1 Compressive Strength Test Results

S. No	Cube Size in mm	7 days strength in N/mm^2	28 days Strength in N/mm^2	56 days compressive strength N/mm^2
1	150 x 150 x 150	17.16	25.73	26.91

Fig 5.3 Compressive Strength Test

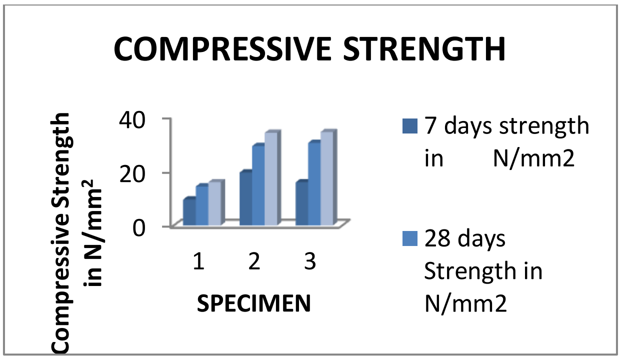

Fig 5.4 Comparison graph for Compressive Strength Test Results

5.3.1.3 SPLIT STENSILE STRENGTH

Tensile strength is determined by casting three cylinders of size 300 mmx150 mm and testing it.

Table 5.2 Tensile Strength Test Results

S.No	Specimen Size in mm	7 days strength in N/mm^2	28 days Strength in N/mm^2	56 days strength in N/mm^2
1	300 x 150	1.96	2.33	2.34

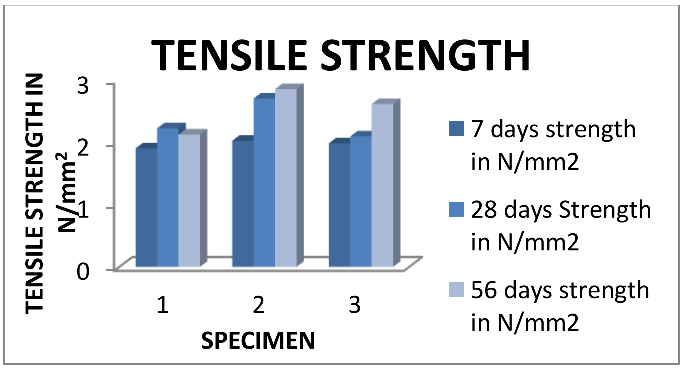

Fig 5.6 Comparison graph for Tensile Strength Test Results

5.3.1.4 FLEXURAL STRENGTH

Flexural strength is determined by casting three beams of size 100 mm x 100 mm x 500 mm and testing it in universal testing machine.

Table 5.3 Flexural Strength Test Results

Fig 5.8 Specimen after testing

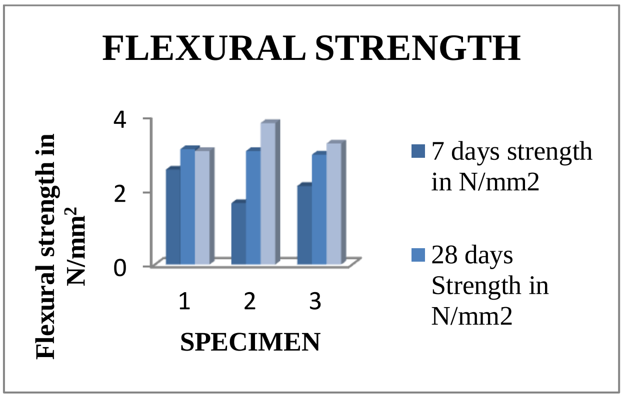

Fig 5.9 Comparison for Flexural Strength Test Results

5.3.2DURABILITY PROPERTIES:

The following properties were tested for determining the durability.

- Abrasion resistance
- Permeability
- Impact strength
- Void ratio

5.3.2.1ABRASION RESISTANCE

Because of the rougher surface texture and open structure of pervious concrete, abrasion and raveling of the aggregate particles can be a problem, particularly where snowplows are used to clear pavements. This is one reason why applications such as highways are generally not suitable for pervious concretes. However, anecdotal evidence indicates that pervious concrete pavements allow snow to melt faster, requiring less plowing.

Table 5.4 Abrasion resistance Test Results

S.No	Specimen	Weight Before Test	Weight After Test	Percentage of Wear
1	700mm x 700mm x 350mm	0.275	0.268	2.54

Fig 5.10 Abrasion testing machine

5.3.2.2 PERMEABILITY TEST:

The flow rate of the pervious concrete depends on the material and placing operations. Typical flow rates for water passing through pervious concrete are 120L/m^2/min or 0.2cm/s. to 320L/m^2/min or 0.54cm/s with rates up to 700L/m^2/min,1.2cm/s. Even higher rates have been measured in the laboratory.

