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Experimental analysis of pervious concrete with high water reducer and fly ash for strength development

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Abstract —*Pervious concrete technology is a unique and effective means to meet growing environmental demands. By capturing rainwater and allowing it to seep into the ground, pervious concrete is instrumental in recharging groundwater, reducing storm water runoff and meeting Environmental Protection Agency (EPA) storm water regulations. In fact, the use of pervious concrete is among the best management practices recommended by the EPA and by other agencies and geotechnical engineers across the world, for the management of storm water runoff on a regional and local basis. Pervious concrete is a composite material consisting of coarse aggregate, Portland cement, water and chemical admixtures. It is little bit different from the conventional concrete in that it contains little to no fine aggregates. The coarse aggregate usually consists of a single size and is bonded together at its points of contact by a paste formed by the cement and water. The result is a concrete with a high percentage of interconnected voids that, when functioning correctly, permit the rapid percolation of water through the concrete. The main objective of this project work is to study the strength of pervious concrete. To determine an appropriate mix design of pervious concrete at which we can get the optimum strength and permeability characteristics. In this project work, the effect of variation in quantity of a component (sand) in mix design of pervious concrete on its strength is investigated. The goal is to achieve a maximum strength without inhabiting the permeability characteristics of the pervious concrete. For the project study, three mixes were prepared i.e. Control Mix, Mix no 1 and Mix no 2 with varying sand percentage as 2.20 %, 0.0 % and 4.0 % respectively. The mix consisted of ½ inch down coarse aggregate, ordinary Portland cement, fly ash and water. The mix also included admixtures including a high range water reducer (HRWR) and hydration stabilizer. Cylinders and beams specimens were casted for this study. Pervious concrete slab was also casted to perform the infiltration test of pervious concrete pavement. The results of compression test, flexure test and infiltration rate test of the three mixes were then compared to make conclusions about the research study. The results of all the tests performed on the specimens casted for this project work study shows that with increasing the sand percentage in the previous concrete mixes, the strength of the concrete increases but the permeability of the concrete decreases.*

Keywords- *Pervious concrete technology, high range water reducer, hydration stabilizer and fly ash.*

