Transportation Consortium of South-Central States

Tran-SET

Solving Emerging Transportation Resiliency, Sustainability, and Economic Challenges through the Use of Innovative Materials and Construction Methods: From Research to Implementation

Investigation of Physical and Dynamic Properties of High Porous Concrete

Project No. 18CLSU14

Lead University: Baton Rouge Community College

Final Report

September 2019

Disclaimer

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16. Abstract

This project pursued two main objectives: (1) providing opportunities to Baton Rouge Community College (BRCC) students to develop hands-on laboratory skills and exposure to the transportation field, and (2) investigating porous concrete properties. Several BRCC student groups performed the work presented within this report; students prepared samples with different porosity and permeability according to standard specifications. The testing of the samples was performed at the Louisiana Transportation Research Center (LTRC) facility under the supervision of LTRC specialists. Findings indicate that the porosity of samples is backward proportional to the compression strength. This function is not linear but can be estimated as an exponential decay curve for the aggregates used. More water content in the mixture gives stronger samples with low permeability that could reduce water absorption by the porous concrete in industrial applications. The optimal mixture recipe provides 30,000 psi compression stress with 15% porosity, which is enough for parking lot and walking path applications.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

A	Aggregate
BRCC	Baton Rouge Community College
C	Cement content
$Cp_{c.}$	Specific gravity of cement
$Cp_{A.}$	Specific gravity of coarse aggregates
LTRC	Louisiana Transportation Research Center
W	Water content

EXECUTIVE SUMMARY

Baton Rouge Community College (BRCC) is an undergraduate institution pursuing workforce development and educational basis for various pre-engineering programs of study. BRCC prepares students for four-year universities: such as Louisiana State University (LSU), University of Louisiana at Lafayette (ULL), and Southern University (SU). BRCC students struggle to choose the right engineering focus due to a lack of opportunity for real-world problem engagement. This study consists of two purposes. First, students are involved in a research activity in their area of education, which increases interest in the profession, increases student retention academically, and makes engineering a more probable area of study.

Several BRCC students worked on this study; students prepared 22 samples of concrete with different porosity/permeability, and mixture composition according to the standard specifications offered by the Louisiana Department of Transportation and Development. The technical equipment and help of the Louisiana Transportation Research Center (LTRC) and their specialists was offered to test the dynamic properties of the prepared samples in order to determine the maximum stress and permeability. Under the supervision of LTRC specialists, students observed crush tests of each sample and recorded the maximum compression strength. The data was analyzed later using statistical methods. Students learned how to use various computer programs in order to define average values, uncertainty of the experimental work, build plots and derive conclusions from the graphical information.

The porosity of the samples was determined based on water absorption tests. Samples were emerged in water and the amount of water was measured afterwards. The ratio of obtained volume of the water to the total sample volume gave the porosity value.

The permeability test was performed at the LTRC facility. Unfortunately, the electric resistivity test did not show any sufficient results. This type of test may not be applicable to porous concrete samples.

Three samples with different composition of aggregate content were tested for water penetration. The dried samples were immersed in water for three hours and then underwent mechanical destruction in order to see the water penetration inside the sample.

Some interesting results were obtained in maximum compression stress testing. The compression stress and porosity relationship was found to have an exponential decay relationship and backward proportional to each other.

The cracks were developed during the compression test along the body of the sample. It was expected initially that cracks would developed between the aggregate particles. However, the cracks were running not only through the cement connecting the aggregate particles, but breaking the weak aggregate particles. This means the cement/water chemical reaction gave a strong connection of the aggregates inside the sample.

The water absorption test showed that all three samples with different compositions fully absorbed water during four hours. Thus, water absorption does not significantly depend on mixing composition.

