A study on Mechanical Properties of Porous Concrete for its use in Low Traffic Volume Roads and Parking Areas in Muscat

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Abstract

Pervious concrete is a special type of concrete made with cement paste and coarse aggregates. Amount of fine aggregates in porous concrete varies from no fines to lesser quantity of fines. Pervious concrete is often referred as porous concrete made exclusively with special property of very high permeability. As the porous concrete is low in strength it can be used on low traffic volume roads for storm water management. Porous concrete is effective in reducing runoff and recharge ground water table. For hot and arid regions like Oman wherein the rain fall is scanty, ground water tables are deep and soils are mostly gravels, porous concrete use should be encouraged in secondary roads, sidewalks, parking area etc. In urban and built up areas, porous concrete can be used instead of conventional road construction material like Bitumen and concrete for surfacing the roads. A good quality concrete need to be designed to reduce runoff and meet the specifications of low traffic volume roads and paving areas.

In this research work mix design has been carried on conventional concrete. Fine aggregates are replaced by coarse aggregates and concrete with 0% fines are prepared and tested for its mechanical and hydraulic properties. Fine aggregates are added at 10% increments up to 40% of total volume of aggregates and cube and cylinders are casted and tested for 7day and 28 day strength. Also permeability of porous concrete is examined for different % of fines for its use in pavements. Laboratory test results reveal that a porous concrete with 20% fines is more suitable for low volume traffic roads and parking areas.

Keywords — *No fines concrete, Porous concrete, Storm Water Management, Porous concrete for parking areas and low volume roads.*

I. INTRODUCTION

Porous concrete is special type of concrete wherein the fine aggregates are replaced by coursed aggregates without compromising its strength significantly. The pervious or porous concrete mixture is like a conventional concrete mixture, but the difference is the ratios of fine aggregate and coarse aggregate material used. The main intention of making a porous concrete is for the achievement of high void content, where in water is allowed to pass through easily through these voids and get absorbed by the soil drainage layers. The void ratio for conventional concrete varies from 3% to 5%, and void ratio of porous concrete can go up to 15% to 40%. The main difference between conventional concrete and porous concrete is its compressive strength and permeability. In porous concrete strength is low and permeability is very high and unit weight of porous concrete is lower than conventional concrete. (Wanielista, M., & Chopra, M., 2007)

Review of history on concrete making reveals that manufacturing of the porous concrete was very old and porous concrete is not a new technology. It was used in 1852 in Europe. In 1923, Porous concrete was popularly used for residential building construction in different area such as West Africa, Middle East, Venezuela, Australia, and Russia. In those years cement was scare therefore people compelled for using porous concrete because of less consumption of cement compared to conventional concrete. (Wanielista,M., & Chopra, M., 2007). During 1970's its use became popular in United States, due to its less cost and ability prevent runoff and absorb storm water. After that Porous Concrete spread around the world for its use in different construction applications. (Ghafoori, 1995). The compressive strength of porous concrete is significantly affected due to high presence of voids, but it can be improved by using smaller sized aggregates, also compressive strength can be increased by using well graded small size aggregates by adding more than 10% fine aggregate. (Singh, R& Sidhu, A., 2005)

Porous concrete is having many applications but the only drawback is, it lacks durability. Due to this constraint, the use of porous concrete is restricted to low traffic volume roads like path ways, secondary roads and parking areas.