I. INTRODUCTION

The socio-economic climate around the world is changing every day. Engineers must consider not only the economics of the project, but now more than ever, consider the impact that projects will have on the human and natural environment. Pervious concrete has existed, in one form or another, for many years, but only recently have an environmental regulations and storm water treatment costs allowed its true consideration in engineering designs. Pervious concrete research at Iowa State University (ISU) began in 2004 [1] coinciding with an increase in interest spurred by the United States (U.S.) Environmental Protection Agency (EPA) implementing the National Pollutant Discharge Elimination System (NPDES) Phase II requirements for storm water improvements to smaller municipalities and construction sites. Consequently, the research findings for cold weather pervious concrete were well-timed as many engineers, both public and private, began to explore the changing world of engineering designs evaluated through an environmental lens. Validation of the freeze-thaw durability of pervious concrete under the most extreme conditions created an opportunity to explore many other aspects of previous concrete and to improve durability through additional mixture characterization and new construction practices through a comprehensive research project [2]. Based on the laboratory results; a fully instrumented parking lot was constructed at ISU to allow quantification of the benefits provided by a pervious concrete system. This research study includes a selection of mix designs encompassing a variety of different aspects in previous concrete research all with the ultimate goal of improving the resulting quality of previous concrete placements. Pervious concrete pavement is a unique and effective means to meet growing environmental demands. By capturing rainwater and allowing it to seep it to the ground, previous concrete is instrumental in recharging groundwater, reducing storm water runoff and meeting U.S. Environmental Protection Agency (EPA) storm water regulations. In fact the use of pervious concrete is among the Best Management Practices (BMP) recommended by EPA and the other agencies and geotechnical engineers across the country, for the management of storm water runoff on a regional and local basis [3]. This pavements technology creates more efficient and effective land use by eliminating the need of retention ponds, swales and other storm water management devices. In doing so, pervious concrete has the ability to lower the overall project costs on a first-cost basis and provides environmental benefits. American Concrete Institute (ACI) 522R defines pervious concrete as “a zero slump, open graded material consisting of Portland cement, coarse aggregate, little or no fine aggregates, chemical admixtures and water. The combination of these ingredients will produce a hardened concrete material with connected pores ranging in size from 0.08 to 0.32 in. (2 to 8 mm), which allows water to directly pass through it easily [4]. The void content can range from 18 to 35 %, with typical compressive strengths of 400 to 4000 psi (2.8 to 28 MPa). The drainage rate of pervious concrete pavement will vary with aggregate size and density of the mixture, but will generally fall into the range of 2 to 18 gal/min/ft2 (81 to 730 L/min/m2). Pervious concrete is a composite material consisting of coarse aggregate, [5] Portland cement and water. It is little bit different from the conventional concrete in that it contains little to no fine aggregates. The coarse aggregate usually consists of a single size and is bonded together at its points of contact by a paste formed by the cement and water. The result is a concrete with a high percentage of interconnected voids that, when functioning correctly, permit the rapid percolation of water through the concrete. Unlike conventional concrete, which has a void ratio anywhere ranging from (3-5) %, pervious concrete can have a void ratio ranging from (15-35) % depending on its application. Pervious concrete characteristics differ from conventional concrete in several ways [6]. Compared to conventional concrete, pervious concrete has a lower compressive strength, higher permeability and a lower unit weight, approximately 70 % of the conventional concrete. The Environmental Protection Agency recognizes pervious concrete as a Best Management Practice (BMP) to help engineers design procedures for treating polluted storm water. Building owners are realizing better land utilization and LEED credits with pervious concrete parking lots. Pervious concrete is practically used for many applications, but it is limited by its lack of durability under heavy loads. This lack of resiliency restricts the use of pervious concrete to specific functions. Pervious concrete is limited to use in areas subjected to low traffic volumes and loads. Although once used as load bearing walls in homes [7], pervious concrete is now utilized primarily in parking lots but does have limited applications in areas such as green houses, drive ways, sidewalks, residential streets, tennis courts (limited to Europe) and swimming pool decks. Although not a new technology, it was first used in 1852, pervious concrete is receiving renewed interest, partly because of federal clean water legislation. The high flow rate of water through pervious concrete pavements allows rainfall to be captured and to percolate into the ground, reducing storm water runoff, recharging ground water, supporting sustainable construction, providing a solution for construction that is sensitive to environmental concern and helping owners comply with EPA storm water regulations [8]. This unique ability of pervious concrete offers advantages to the environment, public agencies and building owners by controlling rain waters on-site and addressing storm water runoff issues. This can be of particular interest in urban areas or where land is very expensive. Depending on local regulations and environment, a pervious concrete pavement and its sub-base may provide enough water storage capacity to eliminate the need for retention ponds, swales and other precipitation runoff containment strategies. This provides for more efficient land use and is one factor that has led to a renewed interest in pervious concrete. Other applications that take advantage of the high flow rate through pervious concrete include drainage media for hydraulic structures, parking lots, tennis courts, green houses and pervious low duty pavements. Its high porosity also gives it other useful characteristics; it is thermally insulated (for example, in walls of buildings) and has good acoustical properties (for sound barrier walls). Although pavements are the dominant application for pervious concrete in the U.S., it also has been used as a structural material for many years in Europe [9]. All of these applications take advantage of the benefit of pervious concrete characteristics. However, to achieve these results, material proportions, mix design and construction details must be planned and executed with care on site. Pervious concrete is advantageous for a number of reasons. Of top concerns is its increased permeability compared with conventional concrete. Pervious concrete shrink less, has a lower unit weight and higher thermal insulating values than conventional concrete. Although advantageous in many regards, pervious concrete has limitations that must be considered when planning its use [10]. The bond strength between particles is lower than conventional concrete and therefore provides a lower compressive strength. There is potential for clogging thereby possibly reducing its permeability characteristics. Finally, since the use of pervious concrete is fairly recent, there is a lack of expert engineers and contractors required for its special and proper installations on sites [11].

