Experimental Investigation of Pervious Concrete using Titanium Dioxide

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ABSTRACT

This paper reports an experimental investigation into the development of pervious concrete providing the optimal combination of strength and water permeability without using any admixtures. This titanium dioxide is used as partial replacement to cement to study its behavior on mechanical properties of pervious concrete. Pervious concrete trial mixes with different size of aggregate, with and without fine aggregates were tested for its mechanical properties such as compressive strength, water permeability, porosity and density. Trial mix with optimum compressive strength along with sufficient permeability is selected as a basic experimental mix for investigating the effect of partial replacement of cement with titanium dioxide. The highest compressive strength for pervious concrete is observed as 13.66 N/mm2 and water permeability of 15.4 mm/sec is calculated for the experimental mix having 5% replacement of cement with titanium dioxide.

Keyword: -*Pervious Concrete, Titanium dioxide, photocatalysis, compressive strength and permeability*

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1. INTRODUCTION

A larger amount of rainwater ends up falling on impervious surfaces such as parking lots, driveways, sidewalks, and streets rather than soaking into the soil. This creates an imbalance in the natural ecosystem and leads to a host of problems including erosion, floods, ground water level depletion and pollution of rivers, lakes, and coastal waters as rainwater rushing across pavement surfaces picks up everything from oil and grease spills to de-icing Salts and chemical fertilizers. Conventional normal weight Portland cement concrete is generally used for pavement construction. The impervious nature of the concrete pavements contributes to the increased water runoff into the drainage system, over-burdening the infrastructure and causing excessive flooding in built-up areas. Thus pervious concrete can play a vital role in filtration and rain water harvesting due to its porosity. This type of concrete has become significantly popular as a sustainable application during recent decades due to its potential contribution in solving environmental issues [1].

1.1 Pervious Concrete

ACI 522R-10 define the term “pervious concrete” typically describes a near-zero-slump, open-graded material consisting of Portland cement, coarse aggregate, little or no fine aggregate, admixtures, and water. It is such a concrete that has high porosity and allows draining freely unlike dense, high strength concrete. Its applications are therefore in conditions where water from precipitation or other sources needs to be drained. The high porosity is achieved by the absence or very low content of fine aggregates. Pervious concrete is also known as no-fines concrete, gap graded concrete or porous concrete. It essentially consists of cement, coarse aggregate, water and little or no fine aggregate. In normal concrete, the fine aggregates typically fill in the voids between coarse aggregates. But in pervious concrete fine aggregate is non-existent or present in very small amounts. Moreover, there is globally considerable research is being done on pervious concrete that can be used for concrete flatwork applications. Typically pervious concrete has water to cementitious materials ratio (w/cm) of 0.28 to 0.40 with a void content of

18 to 35%.Pervious concrete is used in parking areas, areas with light traffic, residential streets, pedestrian walkways, and greenhouses.[2]

Fig 1.1: Pervious concrete

It is an important application for sustainable construction and is one of the techniques used for ground water recharge. Pervious concrete naturally filters water from rainfall or storm and can reduce pollutant loads entering into streams, ponds and rivers. So in this way it helps in ground water recharge. It also reduces the bad impact of urbanization on trees. A pervious concrete ground surface allows the transfer of water and air to root systems allowing trees to flourish [4]. Pervious concrete demonstrate the following advantages, benefiting the environment.

1. Decreasing flooding possibilities, especially in urban areas
2. Recharging the groundwater level
3. Reducing puddles on the road
4. Improving water quality through percolation
5. Sound absorption
6. Heat absorption
7. Supporting vegetation growth

On the other hand, pervious concrete also has some disadvantages:

1. Low strength due to high porosity
2. High maintenance requirement
3. Limited use as a load bearing unit due to its low strength

While the primary function of concrete is structural, its pervasiveness in our society lends it to other functions and creates the need for it to maintain its integrity and aesthetic quality. Therefore, concrete with added functionality for example, self-cleaning characteristics and the ability to remove pollutants is desirable. Self-cleaning, air-purifying concrete is a promising technology that can be constructed with air-cleaning agents with super hydrophilic photocatalyst capabilities, such as titanium dioxide. [3]