Due to rapid development and urbanization, in city's most of the area is covered either by cement concrete or bitumen surfaces and affecting the runoff and the ground water table. Use of porous concrete or no-fines concrete is an innovative way for storm water management, treatment, control, and to reduce water runoff. This concrete consists of Portland cement, water, coarse aggregate, and same of percentage of fine aggregate. The porous concrete is containing lot of void inside in it, which allow water to infiltrate through it easily. This concrete due to restricted fines content could develop voids between 15 to 40 %, unlike conventional concrete. Porous concrete has got its extensive application in use for reduced runoff on city roads and tremendous ability to recharge ground water. There are many advantages of pervious concrete such as its high permeability unlike conventional concrete, low weight, less shrinks, management and reduction of storm water runoff, reducing ground water pollution, reduced heat island effect, and reduce of surface ponding of water. (Kurt, D. Smith, P.E., and Krstulovich, J. 2012). The disadvantages of pervious concrete are: limited use in heavy vehicle traffic areas, lower compressive strength, and extended curing time. (Kurt, D. Smith, P.E., and Krstulovich, J. 2012)

Aim and Objectives of the study:

The aim of the study is to evaluate the engineering properties of porous concrete for the designed mix at different % of fines and its suitability as pavement material for low traffic volume and secondary roads in Muscat. Specific objectives of the study would include:

- To study the physical and mechanical properties of coarse and fine aggregates.
- To study the properties of concrete for the designed mix.
- To evaluate the strength properties of concrete at different % of fines.
- Evaluation of properties of concrete at different % fines as proportion of total aggregates replacement in 10% increment from 0%-40%.

II. LITERATURE REVIEW

Different researchers conducted investigations on porous concrete to evaluate their mechanical properties. Malhotra (1976) designed concrete mix to achieve permeability and conducted strength tests on cube and cylinders. Menninger (1998) conducted many experiments and determined the relationship between compressive strength and water cement ratio at different days of curing, the relationship between compressive strength and water content, and the relationship between compressive strength and Unit Weight. The author concluded the maximum compressive strength is achieved between 0.3 to 0.35 water cement ratios. Karthik H.obla (2010) carried research on pervious concrete for its use in reducing the runoff from a site and recharging ground water levels. The ratio of permeability of concrete is depended to size of aggregate and the density of the concrete Hydraulic properties of the pervious concrete were evaluated and concluded that by 20% void content in concrete is adequate to attain sufficient strength. S.O. Ajamu, A.A. Jimoh, & J.R. Oluremi (2012) conducted studies on strength characteristics of pervious concrete and concluded that strength depends on the size of aggregate and material proportions. The maximum compressive strength was when use 9.38 mm size of course aggregate and maximum permeability was in 18.75 mm of size of course aggregate. Rasiah Sriravindrarajah(2012), Neo Derek Huai Wang, and Lai Jian Wen Ervin(2012) conducted experimentation on pervious concrete using natural aggregates and recycled aggregates and evaluated compressive strength and permeability properties. Darshan S. Shah(2013) et.al investigated the engineering properties of pervious concrete and its use in rural roads to prevent run off. Ammar A. Muttar(2013) improved the mechanical properties of pervious concrete by adding propylene fibers and found significant improvement in compressive strength. M. Uma Maguesvari, and V.L.Narasimha (2014) conducted studies on porous concrete at various cement contents and different sizes of aggregates. It was concluded that permeability decreases with increase of cement content. M. Harshavarthana Balaji(2015) at el designed ecofriendly porous concrete for use in parking areas to increase the ground water recharge. Silica fumes is used in place of fines and investigated the engineering properties. Ghanim Hussein Qoja(2016) et.al conducted studies on porous concrete and established the relationship among the parameters aggregate – cement ratio, unit weight, permeability and strength.

III.METHODOLOGY

The main objective of the research is to develop a cost effective storm water management technology to prevent runoff and to recharge the ground water table. Muscat the capital city of Sultanate of Oman is located in an arid region where the rain fall is very low and ground water table is deep need to conserve, whatever minimum rainfall it receives. This can be achieved by covering the secondary roads. Low volume traffic drive ways, path ways and parking areas with porous concrete rather than conventional concrete. Adopting American Concrete Institute (ACI) method, mix design is arrived to suit the strength requirements of C25- C30. The mix design adopted is presented below.