1. INTRODUCTION

Porous concrete may be essential for the transportation system in Louisiana. During the hurricane season, water collects on roadways, walkways, and parking lots creating emergencies for pedestrians and drivers. To reduce this risk, porous concrete can be used for pavements and parking lots. Specially designed concrete will absorb excessive moisture and, at the same time, transport water away from the flooded area through the drainage network. Pervious concrete pavement systems not only positively impact water quality and water quantity, but can provide other benefits. Pervious concrete can reduce "black ice" formation, reducing potential slipping hazards, as melting snow drains into the pavement rather than ponding on the surface *(1)*.

The pore size and their connections in the sample can be designed by controlling the water and cement content. The pore size should be carefully designed in a way that water can easily penetrate through the pores in order to be removed from parking lots, walkways, and make ground transportation safe and reliable.

While performing this project, Baton Rouge Community College (BRCC) students did not know initially the recipe of porous concrete. Several types of samples were prepared with different grain size and sand/water content. Students discovered that the mixture composition is directly connected to the properties of the material. Making changes in mixture composition, it is possible to define the optimal recipe with two main boundaries in physical properties: high permeability and good strength. The research team was interested in high permeability of the material in order to have less resistance of water absorbance and transport water away from the flooded areas. High strength of the sample is needed for reliability and long-term operational requirements for roads and walking paths. This quality is associated with low permeability and good compaction with low pore size. Students prepared 22 samples of different permeability and concrete mixture composition.

BRCC does not have testing facility to perform this work. One of our collaborators, Louisiana Transportation Research Center (LTRC), offered their professional and research consultation to solve the research problem as well as to introduce students to the industrial requirements of high way transportation engineering. Students had a tour of their facility and were introduced with standards of roadway transportation and methods of testing various samples coming from industry sites.

2. OBJECTIVES

The project is pursuing several objectives that can be divided into two subgroups: educational and scientific. First is related to financial support and involvement of BRCC students to the research activities in order to boost interest in the engineering profession. Increasing the retention of students also aids in BRCC's mission and vision of excellence in teaching using innovative methods. It is crucial for students to develop skills associated with experiment set up, sample preparation, follow industrial standards, collect and analyze data, and present the results in scientific meetings and conferences.

The second purpose will create research data in order to investigate the possibility of implementation on Louisiana roadways. The porous concrete technology can be a great solution to avoid flooding of pavements, walking paths and roads during hurricane seasons. It may increase safety on the road and avoid accidents. Several objectives are drawn from this purpose:

- Reach up to 20% porosity of the experimental samples;
- Design the sample with optimal maximum compression stress and porosity values;
- Study the cracks development during the compression stress experiment;
- Explore water absorption by the samples of different aggregate content; and
- Explore effect of silica addition to the sample mixture in order to increase compression stress.

Porous concrete is typically made of gravel, cement, and water. Gravel is used as a skeleton of the structure. Cement is used for hardening the structure and water is used for the chemical reaction with cement that takes place after mixing the sample. The space between the gravel particles stays empty and, most importantly, pores become connected with each other. Thus, the porous concrete has a great potential to absorb drainage water during flooding and transport it through communications placed below the concrete level. The amount of water absorption is controlled by the porosity term, defined as a void space percent of the total sample's volume. Changing the water content while mixing the porous concrete sample, it is possible to control the porosity of the sample. Too much water makes cement to fill the empty space between the particles and create hard bonds between the aggregates while hardening; the porosity value drops. According to the literature, 20% porosity is a sufficient value to provide good water transport through the porous concrete layer. This would lead to another objective of the student's project to reach the sufficient porosity values while preparing the porous concrete sample.

The concrete samples are checked in industry for the maximum compression stress in order to see the maximum load that this concrete can hold. This value is also responsible for the concrete application. For example, in the parking lot applications, the concrete should sustain more stress than in walking paths where only people are allowed to walk and therefore less load is applied to the surface of the concrete. The compression stress is controlled by water content of the sample. According to the literature, its value increases with more water amount used in the sample preparation. Less water amount leaves sample with weak cement bonds between the aggregate particles, thus, reducing the compression stress of the sample itself.

As described above, there are two main parameters to control the sample: porosity and maximum compression stress. According to the literature, these parameters are inversely proportional to each other: increasing porosity of the sample leads to reducing the maximum stress and vice versa.

