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DEVELOPMENT OF HIGH QUALITY PERVIOUS CONCRETEPAVEMENT SPECIFICATIONS FOR TELANGANACONDITIONS

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***Abstract:**One of the main objectives of this research was to develop preliminary specifications for high quality pervious concrete suitable for use in Telangana State Highway Administration (SHA) projects. The study utilized aggregates that are used in SHA projects, and the durability studies were conducted assuming Telangana weather conditions. Investigations were conducted to enhance the structural and durability characteristics of pervious concrete through the use of different admixtures. The admixtures included cellulose fibers, a delayed set modifier and a viscosity modifier. Pervious concrete specimens were tested for density, void content, compressive strength, split tensile strength, permeability, freeze-thaw durability, and abrasion resistance. Three different types of freeze-thaw durability tests were conducted to mimic potential field conditions, typical toTelangana, and including the possibility of clogged pavements. The freeze-thaw durability tests included: fully saturated tests, 50% saturated tests, and 0% saturated dry hard freeze tests.*

The study found that of the different admixtures tested, cellulose fibers had the largest impact in improving durability. Including cellulose fibers in the pervious concrete mix resulted in significant increases in resistance in all three freeze-thaw durability tests. It also resulted in significant increases in abrasion resistance. By bridging the gap between the coarse aggregates, the cellulose fibers bound the pervious concrete mixture with an interwoven matrix of fibers. This also improved the tensile strength of the pervious concrete. The delayed set modifier resulted in a more fluid mix and large gains in compressive strength at seven and fourteen days. This admixture may inhibit some of the cement from setting around aggregates and may result in some cement settling to the bottom and forming a less pervious layer. The viscosity modifying admixture created a more workable and easier to mold mix. Its effect on strength and durability were minimal.

INTRODUCTION

Portland cement pervious concrete (PCPC) is gaining a lot of attention. Various environmental benefits such as controlling stormwater runoff, restoring groundwater supplies, and reducing water and soil pollution have become focal points in many jurisdictions across the State.Portland cement pervious concrete is a discontinuous mixture of coarse aggregate, hydraulic cement and other cementitious materials, admixtures and water. By creating a permeable surface, stormwater is given access to filter through the pavement and underlying soil, provided that the underlying soil is suitable for drainage. This allows for potential filtration of pollutants. To achieve this permeability, PCPC is typically designed with high void content (15-25%). the advantages of pervious pavements.

These advantages are:

- Water treatment by pollutant removal;
- Less need for curbing and storm sewers;
- Improved road safety because of better skid resistance; and
- Recharge to local aquifers.

Problem Statement

The porosity of pervious pavements is provided by omitting all or most of the fine aggregates which impart the necessary percolation characteristics to the concrete to develop and maintain standards for the design, construction, maintenance, and rehabilitation of pervious concrete. This recent interest in porous surfaces as a substitution for impervious surfaces can be attributed to desirable benefits such as stormwater retention, which includes stormwater treatment. Because of the high void content PCPC generally has low strength (5MPA-20MPA) which limits applications in cold weather regions and is responsible for various distresses and pavement failures. The need to develop a high performing pervious concrete specification for Telangana conditions was the basis of this report. Several admixtures were tested along with regional materials often used in project. Structural and durability characteristics were measured against a control mix.
Investigation of pervious concrete performance under cold weather conditions has been studied. However, these states do not have the cyclic freezing.Currently, Telangana has not fully adopted a pervious concrete specification but has been gathering various researches on the subject and has developed a draft specification. While numerous states have created such a document, the unique weather conditions in Telangana in combination with Telangana materials have not been evaluated and tested.

Scope of Work
The present study was conducted to investigate pervious concrete made from aggregates used in State projects under weather conditions. In this study, several admixtures were used and the pervious concrete specimens were tested for density and void content, compressive strength, split tensile strength, permeability, freeze-thaw capacity, and abrasion resistance.