A. Mix Design Calculations for C25 Concrete Grade According to the (ACI):

The mix design adopted is falling in the ranging of C25-C30. Adopting the mix design with 1:2:2.5, porous concrete is generated by replacing the fine aggregates with coarse aggregates. Initially a zero fines porous concrete is generated by replacing the total fine aggregates with coarse aggregates by adopting the mix design 1:0:4.5. To examine the improvement in strength at different % of fine aggregates as replacement of coarse aggregates, different mixes have been generated with by substituting fines in place of the total aggregate content(4.5).

- The mean strength Fm = Fmin + Ks
  = 25 + (1.64 x4) = 31.56 Say 31.6 mpa
- Adapt a water cement ratio = 0.38
- Size of aggregate is 20 mm
- Water required would be 165 kg /m^3
- The required cement content = 165/0.39 = 423 kg/m^3
- The bulk volume of C.A is 0.62 per unit
- Therefore the weight of C.A = 0.64 x 1600 = 1024 kg/m^3
- Field weigh of aggregate = Absorbed water content * weight of aggregate
- Field weigh of aggregate = 1.01 * 1024 =1034
- Weight of fresh concrete (porous) concrete = 2500kg/ m^3
- Weight of water = 165 kg/ m^3
- Weight of cement = 423 kg/ m^3
- Weight of C.A = 1034 kg/ m^3
- Weight of F.A = 2500 - (165+435+1034) = 837 kg/ m^3
- Total free surface moisture in F.A = 2/100 x 837= 13.56 kg/ m^3
- Weight of F.A in field = 837 + 16.74 = 853.74 kg/ m3
- Cement =423 kg/ m^3
- F.A = 854.6 kg/ m^3
- C.A = 1034kg/ m^3
- Water = 185
- Density of fresh concrete= 2500 kg/ m3
- C: FA: CA = 423 : 853:1034= 1: 2.01:2.44
- Final mix design proportions adopted is C: FA: CA = 1:2:2.5

Proportions of fines as a percentages of total aggregates has been attempted at increments of 10% and up to 40%. For all the mixes water cement ratio has been kept as constant at 0.38.

Final Quantities adopted for the controlled mix:

- Weight of water= 165 kg/m3
- Weight of cement= 420 kg/m3
- Weight of coarse aggregate= 1050 kg/m^3
- Weight of fine aggregate= 840kg/m3

- Cement: fine aggregate: coarse aggregate: water1 : 2 : 2.50 : 0.38

B. Results and Discussions

Physical and mechanical properties of the fine aggregates, coarse aggregates are evaluated and presented in table-1. Concrete is prepared at the set the proportions, cubes and cylinders have been casted and tested for 7 day strength and 28 day strength. Preparation of porous concrete, casting of cube & cylinder curing and testing is carried at Caledonian College of Engineering Material Testing Laboratory, Muscat and shown in the pictures below Picture: 1-8. Results are presented in the tables: 1 -5

C. **Table I Physical Properties of Aggregates:**

Sl.No.	Tests on Coarse Aggregates		
	Property	**Units**	**Results**
1	Specific Gravity		2.72
2	Angularity Number		6.0
3	Crushing Value		18.66
4	Water absorption		1.04
Tests on	**Fine Aggregates**		
5	Fineness modulus of sand		2.1

Table II - Pervious Concrete Mix Proportions and Quantities

Sl. No	Mix ratio	Fines%	Material quantity (Kg/m^3)		
			Cement	Fine aggregate	Coarse aggregate
1	1:2:2.5	NM	420	840	1050
2	1 :0:4.5	0	420	0	1890
3	1:0.45:4.05	10	420	189	1701
4	1: 0.9: 3.6	20	420	378	1512
5	1:1.35:3.15	30	420	567	1323
6	1: 1.8: 2.7	40	420	756	1134

Table III-Cube Strength of Porous Concrete At 7 Days and 28 Days (S=Sample)