Thus, there is one more objective of the project – to define the optimal sample recipe with sufficient porosity and high compression stress.

Different size of the aggregate can affect porosity. Larger aggregate particles create larger pores associated with high porosity values, thus better water penetration. Small particles create less pore space, therefore, sand is rarely used in porous concrete mixtures. However, presence of small particles in the mixture create higher compression stress values of the sample. Thus, for a different aggregate size should be an optimal solution of water and cement content. In this research, the aggregate size and percent distribution was fixed from purchased commercially available aggregate mixture. The study of the aggregate size distribution helps to understand the mixture properties better and make reasonable conclusions.

While performing the compression stress, it is interesting to see the crack net development and most importantly track the crack path in the sample. From one side, the presence of the larger size aggregate particles leads to the idea that the crack will run between the particles through the cement bonds, as usually it is seen in the literature. From the other side, if the cement bond will be stronger than the aggregate content the crack may break the particle. The cement bond with proper water and cement content will give constant stress properties, and the only parameter affecting the compression stress is the aggregate chemical composition. In the literature, there are several proposals of using crushed brick aggregate for recycling purposes in industrial applications, especially in the concrete mixtures. How the recycled material can affect the maximum compression stress could be a future topic for exploration. In this research only visual crack study was performed.

Water penetration inside the sample is another objective of this research. The regular concrete has very low water absorption and the test usually takes several hours. In the case of porous concrete, the water absorption should take much less time, and it is interesting to see the boundary of wet and dry sides of the sample. This could give some interesting observations to students. Again, only visual analysis was performed during this study.

Silica is one of the components of Portland cement. Increasing content of silica helps raise the compression stress values. Keeping the same aggregate size and water content is important to hold the porosity values as high as possible, and adding some percent silica to the mixture could improve the stress values with the same porosity.

3. LITERATURE REVIEW

High porous (pervious) concrete (HPC) is a special high porosity concrete model that allows water from precipitation or other sources to move through the concrete thickness and, therefore, avoid flooding walking paths, roads, pavements and other applications. There are many small pores among the aggregate skeleton that are connected to each other allowing fluid to flow. The mixture composition has little or no fine aggregate (sand) and has just enough cementitious paste to coat the coarse aggregate particles while preserving the interconnectivity of the voids. The void percent ranges from 18 to 35% with compressive strengths of 400 to 4000 psi (28 to 281 kg/cm). The infiltration rate of HPC will fall into the range of 2 to 18 gallons per minute per square foot (80 to 720 liters per minute per square meter) *(2, 3)*. Researchers mention other environmental benefits of this material such as the ability to reduce tire noise in the streets, limiting the amounts of pollutants entering the groundwater, and reducing urban heat island effects *(4)*.

Pervious concretes have relatively lower compressive strengths as compared to conventional concretes. This is mainly attributed to the presence of macro-sized pores and large pore volumes and to the absence or minimal quantity of fine aggregates *(5)*. The low strength of conventional pervious concrete not only limits its application in heavy traffic highways but also influences the stability and durability of the structures. Therefore, it is important to investigate the main factors affecting the compressive strength of pervious concrete and find ways to improve its applicability. Laboratory tests on no-fines pervious concrete for paving were conducted by Meininger *(6)*, and conclusions were drawn regarding the percentage of air voids needed for adequate permeability, the optimum water–cement ratio range, and the amounts of compaction and curing required. Japan Science and Technology Corporation *(7)* investigated the effects of mix proportions on some properties of a no-fines pervious concrete. Yang and Jiang *(8)* carried out laboratory tests on pervious concrete pavement and found that using smaller aggregate, silica fume (SF), and superplasticizer (SP) in pervious concrete could greatly enhance its strength, abrasion resistance, and freezing and thawing. Gupta et al. *(9)* studied the effects of some factors such as grading and particle size of aggregate, mass ratio of aggregate to cement, mass ratio of water to cement, admixtures, and mixing process on the properties of pervious concrete including porosity, permeability, and compressive strength.