II. LITERATURE REVIEW

In recent times, pervious concrete has been reintroduced for the development of world in an attempt to fulfill the concerning demands regarding environmental problems. It involves the applying of low slump, high consistence concrete mix that has received growing recognition as an answer to the issues arising from the excessive flow of storm water above the ground surface. [12] Environmental Protection Agency (EPA) declared pervious concrete as Best Management Practice for the storm water management as it has been used as storm water harvesting technique to control the contaminants. Pervious concrete constitutes Portland cement, very little or no fine aggregate and controlled quantity of water. [13] The thick cement paste coats the coarse aggregates and makes strong bond which leads to the formation of voids in the concrete. The drainage rate of pervious concrete is usually 5 gal/min/ft2 or 200 L/min/m2. The void content in pervious content usually ranges from approximately 15 to 35 %. [14] The pervious concrete helps to remove the pollutants from surface runoff and recharging the ground water sources. Tennis, Lemming and Akers explained that the pervious concrete voids entraps the oil and prevent them from flowing into the surface runoff which ultimately flows into nearby streams during storms. Pervious concrete prevents the ponding, spraying and provides safety against hydroplaning phenomena, which causes the slippage of vehicle in the rain storms. Pervious concrete has compressive and tensile strength from 400 to 4000 psi and 150 to 550 psi respectively [15] which is less than the conventional concrete, which ranges from 3500 to 5000 psi and 350 to 600 psi respectively. However by the addition of admixtures and fibers, the compressive and tensile strength of pervious concrete mixes can be improved to a very good extent, which is practically used in the construction industry. [16] The two most important characteristics of pervious concrete i.e. higher strength and maximum permeability is generally affected by the amount of cement and water, size and type of coarse and fine aggregates and the method used for the compaction of concrete. Researchers in the past have performed a variety of different experiments to obtain the maximum permeability and higher strength of pervious concrete. Pervious concrete's applications and its properties. Its properties were discussed such as unit weight, mix design proportions, methods of compaction and curing. [17] He performed variety of experiments on pervious concrete cylinders to find out the correlation multiple between compressive strength and any material property. He concluded the result that pervious concrete is dependent on water cement ratio and aggregate cement ratio. He also experimented to find out how the compaction method affects the compressive strength. [18] He used a variety of aggregates in his experiments to find out its effect on the compressive strengths of pervious concrete. It was concluded in research on pervious concrete that the properties of pervious concrete like aggregate to cement ratio, compaction methods used and curing time of pervious concrete. He discovered the relationship between water cement ratio and compressive strength at 28 days, [19] while using the 3/8 inch size coarse aggregate. By using this relationship, he brought the optimum water cement ratio which can be utilized to get the maximum permeability but was not sure whether it will give the maximum compressive strength [20,21] or not. He stated that the pervious concrete shouldn't be used in high automobiles areas. He also studied the relationship of void content and compressive strength, because the void contents play an important role in the strength as well as in the permeability characteristics of pervious concrete. [22,23]

III. RESEARCH METHODOLOGY

The first part is focused on testing concrete mix design to determine the mix with the optimal compressive strength, flexural strength and permeability characteristics. Three design mixes were tested (including the control mix) and then they were compared with each other to determine the optimum mix design. Pervious concrete mixing, sampling and testing was conducted in the laboratory. The three design mixes were achieved by varying the sand content to potentially improve the compressive and flexural strength of pervious concrete. The data collection scheme for this research was developed from information observed in the literature review and industrial standards. Based on the literature review, the following methodologies were employed.

1. Pervious Concrete Mix Design
2. Slump Test (Workability Test)
3. Compression Test
4. Flexure Test
5. Infiltration Rate Test

III. RESULTS AND DISCUSSION

1. PERVIOUS CONCRETE MIX DESIGN

For the project study, three mixes were prepared i.e. Control Mix, Mix no 1 & Mix no 2 with varying sand content as 2.20 %, 0.0 % and 4.0 % respectively. The mix consisted of ½ inch down coarse aggregate, little to no fine aggregate, ordinary Portland cement and fly ash. The mix also included admixtures including a high range water reducer (HRWR) and hydration stabilizer. These admixtures are used to potentially improve the bond between the cement and the coarse aggregate and to improve workability as well as flexural properties of the pervious concrete. A retarder was also included since the low water content of porous concrete pavement mixes causes them to dry quickly. The sand content was varied for all mixes. Trial batches were prepared and tested for acceptable unit weight. The mix proportions for the pervious concrete samples (concrete mixes) are summarized in the table as follows:

Table 1: Pervious Concrete Mix Design

Mix Design	Control Mix	Mix 01	Mix 02
Cement (%)	11.74	11.74	11.74
Fly Ash (%)	3.37	3.37	3.37
Gravel (%)	82.69	84.89	80.89
Sand (%)	2.20	0	4
W/C Ratio	0.34	0.34	0.34
HRWR (%)	0.6	0.6	0.6
Hydration Stabilizer (%)	1.2	1.2	1.2

2. SLUMP TEST (WORKABILITY TEST)

Cement association of Canada (2003) stated that the workability is the ease of placing, combining and finishing freshly concrete mixed and the degree to which it resists segregation. According to cement manufacturers association of India, a good concrete must have workability in the fresh state and should also develop sufficient strength. The test is simple and cheap. It is suitable to use in the laboratory and also at site. Although the test is simple, but the testing has to be done carefully due to a huge slump may obtain if there is any disturbances in the process. The slump test will give a reasonable indication of how easily a mix can be placed although it does not directly measure the work needed to compact the concrete.