Materials	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**
% of Fine	**0%**	**10 %**	**20 %**	**30 %**	**40 %**	**Control mix**
Mix Proportions	1:0. 4.5	1:0. 45:4 .05	1: 0.9: 3.6	1: 1. 35 :3. 15	1: 1. 8: 2. 7	1:2.0: 2.5
W/C	0.38	0.38	0.38	0. 38	0. 38	0.38
Compressive Strength N/mm^2						
At 7 days	3.24	6.45	9.22	11.26	16.4 2	23.18
At 28 days	4.68	8.34	13.7 6	17.4 4	24 .1	33.48

Table IV-Porous Concrete Cylinder Strength of at Different % of Fines

% of Fine	Direct Compressive Strength of Cylinders (N/mm^2)	
	7 days	**28 days**
0	2.52	3.37
10	4.76	6.34
20	6.92	11.01
30	8.78	13.25
40	11.82	18.08
Control (Normal) Mix	17.94	25.08

Table V-Concrete Split Tensile Strength at 7 Day and 28 Day

Fine Aggregates as % of Total Aggregates	0	10	20	30	40	Control mix
At 7 days	0.75	1.28	1.84	2.12	2.98	4.64
At 28 days	0.95	1.68	2.65	3.42	4.6	5.57

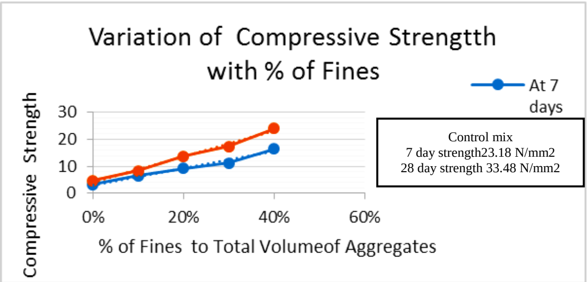


Fig 1: Variation of Cube Strength at Different % of Fines

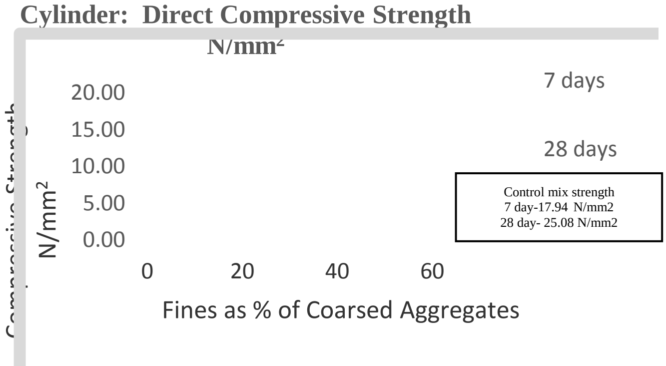


Fig 2: Variation of Cylinder Strength at Different % of Fines

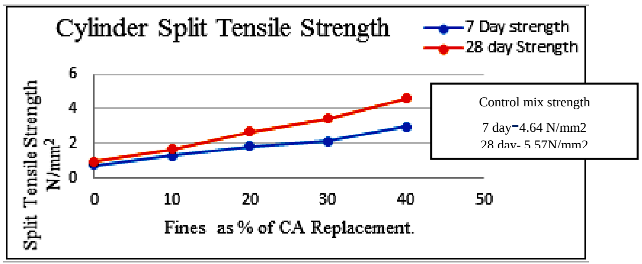


Fig 3: Variation of Cylinder Split Tensile Strength at Different % of Fines

Inferences on Cube and Cylinder Testing:

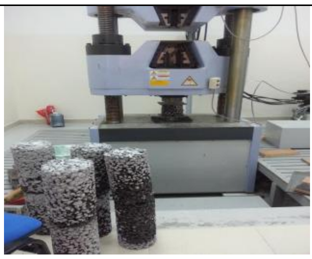
- Mix proportions for normal mix design are arrived at 1:2:2.5 for a minimum target strength of 25 Mpa.
- At 0% of fines the cube strength would be about 14% of the 28 day strength of normal mix.
- As the % of fines increase, strength of the concrete is also increasing.
- At 20% of fines with a mix design of 1: 0.9: 3.6, recorded strength of the concrete is 40% strength of normal mix
- At 20% fines the permeability of the concrete is very high giving 100% free flow of storm water.
- For storm water management a mix with 20% is suggested as it is giving free flow of water.
- Strength obtained at 20% fines would be adequate to sustain the traffic loads expected on secondary roads and parking areas.