Strength of the porous concrete is greatly influenced by cement content, aggregate type, aggregate proportion and design porosity. Previous work regarding porous concrete have suggested the following guidelines for the design of mix for porous concrete:

- In normal concrete, 1 m^3 of concrete has 180 to 200 liters of water. As per IS 456:2000, out of these 180 liters, around 30–35% of the water is consumed by the fine aggregates. Thus, in porous concrete design, this water should be accounted for.
- The water-cement ratio of porous concrete is suggested to be kept between 0.26 and 0.40, so that optimum aggregate coating is obtained *(10)*.
- The porosity in porous concrete is kept between 15 to 25%, to attain a proper infiltration rate without substantial reduction of strength.

The porous concrete has three main constraints: strength, porosity, and permeability. These properties are mutually related to each other through the grain size of chosen gravel and water content in the sample. Increase in aggregate size develops high permeability and porosity of the sample reducing compression strength. All of them together depends on the water-cement ratio and the aggregate proportion and sizing *(9)*.

4. METHODOLOGY

4.1. Description of Materials

The following supplies were utilized to prepare the samples:

- Portland cement;
- Sand;
- Gravel;
- Silica;
- Concrete testing cylinders;
- Aluminum scoops;
- Buckets;
- Tamping rod; and
- Self-protection equipment: goggles, coats, gloves.

4.2. Sample Preparation

According to the literature, there is an optimal water/cement ratio where the compression strength is the highest regardless of porosity. The peak value of compressive stress ranges from 0.34 to 0.36 water cement ratio. Thus, the 0.35 water/cement ratio was used for this investigation.

Volume of the samples vary depending on the plastic cylinder size uncertainty. The average volume was calculated as 1,700 cm^3 with $\pm 20cm^3$. Based on the volume of the sample the percent of aggregates, water and cement was determined.

Water content is highly dependent on grain size distribution. If more coarse aggregate was used the water content was high, and, contrary, if the moderate to small aggregate size was used the water percent was reduced to avoid too much moisture in the slurry.

Portland cement was used for sample preparation. While silica is a part of the cement composition, ten samples were made with additional 20 cm^3 silica added to the mixture to enhance the compression stress values.

Other assumptions taken into consideration were:

- Water content was determined, by giving consideration for fine aggregates [IS456:2000] and was taken as 350mL to 370mL for all samples;
- A fixed water-cement ratio is considered and the corresponding cement content was determined; and
- The void content of the dry aggregate was measured to be 20%. First, the dry aggregate was filled to the top of the sample cylinder. Water was added to the top and poured to the empty cylinder. The mass of it was measured on the triple beam scale. Then the empty cylinder was filled by water and the mass was measured. Later, the empty cylinder was weighted on the scales. Subtracting the mass of the cylinder and water from the previous masses the pure water masses were determined. Then taking the ratio of mass of water from the aggregates to the total water mass of the cylinder volume the porosity was determined.

The coarse aggregate content was determined using the following equation:

$$0.80 = \frac{W}{1000} + \frac{C}{Cp_{c.} * 1000} + \frac{A}{Cp_{A.} * 1000} \quad [1]$$

where:
W = Water content;
C = Cement content;
A = Aggregates;
$Cp_{c.}$ = Specific gravity of cement; and
$Cp_{A.}$ = Specific gravity of coarse aggregates.