BACKGROUND INFORMATION

Sustainable construction designs have become extremely popular within the last few years. Reducing the strain on our environment is essential to the overall health and wellbeing of our society. While a variety of new designs and technologies have transpired from this green movement, one of the more profound impacts has been in the area of storm water management.
Pervious concrete can be defined as an open graded or “no-fines” concrete that allows rain water to percolate through to the underlying sub-base. The principal ingredients are quite similar to conventional concrete: aggregate, Portland cement, admixtures, fine aggregate (optional), and water. The main difference is the percentage of void space within pervious concrete. Typical ranges of void space are between 15-25 percent or roughly .08 in to .32 in (2 mm to 8 mm).To create a pervious concrete pavement, the pervious concrete (ranging from 4 to 8 inches in thickness) is placed on top of an aggregate base. The thickness of this aggregate base is dependent on a number of influencing factors. A filter fabric can be placed to separate the underlying soil from the previous concrete.

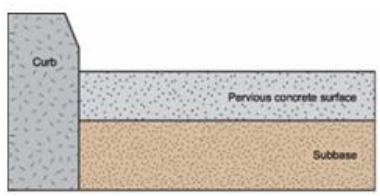


Fig:Section of a Typical Pervious Concrete Pavement

Types of Pervious Pavements

There are several types of pervious pavements that are used in practice. The three common types as shown in Figure are pervious concrete, pervious interlocking concrete pavers, and concrete grid pavers.

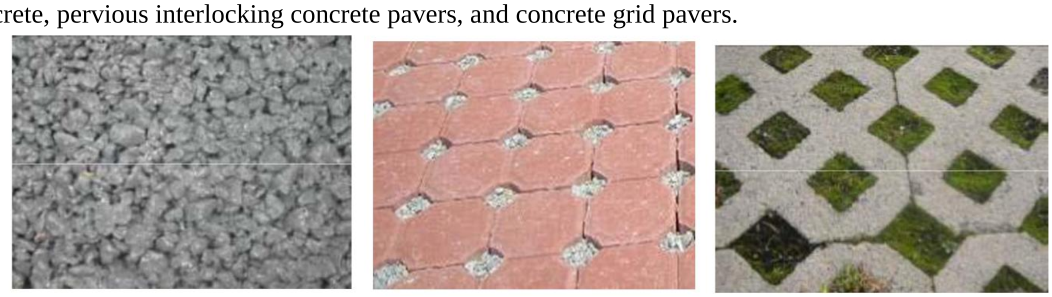


Fig:a. Pervious Concrete, b. Pervious Interlocking Concrete Pavers, c. Concrete Grid Pavers

Detention and Retention Designs
While the key element in designing any pervious concrete pavement is the limitation of stormwater runoff, pervious concrete pavements may be classified as either detention design or a retention design. To be classified as a detention pervious pavement, the design must detain the stormwater until it is discharged into the drainage network. To be classified as a

retention pervious pavement, the design must not only hold the stormwater but also retain and treat until infiltration can occur into the underlying soil.

Passive or Active Mitigation Systems

Pervious concrete pavement can not only handle the surface area runoff from the pavement, it can also be designed to handle surrounding runoff. Local jurisdictions often require the pervious pavement to handle not only the given footprint of the pervious pavement area but also require the drainage of runoff from buildings, construction areas, etc.

Material Properties

Aggregate

The standard type aggregate for use in pervious concrete is typically crushed stone or river gravel. Typical sizes are from 3/8 in. to 1 in. Fine aggregates are either used sparingly or removed altogether from the mix design. It has been shown that using smaller aggregates increases the compressive strength of pervious concrete by providing a tighter bond between coarse aggregate and cement.

Using recycled aggregates has also been researched. Four mix designs were studied using 15%, 30%, 50%, and 100% recycled aggregates and compared to the virgin pervious concrete samples. It was found that samples containing 15% or less recycled aggregates exhibited almost identical characteristic to the virgin sample.

The size of the aggregate also has an important role in pervious concrete. While a 3/4 in. aggregate size allows for greater void space, a 3/8 in. aggregate improves the workability.

Fine Particles

Providing a thicker paste layer around the course aggregates results in improved compressive strength. As seen in Figure 2.3, there is a significant relationship between compressive strength and sand to gravel ratio. When the sand to gravel ratio is increased to 8 %, the mortar bulks up and increases the strength. When the sand to gravel ratio increases beyond the 8 % mark, the 7 day compressive strength begins to fall.