1.2 Photocatalyst Titanium Dioxide

Photocatalysis is the acceleration of a photoreaction in the presence of a catalyst. It is a technology that could help mitigate air pollution and ultraviolet rays. Photocatalytic components use energy from sunlight (or other ultraviolet light sources) and convert into harmless substances. These products reduce NO_x, SO_x, smoke, bacteria etc. from the atmosphere and also serve as self-clean material.Photocatalysis employs semiconductors such as strontium titanate ($SrTiO_3$), titanium dioxide (TiO_2), Zinc Oxide (ZnO), Zinc Sulphide (ZnS) and Cadmium sulphide (CdS) as a photocatalyst. Amongst which TiO_2 possesses the highest photocatalytic activity and is one of the most widely used semiconductors for photocatalysis. The photocatalyst, titanium dioxide is a naturally occurring compound that can decompose gaseous pollutants with the presence of sunlight. [6]Titanium dioxide also known as titanium oxide or

Titania is the naturally occurring oxide of titanium, chemical formula TiO_2. It is mainly sourced from Ilmenite ore. This is the most widespread form of titanium dioxide-bearing ore around the world. When used as a pigment, it is called titanium white. TiO_2 is a white, highly stable and unreactive metal oxide, present in nature in three different polymorphs: anatase, rutile and brookite. Rutile and anatase have been used since the 1920's in many different industrial fields as white pigments due to their high pigmentation power and high stability whereas brookite is not commonly used. The beneficial effects of the photocatalytic activity of titanium dioxide have been applied to various materials. The most important application areas are paints and varnishes as well as paper and plastics, which account for about 80% of the world's titanium dioxide consumption. Other pigment applications such as printing inks, fibers, rubber, cosmetic products and foodstuffs account for another 8%. The rest is used in other applications such as production of technical pure titanium, glass and glass ceramics, electrical ceramics, catalysts, electric conductors and chemical intermediates. In the food industry, TiO_2 is also widely used as a colorant. [13]

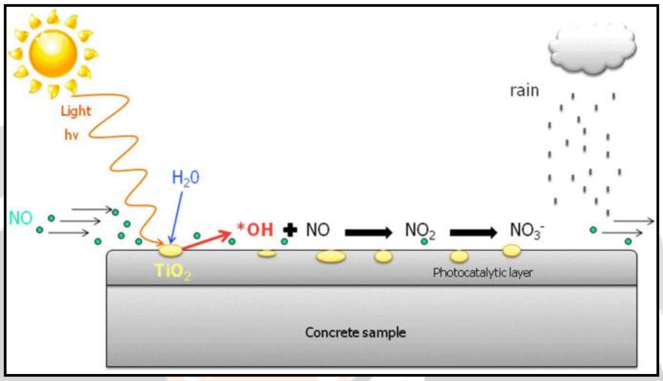

Fig 1.2: Photocatalysis

1.3Sustainable Application

The use of pervious concrete as pavement material with little or almost no fine aggregate and just enough cementations paste to bind together the coarse aggregate has been recognized as Best Management Practice (BMP) by the US Environment Protection Agency (EPA). By allowing the storm water to percolate into the ground surface, pervious concrete allows the recharge of groundwater table in addition to reducing the amount of runoff. The lower amount of runoff now requires sewers of smaller capacity and reduces the need or size of retention basins. Pervious concrete also acts as a filtration device and reduces the pollutant load entering the ponds and rivers. An additional benefit of pervious concrete is to provide air and water to the root system of trees, allowing them to grow well even in urban areas. [2]

Fig 1.4: Pervious concrete parking

Fig 1.5: Pervious concrete pavements

Titanium dioxide also has many uses and environment benefits. Due to its high stability it can be used with other materials efficiently.