The samples were mixed according to standards offered by LTRC personnel. Several steps were completed in filling the plastic cylinder with compaction of the concrete slurry:

1. Measure and place aggregates in the bucket;
2. Measure and add cement in the bucket;
3. Carefully mix both components in order to receive homogenous mixture;
4. Measure and add water to the sample mixture. Note that cement will immediately start chemical reaction with water. Thus, the samples should be completed as fast as possible. Otherwise, the mixture will dry out and it is possible to receive different testing results from the samples prepared from the same bucket;
5. Perform a ball test making a concrete ball by both hands. If water content is too low, the ball will not stick and fall apart. If the water content is too much, the concrete ball will not make a perfect shape. It will tend to spread out and hands will be covered by slurry concrete mixture. If the water content is just right, the ball will hold its shape;
6. Fill a quarter of the sample volume and perform three tamps with the tamping rod to compact the mixture;
7. Complete the rest of the samples the same way;
8. Cover the sample cylinders with the lids and place the samples on the table with known temperature and humidity. Drying the samples is very important. If the environment is too dry, the samples may crack when excessive water content will escape from the sample; and
9. Clean the tools.

The sample preparation and testing were performed according to ASTM C09.49 requirements. JA standard value for the density is 120 lb/ft^3 (1920 kg/m^3). An acceptable tolerance is plus or minus 5 lb/ft^3 (80 kg/m^3) of the design density. The fresh density (unit weight) of pervious concrete is measured using the jigging method described in ASTM C 29. Void content and unit weight can be determined according to ASTM C 140.

4.3. Testing Procedures

The primary interest of the scientific portion of the project was determination of the "ideal" mixture composition from the maximum strength and porosity/permeability point of view.

Three types of samples were chosen for investigation:

- Dry samples: high permeability and porosity values reached due to lack of water content;
- Right amount of water in the samples: this amount is governed by the calculated theoretical value of water to cement ratio; and
- Wet samples: in this case the samples were saturated by water, which reduced the pore space but increased the compression stress.

Additionally, ten samples were prepared alone with additional amount of silica added to the mixture to increase stiffness of the inter-grain connection.

Based on the literature review, the following tests were defined:

- Water absorption test;
- Permeability test;
- Porosity measurement test; and
- Maximum compression test.

Slump and air content tests are not applicable to pervious concrete. If the pervious concrete pavement is an element of the storm water management plan, the designer should ensure that it is functioning properly through visual observation of its drainage characteristics prior to opening of the facility.

4.3.1. Water Absorption Test

The samples were prepared for this testing with different mixture contents. One was made as a regular concrete with sand, cement, and water. The two others had various amount of aggregates added. All samples were placed in the tank with water. Time of water absorption was recorded the same for all samples and equal to three hours.

Figure 1. Water absorption test.

At the end of the test, the samples were removed from water tank and broken mechanically to see the water penetration boundaries.

4.3.2. Permeability Test

The surface resistivity method is one of the widespread techniques to define permeability of the sample *(11)*. The reciprocal of surface resistivity will give a permeability of the sample. Many agencies have adopted the standard tests for electrical indication of concrete's ability to resist chloride ion penetration *(12, 13)*, commonly known as the rapid chloride permeability test (RCPT), in their specifications for qualification and acceptance and as a means of indirectly assessing the permeability of concrete mixtures. The electrical resistivity of concrete is correlated well with important durability parameters such as permeability, diffusivity and in general the micro-structure characteristics of concrete. It is a fast and easy method of quality control during new construction. The primary advantage of the surface resistivity test is it takes less than 5 minutes to take readings.

A four-point Wenner probe with 1.5-inch probe spacing was used for the SR tests (see Figure 2). A total of eight readings per specimen were taken. Unfortunately, the readings were not reliable (17.4, 2.0, and 4.7 kΩ/cm). It seems like this method is not applicable to porous concrete samples.

Figure 2. Measuring permeability using surface resistivity method.

This test was needed for defining water flow resistance through the sample. The test was performed at the LTRC facility using their equipment working on determination of wet sample resistivity method. Unfortunately, standard permeability test was not clear and giving too disperse data. The LTRC instructor made a proposal that the regular equipment for permeability testing is not useful for porous concrete.

4.3.3. Porosity Test

Porosity was determined by the water displacement method. The samples were sun dried for one day. Then, they were immersed in a container containing water for 24 hrs. Later, the difference in the water level was observed. This volume indicates water which refused to enter the sample. Thus, the water which penetrated the sample can be found out by subtracting this volume from the volume of the cylinder. When this result is expressed in terms of a percentage of the volume of the sample, the porosity of the sample is obtained.