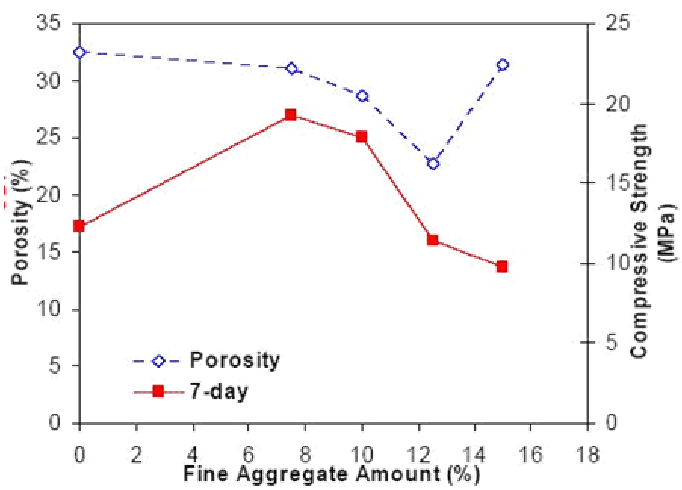


Fig: Relationships between Fine Aggregate and Porosity/Compressive Strength

Cementitious Materials

Portland cement conforming to have been used as the binder for the aggregates. Additional materials that can be used in the cementitious mix are silica fume, fly ash, and slag cement.

A mix design with little water can create a very weak binder. This will create a very dry mix that is susceptible to spalling and crumbling.

Fig: Concretewith a. Too little Water, b. Appropriate Amount of Water, c. Too much Water

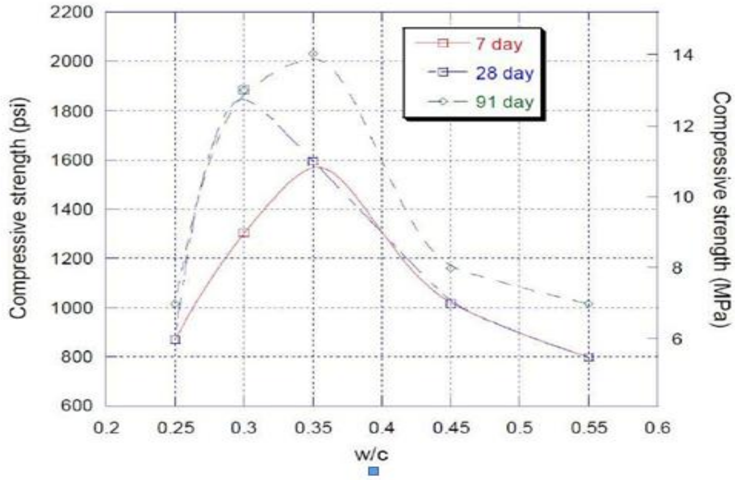


Fig: Relationship between Water-to-Cement and Compressive Strength

Another study determined that water-to-cement ratio has a direct correlation to cement paste characteristics, and mixing time of the porous concrete. By achieving an even thickness of the paste (150-230 mm) **(IS 383 - 1970)** within theporous concrete mix, this can achieve suitable void ratios of 15-25% and strengths ranges from (22-39 MPA).

Admixtures

The use of admixtures in conventional concrete is essential and vital to performance and workability. High-range water-reducing (HRWR) admixtures are applied to concrete mixes to affect the set time of concrete. They require less water and increase the slump of concrete.

Void Ratio

Percentage of voids in a sample of pervious concrete can vary significantly. Compared the relationship between percentage of voids in pervious concrete and compressive strength. Not surprisingly, he found there was an inverse proportion of compressive strength to void ratio. Generally, pervious concrete will have a void ratio between 15%-30% with an average of 20%. This accommodates both the structural requirements and the hydrological requirements of the design.

Permeability

Concrete

The ability of the concrete to drain runoff water is the key to the success of pervious concrete. Interconnected voids within the concrete allow the water to penetrate to the sub-base and remove trace contaminants. While there is no set standard for testing the permeability of concrete, have devised a testing procedure that evaluates the filtration ability of pervious concrete cores.