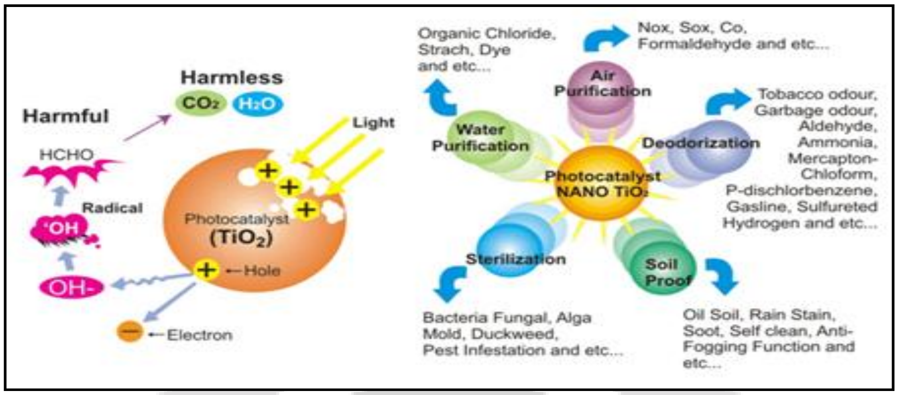

Fig 1.6: Environment benefits of titanium dioxide

The development of innovative sustainable technologies for the environmental improvement is an absolute need. Photocatalytic pervious concrete can represent a significant contribution in this path and can be widely implemented in the construction industry vide pervious concrete pavements, roadways and walkthroughs. Photocatalytic cement-based products are increasingly used worldwide in the construction sector. Pervious concrete with titanium dioxide, possessing high water draining properties and sound-absorbing properties combined with photocatalytic effect of titanium dioxide, is one of the most promising concrete solutions for removal of air and water pollutants and water drainage and runoff problems in urban cities.

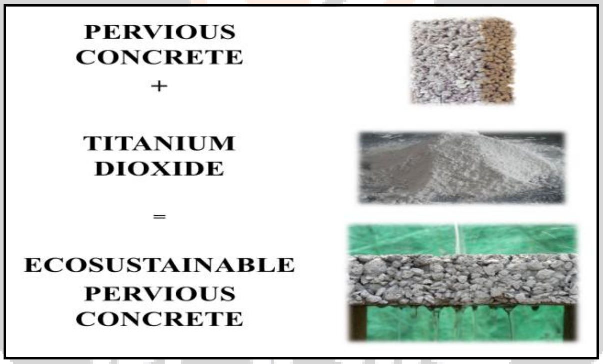

Fig 1.7: Concept of Eco-sustainable pervious concrete

Sustainable engineering practice can be obtained with this no-fine concrete, whose aggregate grading allows adequate drainage of recyclable rainwater, whose maintenance works are strongly reduced with significantly increased durability by application of photocatalyst titanium dioxide. Thus, pervious concrete with titanium dioxide can be utilized as an efficient sustainable application.

2. TESTING OF MATERIAL

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2.1 Cement

Ordinary Portland cement was used for the project work. The cement was tested as per IS codal provisions. Following are the observations

Table 2.1 Summary of test results of Cement.

Sr.no	Properties	Result Obtained	Standard Values as per Indian Standards	Codal Provision
1	Standard Consistency	35%	-	IS 269:1989 Clause No. 11.3 IS 4031 (Part4): 1988 Clause 5.1
2	Initial Setting Time	33 min	Not be less than 30 minutes	IS 269:1989 Clause No. 5.2 and 6.3
3	Final Setting Time	330 min	Not be greater than 600 minutes	IS 269:1989 Clause No. 5.3 and 6.3
4	Soundness	5mm	<10	IS 269:1989 Clause No.6.2.1 IS 4031(Part 3):1988
5	Fineness	1.39	<10	IS 269:1989 Clause No. 6.1 IS 4031(Part 2):1988
6	Specific gravity	3.15	-	-

2.2Fine Aggregates

Natural fine aggregates which were locally available were used in the project work. Following are the result obtained after testing of fine aggregates.

Table 2.2 Summary on Physical Properties of fine aggregates.

Sr. No.	Properties	Result Obtained
1	Type	Natural
2	Specific Gravity	2.69
3	Bulkage	6%
4	Dry Loose Bulk Density	1560 kg/m^3
5	Fineness Modulus	2.48
6	Surface Texture	Smooth
7	Particle Shape	Rounded
8	Grading Zone (Based on percentage passing 0.60 mm)	Zone-II
9	Silt Content	1.6%

2.3Coarse Aggregates

Natural coarse aggregates which were locally available were used in the project work. Following are the result obtained after testing of coarse aggregates.