It is also mentioned that a slump less than 1 inch will indicate a very stiff concrete and a slump that more than 5 inch will indicates very runny concrete, but in case of pervious concrete the scenario is different. Pervious concrete mixes have almost zero slumps.

Table 2: Pervious concrete mixes for slump test

Description	Control Mix	Mix No 1	Mix No 2
Sand Percentage	2.20 %	0.0 %	4.0 %

Figure 1: Slump test of pervious concrete

The slump test was performed according to ASTM C 143 on all the three mixes as mentioned above in the table. The slump in inches was reported. If practicable, two slump tests should be made on each mix and average of two slumps should be reported. The entire operation from the start of filling to the removal of mould should be carried out without interruption and be completed within an elapsed time of 1.5 minutes. The observations of test are shown in Table 6.2 and results of slump test are shown in Table which is as follows:

Table 3: Observations of Slump Test

Description	Control Mix	Mix No 1	Mix No 2
Sand Percentage	2.20 %	0.0 %	4.0 %
Aggregate Size	½ inch down	½ inch down	½ inch down
Slump (inches)	0	0	0

Table 4: Results of Slump Test

Description	Control Mix	Mix No 1	Mix No 2
Sand Percentage	2.20 %	0.0 %	4.0 %
Slump Type	Zero	Zero	Zero
Degree of Workability	Very Low	Very Low	Very Low

3. COMPRESSION TEST

The compression test was performed according to ASTM C 39. The test was performed on Universal Testing Machine (UTM). The compression test was performed on the cylinder specimens for 7 days and 28 days compressive strength. The cylinder specimens were caped with capping compound before testing. The height and diameter of specimens were also measured prior to the testing.

Figure 2: Figure shows testing of cylinder specimen in UTM

The result of 7 days compressive strength of pervious concrete shows a linear behaviour. As the percentage of sand increases in the concrete mix, the compressive strength increases. By increasing the sand content in the mix, the percentage of voids becomes less and the bond to bond strength of concrete mix increases hence the compressive strength of concrete increases. The mix with 0 % sand shows a decrease of 14 % from the values of control mix. The mix with 4 % sand shows an increase of 21 % from the values of control mix.

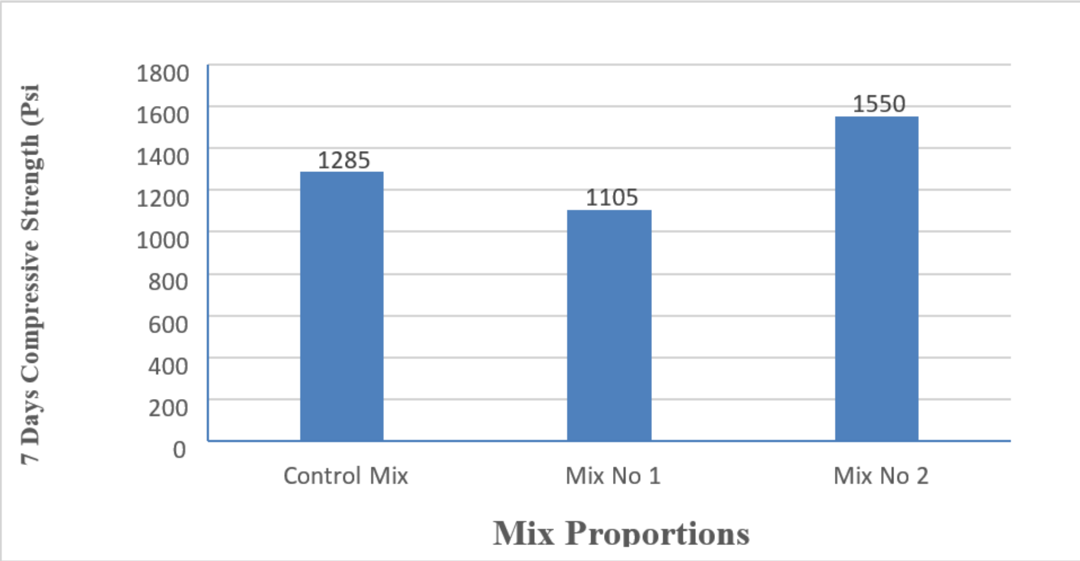

Figure 4: Results of 7 days compressive strength of all three mixes

The result of 28 days compressive strength of pervious concrete shows a linear behavior. As the percentage of sand increases in the concrete mix, the compressive strength increases. By increasing the sand content in the mix, the percentage of voids becomes less and the bond to bond strength of concrete mix increases hence the compressive strength of concrete increases. The mix with 0 % sand shows a decrease of 10 % from the values of control mix. The mix with 4 % sand shows an increase of 5 % from the values of control mix.