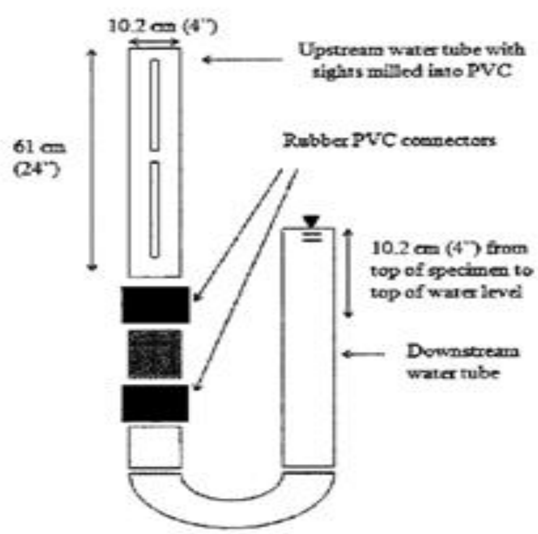


Fig: Falling Head Permeameter

Sub-base

Once the groundwater has percolated through the pervious concrete, the sub-base then needs to filter and infiltrate the stormwater. The size, depth, and type of sub-base material are just as important in reducing stormwater runoff as pervious concrete. The sub-base beds should have a total volume to capture and store runoff water generated by a storm in a 24 hr period.

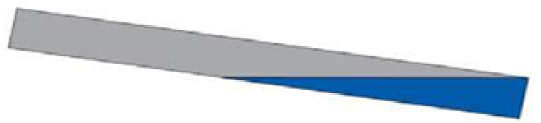


Fig: Ponding of Water to Occur on Sloped Pavements

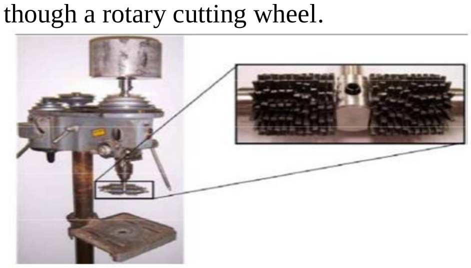
The trenches are dug across the slope, perpendicular to the pavement. A perimeter drain usually constructed of PVC pipe is installed at the bottom of the trench and then filled with washed stone. The depth and spacing of the trenches are often. Dictated by the slope of the pavement, the soil infiltration rate, and the maximum rainfall intensity.

Fig: Sloped Pervious Concrete Pavement with Dug Trenches Filled with Stone

Durability

Abrasion

Surface abrasion is a potential problem. With the use of snow plows, shovels, and snow blowers in the winter time, and other hard contact applications like chains and tires during the other months, the ability of pervious concrete to resist abrasion is critical. Since the texture of pervious concrete differs from conventional concrete, the potential for raveling of aggregate particles and cracking is a serious issue. The standard method of testing abrasion resistance. A constant load of 98 N is applied though a rotary cutting wheel.



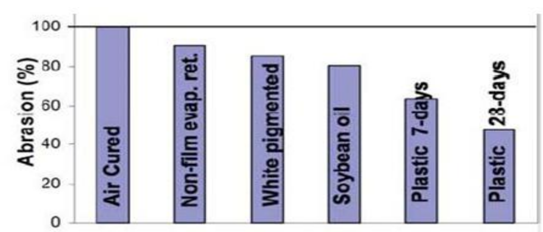


Fig: Surface Abrasion Testing Apparatus Fig: Abrasion Resistance from Different Curing Compounds

Noise and Skid Resistance

To measure the skid resistance as it relates to the coefficient of friction, six different types of surfaces: dry, wet, snow, slush, compacted snow, and ice. Each surface was tested along with a standard dense asphalt mix.

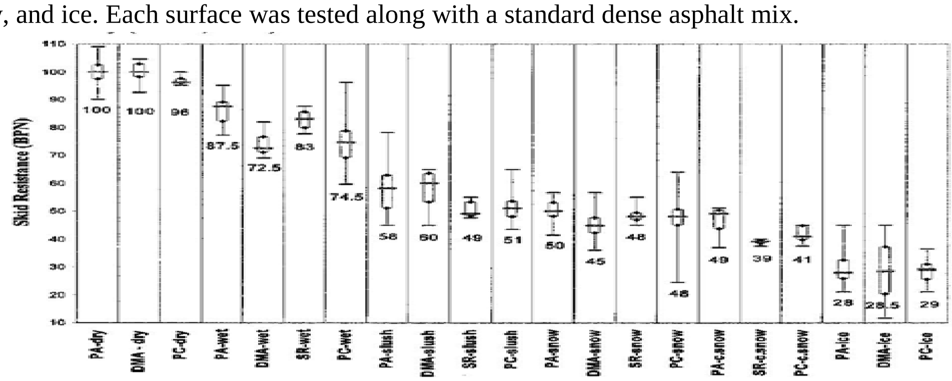


Fig: Results of Skid Resistance Test on Different Pavement Types; PA = Porous Asphalt; DMA = Dense-Mix Asphalt; PC = Pervious Concrete; SR = Standard Reference

Mix design

While pervious concrete contains the same basic ingredients as the more common conventional concrete (ie. aggregate, Portland cement, water, and a variety of admixtures), the proportioning of ingredients is quite different. One major difference is the requirement of increased void space within the pervious concrete. The amount of void space is directly correlated to the permeability of the pavement.. These ranges are based on previous research.