Table 2.3 Summary on Physical Properties of Coarse Aggregates

Sr No	Properties	Result Obtained
1	Type	Natural
2	Specific Gravity	2.73
3	Dry Loose Bulk Density	1830 kg/m^3
4	Fineness Modulus	7.246

5	Surface Texture	Rough
7	Particle Shape	Angular

2.4Titanium Dioxide

Titanium dioxide was provided by CSIR NEERI, the physical and chemical properties of titanium dioxide are as follows

Table 2.4 Physical and Chemical Properties Titanium dioxide

Sr. No	Properties	Unit	Value
1	Specific surface area	m^2/g	50 ± 15
2	Average primary particle size	nm	21
3	Moisture (2hrs at 105°c)	wt.%	1.5
4	Ignition loss (2hrs at 1000°c)	wt.%	2.0
5	pH (in 4% dispersion)	wt.%	4.5
6	TiO_2	wt.%	99.50
7	Al_2O_3	wt.%	0.300
8	SiO_2	wt.%	0.200
9	Fe_2O_3	wt.%	0.010
10	Sieve residue (45 µm)	wt.%	0.0500
11	Density	Kg/m^3	130

3. MIX PROPORTION

There are no codal provisions relevant to the mix design of pervious concrete in Indian standards or other standards of the world. American standards such as ACI 522R only deals with the different applications, material specifications and strength properties of pervious concrete. There is no specific reference of mix design of pervious concrete in these codes. Most of the pervious concrete mix depends upon the requirement and specifications and are accomplished by adopting trial mixes. Although pervious concrete contains the same basic ingredients as the conventional concrete, the proportions of the ingredients can vary. One major difference is the requirement of increased void content within the pervious concrete. The amount of void space and porosity is directly correlated to the permeability of the pervious concrete. More the porosity and voids more will be the water permeability but the compressive strength will be less.

3.1Trial Mix

Pervious concrete trial mixes were casted with different size of coarse aggregates with and without fine aggregates for testing the mechanical properties of pervious concrete. Following is the summary of trial mix casted for pervious concrete.

Table 3.1 Mix Proportion for Trial mix

Sr.No	Mix Type & No	Coarse Aggregates	Fine Aggregates
1	Trial mix-1	20mm	Not used

Sr.No	Mix Type & No	Coarse Aggregates	Fine Aggregates
2	Trial mix-2	10mm	Not used
3	Trial mix-3	20mm (50%) +10mm (50%)	Not used
4	Trial mix-4	20mm (50%) +10mm (50%)	2% by wt. of CA
5	Trial mix-5	20mm (50%) +10mm (50%)	4% by wt. of CA

3.2Experimental Mix

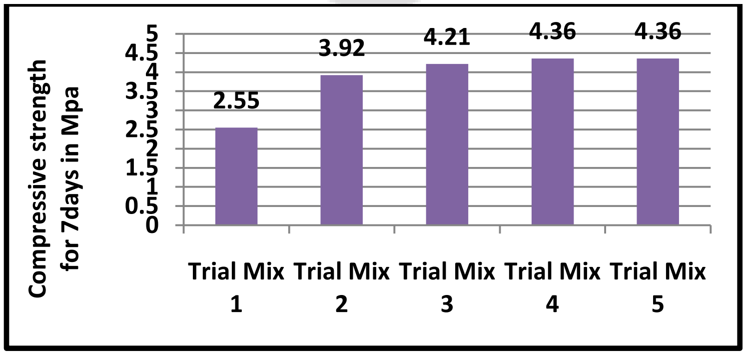
Experimental mixes include pervious concrete trial mix having optimum compressive strength and partial replacement of cement with titanium dioxide was adopted. Following are the experimental mix adopted for the investigation.