4.3.4. Maximum Compression Strength Test

This test is needed to define the compression strength of the sample. Based on findings the applicability of the porous concrete structure could be determined. The test was performed at the LTRC facility. Sample was inserted into the wet lab room with 100% humidity for a week to soak. Later each sample was placed under the hydraulic press registering the maximum compression force. The data was recorded and then converted to the stress values knowing the cross sectional area of the sample.

Figure 3. Ready for testing samples on the left and installation of the sample into the hydraulic press on the right.

Some samples were having an inclination angle between the top and bottom surfaces. This could led to wrong installation of the sample to the hydraulic press and register wrong compression force values. The LTRC technicians placed the epoxy caps on top and the bottom of these samples in order to get the surfaces parallel.

4.3.5. Ball Test

The ball test was done after the mixing is completed in order to check the quality of the concrete.

Figure 4. The ball test was performed in order to track water content in the mixture.

5. ANALYSIS AND FINDINGS

5.1. Maximum Compression Stress Test

The average values from each group of tests and samples were used to analyze the obtained experimental data. Samples 11 to 19 have extra silica added (20 ml) to each sample to increase durability. Tables 1, 2, and 3 show the data collected for dry samples, right amount of water, and extended gravel content samples, respectively. Table 4 shows data from the samples that did not match expectations, and therefore, disregarded.

Table 1. Too dry samples.

Sample	Max compression force, lbf	Max compression stress, psi	Mixture details	Porosity, %
4	26,055	2,074	Too little water	14.90
5	23,400	1,863	Too little water	20.50
10	26,720	2,127	Too little water	20.15
11	31,585	2,515	Little water	16.95
9	33,765	2,688	Little water	12.75
12	39,830	3,171	Little water	10.21
14	40,170	3,198	Little water	10.23
17	38,980	3,104	Little water	11.99

From the Table 1 it is seen that lack of water samples have different compression stress range depending on addition of silica. Samples 17, 14, and 12 contain additional 20 mL silica and compression stress is about the same 3,160 psi in average. The sample 9 and 11 have no additional silica in the composition, and their compression stress is lower by 500-600psi. All samples have the same water content.

Table 2. Right amount of water.

Sample	Max compression force, lbf	Max compression stress, psi	Mixture details	Porosity, %
6	54,725	4,357	Proper amount of water	6.08
7	59,475	4,735	Proper amount of water	6.10
8	61,540	4,900	Proper amount of water	11.92
15	47,950	3,818	Proper amount of water	9.07
16	52,090	4,147	Proper amount of water	7.01
19	50,750	4,041	Proper amount of water	7.45

The graph between samples porosity versus compression stress is shown in Figure 5. Water content was the controlling factor of this relationship. It is seen that porosity values are decreasing with increase of stress and the function is not linear.