Design Void Content: 15% to 25%

Water to Cement Ratio: 0.27 to 0.33

Binder to Aggregate Ratio: below 0.25

A 25% void content would have allowed more than enough void space in the samples to accommodate a peak storm even in Maryland but may not have provided the strength and durability that was required for the research project. Taking into account the goals of the project and the literature review, a target void content of 20% was desired with a water-to-cement ration of 0.3. Prior to the application of the admixtures, several test mixes were performed to determine an appropriate mixdesign for the project. While trying to increase strength and maintaining permeability, different values of water to cement ratio were tested. Three different water-to-cement ratios were tested: 0.27, 0.30, and 0.33. Three cylinders, 4 inch diameter by 8 inch tall were cast for each ratio. During mixing, it was noted that the lowest water-to-cement ration of 0.27 was very dry.

Required Pervious Concrete Mixture Properties		
Design Void Content	20.00%	
Water to Cement Ratio	0.3	
Supplemental Cementitious Material		0
Required Materials / Design for 1 cy of concrete		
	Weight (kg's)	Volume
Coarse Aggregate	2426	53.10%
Fine Aggregate	183	4.10%
Cementitious Material	620	11.70%
Water	181	11.00%
Water Gallons	21.7	
Volumetric Void Content	20.00%	
Design Unit Weight	126.4	

Table: Concrete Mixture Properties

The standard mix proportions for the mix were as follows:

Cement: Coarse Aggregate: Fine Aggregate: Water which will be equivalent to 1:4.1:0.30:0.30 by weight. The pervious concrete mix design that was used for this research project was determined from a thorough literature review of past research.

Material quantity:

	Test			
	CM	DM	CF	VM
Portland Cement (kg's)	43.4	43.4	43.4	43.4
Coarse Aggregate (kg's)	170	170	170	170
Fine Aggregate (kg's)	12.81	12.81	12.81	12.81
Water (kg's)	12.67	12.67	12.67	12.67
Delayed Set Modifier (grams)	X	560	X	X
Cellulose Fibers (kg's)	X	X	500	X
Viscosity Modifier (grams)	X	X	X	560

Table: Material Quantities

RESULTS AND DISCUSSIONS

Density and Void Ratio

Density of the Mix		
Control Mix	2066	Kg/m3
Delayed Set Modifier	2038.3	Kg/m3
Viscosity Modifier	2056.61	Kg/m3
Cellulose Fiber	2090.89	Kg/m3
Theoretical Density of the Concrete:		
S.G. Coarse Aggregate	2.71	
S.G. Fine Aggregate	2.62	
S.G. Portland Cement	3.15	
S.G. Fibers	1.1	
Coarse Aggregate Mass	2426	Kgs
Fine Aggregate Mass	183	Kg's
Portland Cement Mass	620	Kg's
Water Mass	181	Kg's
Fiber Mass	2	Kg's

Void Content:		
Control Mix	19	%
Delayed Set Modifier	20	%
Viscosity Modifier	19	%
Cellulose Fiber	18	%

Compressive Strength Test

7 day results

Day 7 Test	3-June-2016				
Control Mix 1	25640	Kgs	14.07	MPa	
Control Mix 2	24020	Kgs	13.18	MPa	
Control Mix 3	20200	Kgs	7.36	MPa	
				11.5366	MPa
Delayed Set Modifier 1	32900	Kgs	18.060	MPa	
Delayed Set Modifier 2	29500	Kgs	16.19	MPa	
Delayed Set Modifier 3	25040	Kgs	13.74	MPa	
				15.996	MPa
Viscosity Modifier 1	11520	Kgs	6.323	MPa	
Viscosity Modifier 2	18500	Kgs	10.155	MPa	
Viscosity Modifier 3	10900	Kgs	5.983	MPa	
				7.483	MPa
Cellulose Fiber 1	26260	Kgs	14.413	MPa	
Cellulose Fiber 2	16000	Kgs	8.783	MPa	
Cellulose Fiber 3	22540	Kgs	12.37	MPa	
				11.857	MPa