Table 3.2: Mix proportion for Experimental mix

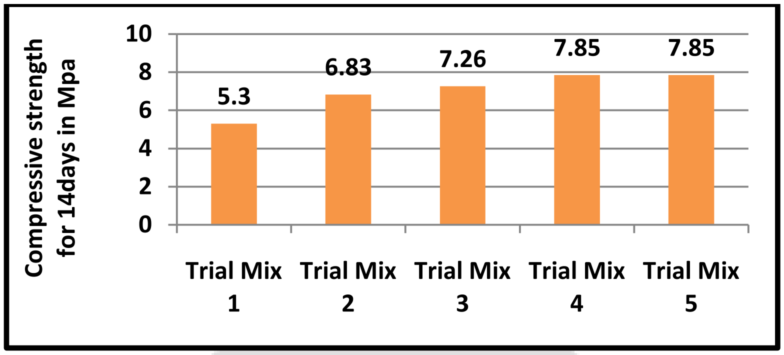
Sr. no	Mix Type & No	Coarse Aggregates	Fine Aggregates	Titanium Dioxide
1	Experimental mix-1	20mm (50%) +10mm (50%)	4% by wt. Of CA	2.5% by weight of Cement
2	Experimental mix-2	20mm (50%) +10mm (50%)	4% by wt. Of CA	5% by weight of Cement
3	Experimental mix-3	20mm (50%) +10mm (50%)	4% by wt. Of CA	7.5% by weight of Cement
4	Experimental mix-4	20mm (50%) +10mm (50%)	4% by wt. Of CA	10% by weight of Cement

4. TEST RESULTS AND INTERPRETATION

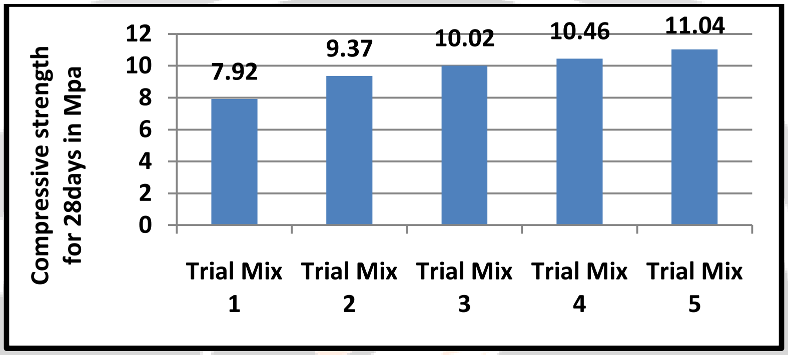
4.1 Interpretation of compressive test results for trial mix