Pic 1: Porous Concrete Preparation

Pic 2: Casting Cubes and Cylinders of Porous Concrete

Pic 3: Cubes and Cylinders for 7day and

Pic 4:Cubes and Cylinders after Curing Ready for

		28 day Curing	testing
 Pic 5: Cubes Testing for 20% Fines	 Pic 6: Other Porous Concrete Specimen Testing	 Pic 7: Cylinder Testing	 Pic 8: Permeability Examination

Pic:9 Roads inUndated with Rain Water Due to Poor Drainage During April 2016 Rains in Muscat (Source: Google)

D. *Practical Applications*

Muscat city is the capital of Sultanate of Oman. City area spreads over an area of 3500Sqkm and lies along the Arabian sea in the East and Al Hajar Mountains on West. Muscat features hot and arid climate with its annual rain fall measuring 10cm. Representative rain fall data collected for number of rainy days in a month for an year is presented in Table:6 and figure:4

Table VI
Distribution of Rainfall Data in Muscat

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
mm	10	30	10	20	10	10	10	10	10	10	10	10
Days	5	2	3	1	0	0	1	1	0	0	1	2

Even though rain fall is very low, occasional flash floods(Pic-9) in the city are causing inundation of the areas as the residential areas are fully covered by paved roads.

There is a need to prevent runoff and recharge the ground water table by effective use of porous concrete in place of conventional concrete.

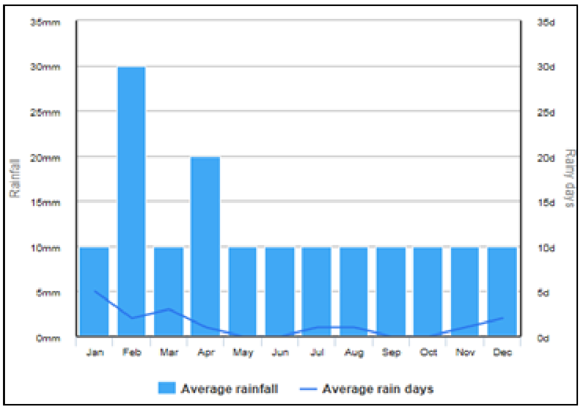


Fig: 4 Rain Fall Data (Source: http://www.holiday-weather.com/muscat/averages/)

For this different models in plan and section for pavement construction are developed and are presented below in Fig-5-7.