14 day results

Control Mix 1	42020	Kgs	3345.541	MPa	
Control Mix 2	38880	Kgs	3095.541	MPa	
Control Mix 3	28570	Kgs	2274.682	MPa	
				2905.255	MPa
Delayed Set Modifier 1	49710	Kgs	3957.803	MPa	
Delayed Set Modifier 2	35360	Kgs	2815.287	MPa	
Delayed Set Modifier 3	44000	Kgs	3503.185	MPa	
				3425.425	MPa
Viscosity Modifier 1	13890	Kgs	1105.892	MPa	
Viscosity Modifier 2	23120	Kgs	1840.764	MPa	
Viscosity Modifier 3	17470	Kgs	1390.924	MPa	
				1445.86	MPa
Cellulose Fiber 1	42550	Kgs	3387.739	MPa	
Cellulose Fiber 2	35650	Kgs	2838.376	MPa	
Cellulose Fiber 3	32910	Kgs	2620.223	MPa	
				2948.779	MPa

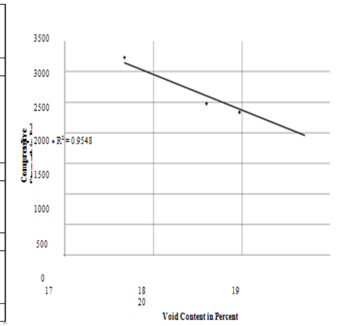
28 day results

Control Mix 1	26240	Kgs	2089.172	MPa	
Control Mix 2	28050	Kgs	2233.28	MPa	
Control Mix 3	39020	Kgs	3106.688	MPa	
				2476.38	MPa
Delayed Set Modifier 1	24100	Kgs	1918.79	MPa	
Delayed Set Modifier 2	23540	Kgs	1874.204	MPa	
Delayed Set Modifier 3	29550	Kgs	2352.707	MPa	
				2048.567	MPa
Viscosity Modifier 1	43010	Kgs	3424.363	MPa	
Viscosity Modifier 2	27170	Kgs	2163.217	MPa	
Viscosity Modifier 3	17750	Kgs	1413.217	MPa	
				2333.599	MPa
Cellulose Fiber 1	45250	Kgs	3602.707	MPa	
Cellulose Fiber 2	38050	Kgs	3029.459	MPa	
Cellulose Fiber 3	38330	Kgs	3051.752	MPa	
				3227.972	MPa

120 day results

Control Mix 1	29520	Kgs	2350.318	MPa	
Control Mix 2	37840	Kgs	3012.739	MPa	
Control Mix 3	31150	Kgs	2480.096	MPa	
				2614.384	MPa
Delayed Set Modifier 1	22680	Kgs	1805.732	MPa	
Delayed Set Modifier 2	32450	Kgs	2583.599	MPa	
Delayed Set Modifier 3	36280	Kgs	2888.535	MPa	
				2425.955	MPa
Viscosity Modifier 1	40250	Kgs	3204.618	MPa	
Viscosity Modifier 2	29660	Kgs	2361.465	MPa	
Viscosity Modifier 3	29990	Kgs	2387.739	MPa	
				2651.274	MPa
Cellulose Fiber 1	31610	Kgs	2516.72	MPa	
Cellulose Fiber 2	46480	Kgs	3700.637	MPa	
Cellulose Fiber 3	42180	Kgs	3358.28	MPa	
				3191.879	MPa