Graph 4.1: Compressive strength of Trial mixes for 7days of curing

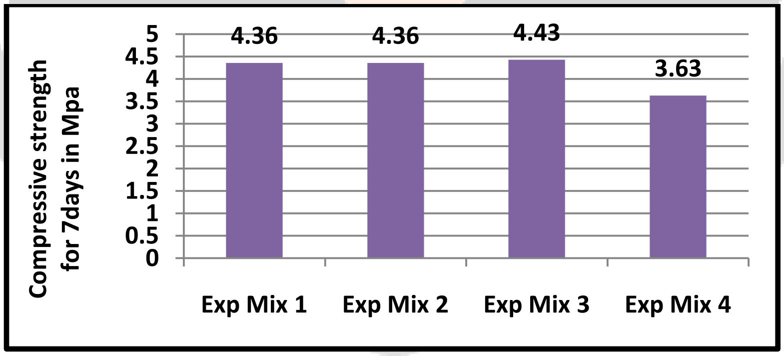


Graph 4.2: Compressive strength of Trial mixes for 14days of curing

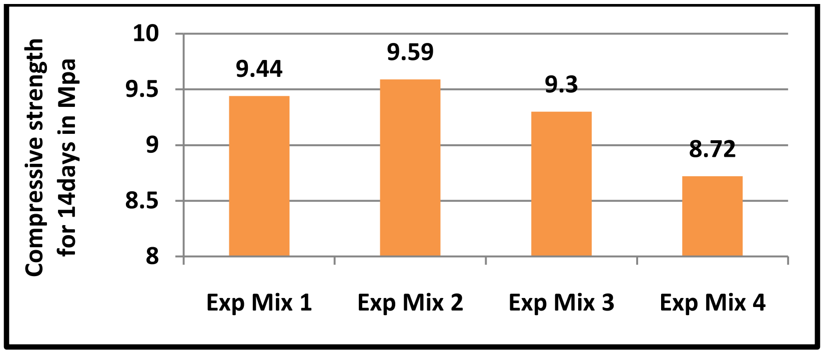


Graph 4.3: Compressive strength of Trial mixes for 28days of curing

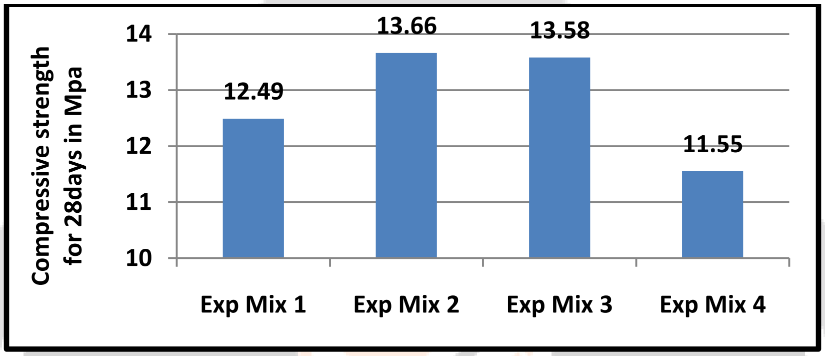
4.2 Interpretation of compressive test results for Experimental mix



Graph 4.4: Compressive strength of Experimental mixes for 7days of curing

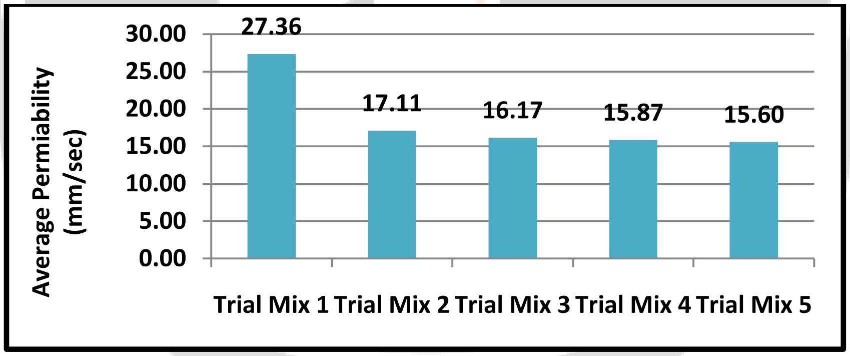


Graph 4.5: Compressive strength of Experimental mixes for 14days of curing



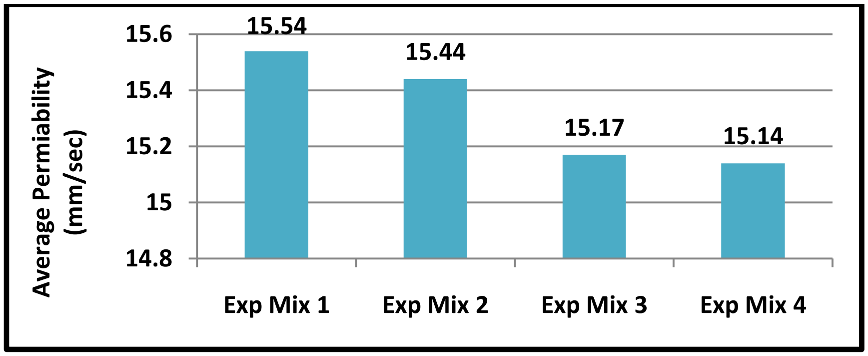
Graph 4.6: Compressive strength of Experimental mixes for 28days of curing

4.3 Interpretation of Permeability test results for Trial mix



Graph 4.7: Permeability of Trial mixes of pervious concrete

4.4 Interpretation of Permeability test results for Experimental mix



Graph 4.8: Permeability of Experimental mixes of pervious concrete

4.5 Summary of Results

1. Highest compressive strength (28days) for pervious concrete is observed as 13.66 N/mm2 for Experimental Mix-2 having 5 percent replacement of cement with titanium dioxide. The water permeability for this mix calculated is 15.4mm/sec.
2. Addition of Titanium dioxide up to 2.5percent as partial replacement of cement in pervious concrete resulted in the percentage increase of 13.13percent in the compressive strength.
3. Addition of Titanium dioxide up to 5percent as partial replacement of cement in pervious concrete resulted in the percentage increase of 23.73percent in the compressive strength.
4. Partial replacement of cement with titanium dioxide up to 10percent resulted in percentage decrease of 8percent in compressive strength when compared to the pervious concrete with 5percent addition of titanium dioxide.
5. Lowest compressive strength (28days) of 7.92 N/mm2 is observed for Trial Mix-1.
6. Highest average water permeability value 27.36 mm/sec is calculated for the Trial Mix-1 comprising of 20mm aggregates only with no fine aggregates.