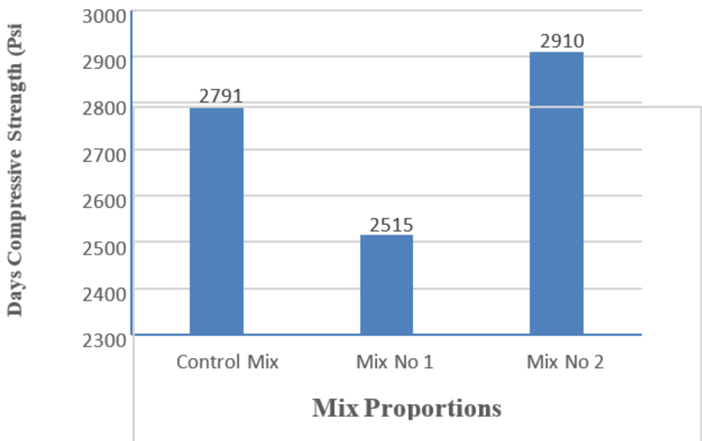

Figure 5: Results of 28 days compressive strength of all three mixes

4. FLEXURE TEST

The flexure test was performed according to ASTM C 293. The test was performed on Universal Testing Machine (UTM). The flexure test was performed on the beam specimens for 28 days flexural strength. The length, width and depth of specimens were also measured prior to the testing. After the testing on UTM, modulus of rupture was calculated for all the beam specimens. The flexure strength is a material property, defined as the stress in a material just before it yields in a flexure test. The transverse bending test is most frequently employed, in which a specimen having a rectangular cross-section is bent until fracture or yielding using a center point or three point flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress. This test method covers determination of the flexural strength of concrete specimens by the use of a simple beam with center point loading. The mentioned test method is broadly used to determine the modulus of rupture using test specimens, prepared and cured, in accordance with practices C 31 or C 192. The results for strength determination would be different for specimens with differences in size, preparation, moisture condition, and curing.

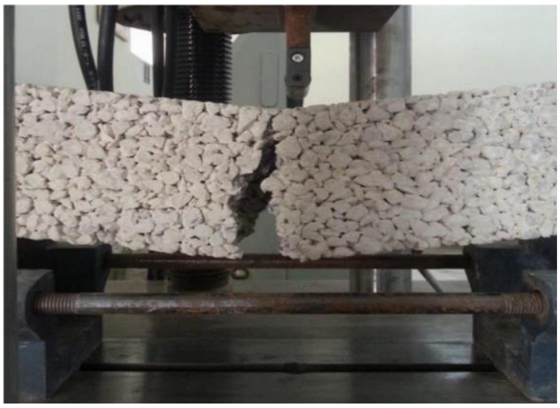

Figure 6: Figure shows the failure pattern of beam specimen

The result of 28 days flexural strength of pervious concrete also shows a linear behaviour. The modulus of rupture ranges from 424 psi to 630 psi for the concrete mixes. As the percentage of sand increases in the concrete mix, the flexural strength increases. By increasing the sand content in the mix, the percentage of voids becomes less and the bond to bond strength of concrete mix increases hence the flexural strength of concrete increases. The mix with 0 % sand shows a decrease of 21 % from the values of control mix. The mix with 4 % sand shows an increase of 17 % from the values of control mix.

5. INFILTRATION RATE TEST

The infiltration rate test was performed according to ASTM C 1701. For this test, slab of pervious concrete pavement was casted in lab and then placed on site. A sub base of 6 – 8 inches was also prepared for this piece of pervious pavement. The pervious concrete slab was casted on all the three mixes and infiltration rate test was performed on all the three mixes. The site for pervious concrete pavement infiltration test was selected inside the campus. All the three pervious concrete slabs were placed and infiltration test was performed on them. The infiltration rate test is an infield permeability test of pervious concrete. This test method covers the determination of the field water infiltration rate of in place pervious concrete. An infiltration ring is temporarily sealed to the surface of a pervious concrete pavement. After pre-wetting the test location a given mass of water (40 lb) is introduced into the ring and the time for the water to infiltrate the pavement is recorded, which gives the infiltration rate. The formula used for infiltration test is as follows:

$I = (KM) / (D2\ t)$

where:

K = 126,780 in (inch-pound) units.