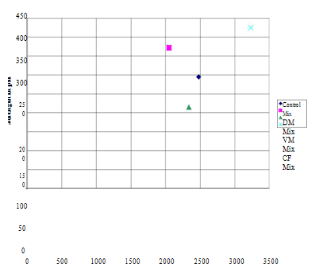
Correlation between Void Content & Cs



Split Cylinder Test

Comparison between Compressive Strength and Tensile Strength

Control Mix 1	4200	Kgs	334.3949	Mpa	
Control Mix 2	3300	Kgs	262.7389	Mpa	
Control Mix 3	3600	Kgs	286.6242	Mpa	
				294.586	Mpa
Delayed Set Modifier 1	4500	Kgs	358.2803	Mpa	
Delayed Set Modifier 2	4100	Kgs	326.4331	Mpa	
Delayed Set Modifier 3	5400	Kgs	429.9363	Mpa	
				371.5499	Mpa
Viscosity Modifier 1	2200	Kgs	175.1592	Mpa	
Viscosity Modifier 2	3100	Kgs	246.8153	Mpa	
Viscosity Modifier 3	2800	Kgs	222.9299	Mpa	
				214.9682	MPa
Cellulose Fiber 1	4500	Kgs	358.2803	MPa	
Cellulose Fiber 2	6500	Kgs	517.5159	MPa	
Cellulose Fiber 3	5000	Kgs	398.0892	MPa	
				424.6285	Mpa



Permeability Test

	Permeability in/hr
Control mix 1a	417
Control Mix 1b	400
Control Mix 1c	412
Delayed Set Modifier 1a	420
Delayed Set Modifier 1b	410
Delayed Set Modifier 1c	417
Viscosity Modifier 1a	405
Viscosity Modifier 1b	420
Viscosity Modifier 1c	417
Cellulose Fiber 1a	417
Cellulose Fiber 1b	405
Cellulose Fiber 1c	410

Abrasion Test

		Applied Load #1	Applied Load #2
Date of Test	11/06/2016	Percent Mass Loss	Percent Mass Loss
	Control Mix 1	0.2 %	0.5 %
	Control Mix 2	0.3 %	0.5 %
	Delayed Set Modifier 1	0.4 %	0.6 %
	Delayed Set Modifier 2	0.3 %	0.6 %
	Viscosity Modifier 1	0.3 %	0.5 %
	Viscosity Modifier 2	0.3 %	0.5 %
	Cellulose Fiber 1	0.1 %	0.3 %
	Cellulose Fiber 2	0.1 %	0.3 %

Discussion of Results

With the low water-to-cement ratio for pervious concrete, the hydration of the cement is considered to flash. This speeds up the hydration of the cement and lowers the amount of allowable time for transport.

During mixing and sample preparation, it was noted that the mix seemed more fluid than the control mix. When discharging from the mixer, the mix poured out easily.

The density and void content of the delayed set modifier was slightly higher than the other three mixtures. This could have been attributed to the formation of the thin layer around the cement and aggregate. With a more fluid material discharging from the mixer, this created less paste and more open voids.

The compressive strength showed the delayed set modifier had the highest strength gained for the 7, 14, and 120 day tests. The 28 day strength, however, was significantly lower than the other three admixtures. The samples taken at 28 days could have had more of an open voided structure due to the excess paste that did not form and hydrate around the aggregates.

Viscosity Modifier Results

The viscosity modifying admixture (VMA) created a more workable and easier to mold mix. This is due to the presence of high molecular weight polymers that interact with the water/cement. The density and void content were comparable to the control mix.

The viscosity modifying admixture resulted in relatively low compressive and tensile strength. Day 7 and day 14 had the lowest compressive strength compared to compressive strength of specimens with other admixtures. This may be explained by the high dosage rate of the viscosity modifying admixture used in the previous concrete mix design.

Cellulose Fiber Results

Not surprisingly, cellulose fibers had an important impact on the durability of pervious concrete. Although the traditional polypropylene fibers have shown great promise in pervious concrete, it was unclear how the cellulose fibers would compare.

Conclusions

The important characteristic that needed to be maintained was a proper void ratio within the pervious concrete mixture. Sacrificing permeability for an increase in strength or durability was not seen as a viable option. Therefore, the target void ratio for the different mix designs was a standard 20.The delayed set modifier did appear to result in a more fluid mix. The viscosity modifier resulted in little change in strength or durability. However, the mix was easier to move and mold into shape.

Recommendations

While much of the results of this research suggest the potential for expanding the application of pervious concrete, there are still other areas that need to be studied and evaluated. A non-destructive test to determine the level of compaction as well as the uniformity of compaction throughout the sample would be helpful. Other non-destructive test methods could be reviewed and compared to find one that is suitable for previous concrete.As pervious concrete becomes more applicable to light and medium traffic loading, the need for a fatigue analysis is going to become important. Much of the applications for pervious concrete involve parking lots, pedestrian walkways, and other lightly loaded areas. To be able to incorporate pervious concrete in wider applications, fatigue analysis will be needed.

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