5. CONCLUSION

1. Compressive strength of pervious concrete increases and water permeability decreases with the increase of fine aggregate in pervious concrete.
2. Pervious concrete with maximum compressive strength can be obtained by combination of 20mm and 10mm aggregates or with single size 10mm aggregates along with use of fine aggregates in small quantity.
3. Water permeability is one of the important characteristics of pervious concrete and therefore the fine aggregate shall be used in pervious concrete within range of 2 to 4 percent by weight of coarse aggregates.
4. Addition of titanium dioxide as partial replacement to cement improves the compressive strength and splitting tensile strength of pervious concrete
5. Partial replacement of cement with titanium dioxide in the pervious concrete has no considerable adverse effect on water permeability of pervious concrete.

6. REFERENCES

1. N. Ghafoori[1], S. Dutta[2], ‘Building and non-pavement applications of no-fines concrete’, Journal of Materials in Civil Engineering, 1995: 7(4): pg. 286-289
2. P.D. Tennis[1], M.L. Leming[2] and D.J. Akers3, ‘Pervious concrete pavements’, National Ready Mixed Concrete Association, Maryland, 2004
3. Tejas M. Joshi, ‘Effect of sand content in permeability of pervious concrete’, Institute of technology, Nirma University, Ahmedabad, Gujarat, India, 2011.
4. Thilak Jayathunga[1], Ranjith Dissanayake[2], ‘Pervious concrete – a sustainable choice in civil engineering and construction’, Head of Innovation and Applications, Holcim (Lanka) Limited, Department of Civil Engineering, University of Peradeniya, Sri Lanka,2013.
5. Dr. S.S.Valunjkar, Professor and HOD, Department. of Civil Engineering, Government College of Engineering, Karad, India ‘An experimental study on compressive strength, void ratio and infiltration rate of pervious concrete’, International Journal of Engineering Research & Technology ISSN: 2278-0181, IJERTV4IS040140 ,Vol. 4 Issue 04, April-2015.
6. Watts[1], Michael J. Cooper[2], ‘Photocatalysis of 4-chlorophenol mediated by TiO_2 fixed to concrete surfaces’, 2008.
7. Ali Nazari[1], Shadi Riahi[2], ‘Assessment of the effects of the cement paste composite in presence TiO_2 nanoparticles’, Department of Technical and Engineering Sciences, Islamic Azad University, Islamic Republic of Iran.
8. SMin-Hong Zhang[1], Davis Tanadi[2], ‘Effect of photocatalyst TiO_2 on workability, strength and self - cleaning efficiency of mortars for applications in tropical environment”, National University of Singapore, Singapore, 2010.

9. FarzadSoleymani, ‘Effects of TiO_2 nanoparticles on increasing split tensile strength of lightweight concrete’, Department of Metallurgical Engineering, Payame Noor University, Tehran, Iran, 2012.
10. Shihui Shen[1], Maria Burton[2], ‘Pervious concrete with titanium dioxide as a photocatalyst compound for a greener urban road environment’, Washington State University, Pullman, United States, 2012.
11. Ranjit K. Nath[1], Abdul Amir[2], ‘Mixed Photocatalyst for Sustainable Concrete Construction’, Dept. of Civil and Structural Engineering, University Kebangsaan Malaysia, Bangi, Malaysia, 2013.
12. A.R.P. Jayapalan, ‘Properties of cement-based materials in the presence of nano and microparticle additives’, 2013.
13. Jason. R. Bolt, ‘The Impact of Photocatalytic TiO_2 on Permeable Concrete Mix Designs and its Application for the Degradation of Organic Pollutants in Water.’ Department of Applied Science Chemistry, 2013.
14. Indian Standard code IS 12269: 1989 Specification for 53grade Ordinary Portland Cement.
15. Indian standard code IS 383 - 1959 for coarse and fine aggregate from natural sources for concrete.
16. Indian standard code IS 2386 - 1963 for method of test for aggregate for concrete.
17. Indian standard code IS 4031 - 1988 for method of physical tests of Hydraulic cement
18. Indian standard code IS 516:1959:- Methods of tests for Strength of Concrete
19. ACI, Pervious concrete ACI 522R-06, 2006.

BIOGRAPHIES

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