It is reported that for pervious concrete, based on permeability measurements for void fractions, the percolation threshold for the voids is somewhere in the range of 10% to 15%.

One of the most important features of pervious concrete is its ability to percolate water through the matrix. The percolation rate of the pervious concrete is directly related to the air void content. Through experiment it is found that 15% is required to achieve significant percolation.

Because the percolation rate increases as the void content increases and consequently, compressive strength decreases, the challenge in pervious concrete mixture proportioning is achieving a balance between an acceptable percolation rate and an acceptable compressive strength.

The permeability of pervious concrete can be measured by simple falling head parameters as shown in figure. Water is added to the graduated cylinder to fill the specimen cell and the drainage pipe. The specimen is preconditioned by allowing water to drain out through the pipe until the level in the graduated cylinder is the same as the top of the drain pipe. This minimizes any air pockets in the specimen and ensures that specimen is completely saturated. With the valve is closed, the graduated cylinder is filled with water. The valve is then opened, and the time in seconds 't' required for water to fall from an initial head $h_1$is to final head $h_2$is measured.

The coefficient of permeability k in m/sec can be expressed as, Where A=0.084m

K=A/T

The flow rate of specimen using 12.5mm aggregate was 668.05 L/m^2/min.

Fig 5.11 Permeability of pervious concrete

Table 5.5 Permeability test results

S.No	Size of the specimen mm	Permeability
1	150 x 95	668.05 L/m^2/min.

5.3.2.3 IMPACT STRENGTH

Impact test is performed by impact testing machine with drop hammer. The test procedure for impact test is as follows.

- The concrete specimen of 150mm diameter and 63.5mm thickness was placed on base plate and it was free to move horizontally 2.8mm off between the four positioning lugs at the periphery of the base plate

- A bracket having a cylindrical sleeve was placed over the test specimen
- Hardened steel ball was placed within the sleeve on the top of the specimen
- The ball was free to move vertically within the sleeve
- A drop hammer was used to apply the impact load. The weight of the hammer is 45N
- The number of blows required by dropping the hammer through a height of 457mm to cause the first visible crack and to cause ultimate failure was recorded
- Ultimate failure is defined in terms of number of blows required to open the crack in the specimen to enable the fractured pieces to touch three or four positioning lugs on the base plate
- Each blow of hammer represents 20.2Nm of energy. The stages of ultimate failure are clearly recognized by fractured specimen butting against the legs of the base plate

Impact value = Number of blows corresponding to ultimate failure

Table 5.5 Impact strength result

s.no	Specimen size	No of blows	Impact energy in Nm
1	145 x 60	7	365.32
2	145 x 60	6	313.13

5.3.2.4 Void ratio

The void ratio of pervious concrete was determined by calculating the difference in weight between the dry sample and the saturated under water sample and using the Equation 1(Park and Tia2004).

$$V_r = \left[1 - \frac{W2-W1}{\rho_W \cdot vol} \right] \times 100\ \%$$

Where,

V_r = total void ratio, %

W_1 = weight under water, kg

W_2 = oven dry weight, kg

Vol = Volume of sample,m^3

ρ_W = density of water, kg/m^3

Table 5.6 Void ratio test results

Aggregate size	W_1 (Kg)	W_2 (Kg)	V_r
12.5mm	0.65	1.25	37.10%

6.1 Cost comparison of ordinary and pervious concrete

Ordinary concrete M20 grade = 4500 /m^3

Pervious concrete:

12.5 mm aggregate = 0.99m^3 @ Rs 741.30 m^3 = Rs 733.89

Fly ash - 93.23 Kg @ 1.00 Kg = Rs 93.23

Cement – 372.96 kg @ 5.00 kg = Rs 1864.80

Labor charges – Rs 635.58

Others – Rs 50.00

Total cost of concrete = Rs 3377.50

CONCLUSION

- The unit weight of Pervious concrete is achieved as 2115.5Kg/m^3.
- The average compressive strength achieved in 7 days as 17.15N/mm^2,28 days average compressive strength is achieved as 25.73 N/mm^2 and the 56 days compressive strength is achieved as 26.91 N/mm^2
- The average tensile strength achieved in 7 days as 1.96 N/mm^2,28 days average tensile strength is achieved as 2.33 N/mm^2 and the 56 days tensile strength is achieved as 2.35 N/mm^2
- The average flexure strength achieved in 7 days as 2.10 N/mm^2,28 days average flexure strength is achieved as 3.03 N/mm^2 and the 56 days flexure strength is achieved as 3.36 N/mm^2
- The average abrasion resistance of pervious concrete is achieved as 2.54%
- The flow rate of the Pervious concrete is 668.05 lit/m^3/min.
- The average impact energy was achieved as 339.22 Nm.
- The void ratio of Pervious concrete is achieved as 37.10%

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