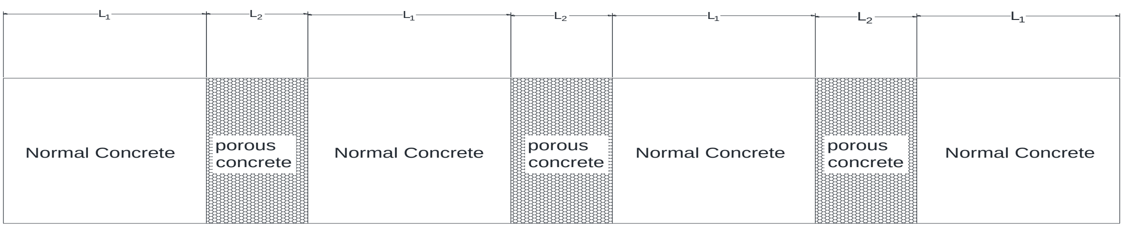


Fig 5: Suggested Porous Concrete Road Plan for Low Traffic Volume Roads

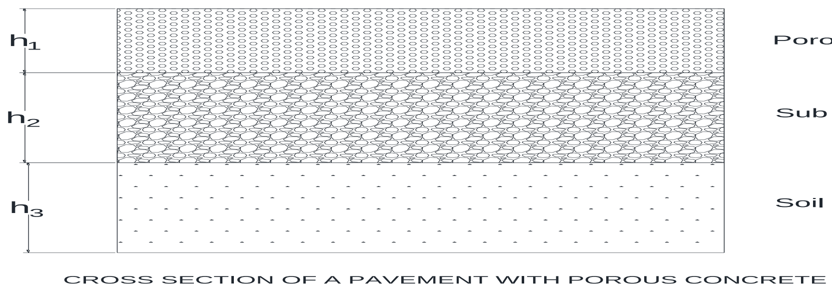


Fig 6: Suggested Pavement Cross Section for Low Traffic Volume Roads using Porous Concrete Surface.

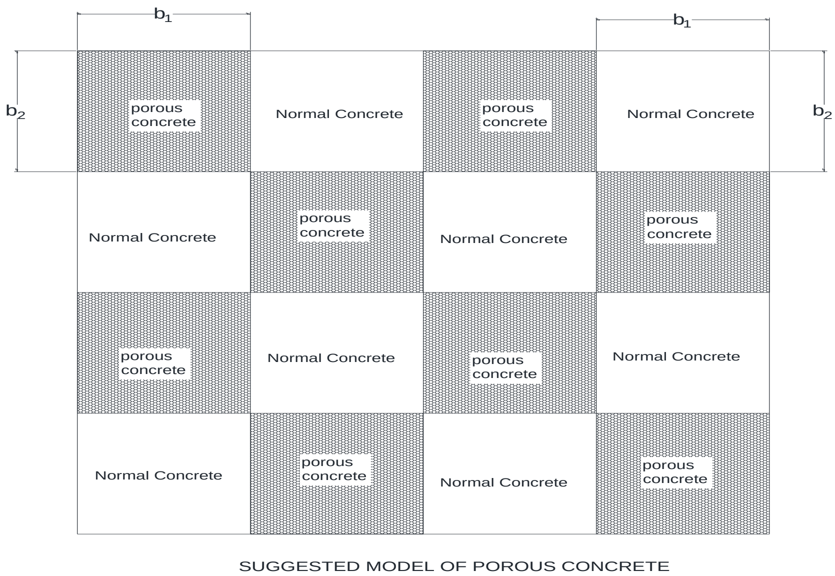


Fig 7: Suggested Plan of Parking Layout with Porous Concrete.

Fig 5-7 Pavement Models for Preventing Runoff

The models suggested in the listed figures: 5-7 are indicative and can be adopted with modifications to suit specific site conditions.

In figure: 5 L1 and L2 are the lengths of the panels for normal concrete and porous concrete. The lengths of the panels may vary based on intensity of rainfall and subsoil drainage conditions.

Thickness of pavement component layers h1, h2 and h3 are to be designed to suit site conditions and likely to vary based on modulus of subgrade reaction, modulus of elasticity of concrete and expected traffic loads. Similarly the parking layout in figure: 7 is an indicative model and the dimensions of the panel vary based on climatic conditions.

E. Concluding remarks

Muscat city falls in hot and arid climate zone and receives very scanty and erratic rainfall. Many a times city roads are inundated by flash floods due to poor drainage conditions. In this technical paper use of porous concrete in storm water management as an effective way to prevent run off and recharge groundwater is discussed. For this porous concrete is designed with varying % of fines ranging from 0% to 40% of total aggregates and tested for cube and cylinder strength. At 20% fines (1:0.9:3.6) porous concrete is found more appropriate and suitable for its use in low traffic volume roads and parking areas. Also pavement planning models for secondary roads and parking areas is suggested. The results presented in the paper is indicative and are for demonstration purpose only. The highway engineer need to establish the design mix for porous concrete, for specific use to suit to the local traffic and environmental conditions and materials.

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