M = Mass of Infiltrated Water (lb) = 40 lb

D = Inside Diameter of Infiltration Ring (in) = 12 inches t = Time Required for Measured Amount of Water to Infiltrate through Concrete (sec).

Figure 7: Infiltration test performed on pervious concrete on site

The infiltration rate ranges from 782.6 in/hr to 927.8 in/hr for the concrete mixes. As the percentage of sand increases in the concrete mix, the permeability or infiltration rate decreases. By increasing the sand content in the mix, the percentage of voids becomes less and hence the permeability (infiltration rate) of concrete mix decreases and vice versa. The mix with 0 % sand shows an increase of 11 % from the values of control mix. The mix with 4 % sand shows a decrease of 7 % from the values of control mix.

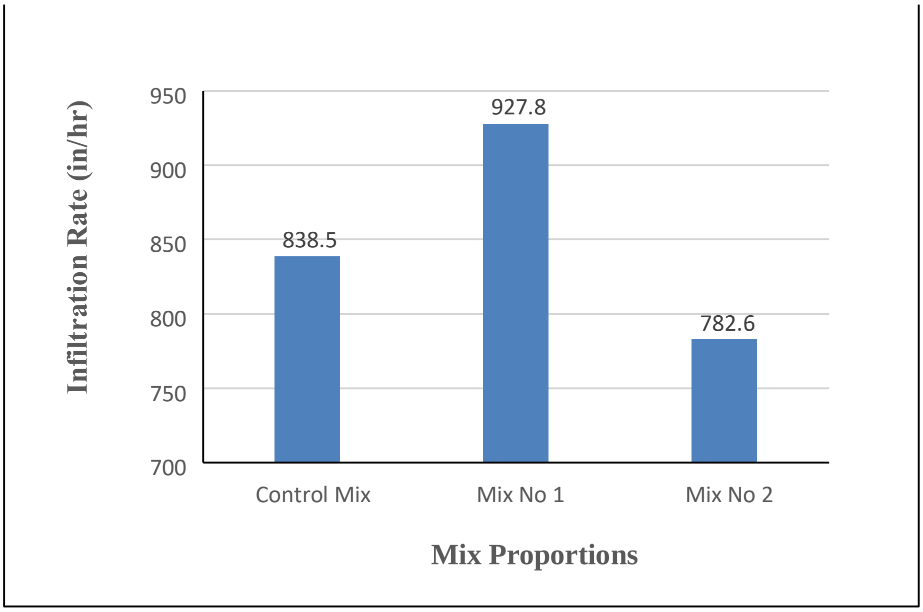

Figure 8: Results of Infiltration test on all three mixes

IV CONCLUSION

Based on the results obtained from the tests performed in our project work, the following conclusions about the study can be drawn, which are as follows: Mix no 2 shows the maximum strength of pervious concrete. Mix no 1 shows the maximum permeability characteristics. Control mix shows optimum strength and permeability characteristics. The result shows that with increasing the sand content in pervious concrete mix, the strength of concrete increases, but the permeability of concrete decreases.

V. RECOMMENDATIONS

Based on this evaluation of pervious concrete performance, the following recommendations are provided to generalize and to build upon the findings of this study:
If more strength is required, then Mix no 2 should be used.
If more permeability is required, then Mix no 1 should be used.
If both strength & permeability is needed, then Control mix should be used.
The previous sections have demonstrated that in general, the utilization of pervious concrete can provide great number of advantages, especially to the construction industry and developing countries. The promotion of use of pervious concrete can be achieved through:
Advertisements, exhibits and pilot-projects.
Recommending the use of pervious concrete in public and government sectors.
Promotion of research and development in this area so as to maximize its use.
Organization of training programs for the production and use of pervious concrete.
The adoption of the above mentioned measures could greatly contribute in making the use of pervious concrete to this society in terms of availability, use and environmental benefits. In the past, much research study has been done to achieve good permeability characteristics but further study needs attention on increasing the strength of pervious concrete.
To increase the strength of pervious concrete, further research study can be done generally on the following aspects by
Decreasing the aggregate size.
Increasing the sand percentage in mixes.
Decreasing the aggregate to cement ratio.
Adding fibers to obtain greater strengths.

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