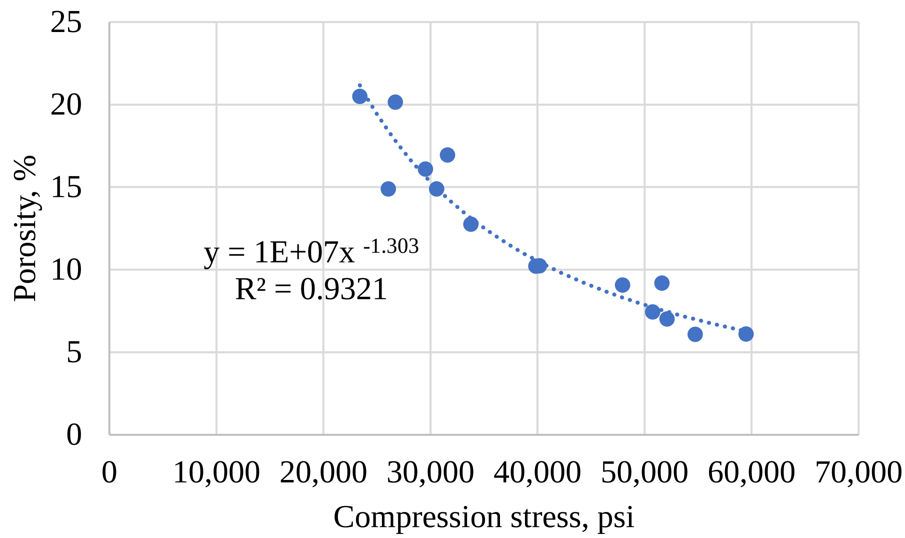

Figure 5. Porosity and compression stress relationship.

The samples with higher values of porosity (15-20%) were able to hold up to 30 psi compression stress, which is lower than the standard values for permeable concrete. With 40,000 psi and higher stress the samples can absorb very small amount of water – from 6 to 10% void space only.

Some samples were not properly prepared. There might be a human error when the waiting time between the samples from the same mixture took too long. So, the when the first sample was completed and packed to the cylinder, the rest of the mixture was waiting and drying due to chemical processes. During that time cement had already started the chemical reaction with water and the mixture became dryer than the first sample. Table 4 shows out of spec samples. As shown, the compression test results are low which indicates an over dry mixture.

Table 3. Samples with excessive gravel.

Sample	Max compression force, lbf	Max compression stress, psi	Mixture details	Porosity, %
1	29,520	2,350	Dry sample	16.1
2	30,585	2,435	Dry sample	14.9
3	51,630	4,111	Proper amount of water	9.18

Table 4. Out of spec samples.

Sample	Max compression force, lbf	Max compression stress, psi	Mixture details
13	14,780	1,176.8	195 mL water
18	8,275	658.8	210 mL Water

Visually, students observed cracks running from the top to the bottom of the sample (see Figure 6). It was interesting to note that the crack was running not only through cement medium between the aggregate particles, but crushing the aggregates itself. Which means the cement properties were able to hold the shape of the sample cylinder.

Figure 6. The crack is running from the top to the bottom of the sample cylinder (upper let picture). The piece of sample is missing due to compression test and the aggregate particles cut by crack (bottom left and right pictures).

5.2. Water Absorption Test

Three samples were mixed to run the water absorption test. All three samples had different compositions as shown in Table 5. After drying, the samples were immersed in water for four hours.

Table 5. Water absorption test sample preparation.

Sample	Sand Parts	Water	Aggregate Parts	Concrete Parts
20	3	50% of concrete	0	1
21	1.5	50% of concrete	1.5	1
22	0.6	50% of concrete	2.4	1

The results of the test show that all samples absorbed water regardless of aggregate content. Four hours as too long to see the boundary of water penetration in the sample cross sectional area. For future efforts, it is recommended to make the same type of samples and run the test for different ranges to see the process more specifically.

6. CONCLUSIONS

The following can be concluded from the study:

1. The samples with higher values of porosity (15-20%) were able to hold up to 30 psi compression stress, which is lower than the standard values for permeable concrete. Contrary, the samples with 40,000 psi and higher stress can absorb very small amount of water – from 6 to 10% porosity values. The maximum porosity was recorded 20.15% with 2,127.4 psi compression stress, and minimum porosity was recorded as 6.07% with 4,357.1 psi compression stress.
2. The traditional permeability test based on wet resistivity measurements is not applicable for porous concrete. The measured values have very wide range of reading on the same sample surface which makes some confusion.
3. Compression stress showed the crack development ongoing not only through the cemented area between the aggregate grains but through the aggregate particles. The fact that the aggregate particles were broken by compression leads to a conclusion related to a great adhesive cement property. The secondary use of recyclable material such as crushed red brick should be carefully studied in order to use in porous concrete applications.
4. Silica addition to the sample mixture did not show any strength increase while using in samples with proper amount of water. The compression stress and porosity values were falling at the same range. From the other side, the samples with lack of water showed increase in compression stress by 500-600 psi with the same water content.

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