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Evaluatıon of Pervıous Concrete Utılızıng Recycled HDPE as Partıal Replacement of Coarse Aggregate wıth Acrylıc as Addıtıve

Neslyn Lopez[1,*], *Emilla* Collado[1], *Lois Alexandra* Diacos[1], and *Harold Dave* Morente[1]

[1]Malayan Colleges Laguna, Pulo Diezmo Road, Cabuyao City, Laguna 4025, Philippines

Abstract. Pervious concrete is an eco-friendly alternative and is beneficial to providing good rainwater drainage in order to prevent flooding. But the application is limited to lower trafficked roadways and often times disregarded due to its low strength capabilities. This study investigates on the effect of High-denstiy Polyethylene as partial replacement of coarse aggregates on the physical and mechanical properties of Acrylic Polymer Pervious Concrete (AcPPC). Two different coarse aggregate sizes were evaluated which are ½" and ¾" with varying ratios of 10%, 20%, and 30%. It was determined that the partial replacement of recycled HDPE caused an increase in the porosity and permeability of the AcPPC. However, it decreased the AcPPC's compressive and flexural strength. Only the ½" 10% HDPE modified Pervious Concrete with 15% Acrylic Additive (PCHA) achieved a compressive strength that is within the range of the acceptable compressive strength for pervious concrete. While for the flexural strength, both the ½" 10% PCHA and ¾" 10% PCHA was within the standard values for flexural strength of pervious concrete. Thus, making the ½" 10% PCHA as the optimum mix in this study. The application of PCHA is limited to typical application of a pervious concrete.

1 Introduction

Over the decades, human population continues to grow and expand. And as the said population increases, advances in technology continuously happen. Breakthroughs in technology happen at a frequent rate. One product of today's innovation in technology is the paving of roads. These said roads are made of impermeable surfaces such as asphalt, concrete, traditional stone, and brick, among other possible pavers. These impermeable or impervious concrete surfaces do not allow water to pass or penetrate through. Today, it is very common to see our roads as paved surfaces, even in rural regions.

Unfortunately, society's development has its consequent drawbacks. Aside from the obvious waste produced by human activities, modernization sometimes poses a threat to our environment and its natural cycles. Among the various downsides of the negligence to our environment is the common event of flooding and drainage failure.

According to [1], the effect of impervious pavement is not only limited to flooding. Some effects of these surfaces on the environment are (1) Pollution of surface water; when runoff occurs, it gathers pollutants and flows directly into bodies of water such as rivers, lakes, etc.; (2) Water table is not adequately recharged; on a natural condition or in permeable surfaces, water can penetrate with ease, therefore, before reaching the groundwater, it is recharged or simply filtered. However, on impermeable surfaces, water is hindered to penetrate, groundwater is consequently used faster than it is recharged; (3) Formation of stagnate water puddles, and; (4) Heat island effect, as stated by EPA— United States Environmental Protection Agency [2] the interpretation of the heat island effect is simply making an "island" with temperatures much higher than that of its environment. This is due to the heat-absorbing property of asphalt, concrete or any other paving material. It simply gathers heat during the day and releases it at night [1].

Fortunately, the construction industry has adapted to the idea of creating and using Pervious Concrete (hereby referred to as PC), also known as permeable concrete, to address the various potential impermeable surface complications especially on paved roads. Pervious concrete is the no-fines, porous, gap-graded, and enhanced porosity concrete [3]. Interconnected void spaces are very evident in typical pervious concrete. These voids act as an opening for air and water to easily pass through, allowing it to seep into the ground, thus resulting to a fast drainage of other large volumes of water, preventing runoffs from occurring [4].

* Corresponding author: nelopez@mcl.edu.ph

Pervious concrete has a distinctive appearance and surface texture due to its constituents and ratios. Unlike the conventional concrete mix, PC lacks in fine aggregates and is composed primarily of rounded and angular aggregates, making it permeable due to the large amount of voids in the concrete, unfortunately reducing its strength [5].

According to the report of [6], as stated in the UN report, the average weather-related disasters per year rose to an average of 335 from 2005-2014 worldwide which is 14% higher than the number in 1995-2004, and the major cause of these disasters were floods with more than 40%, followed by storms with more than 20%.

Pervious concrete, if applied, could prevent or decrease the disasters caused by flooding. PC is an eco-friendly alternative and is beneficial to providing good rainwater drainage in order to prevent flooding. It is also applicable in reducing contamination in waterways and recharging groundwater supplies. Additionally, it is more efficient in reducing heat island effect. Despite the many benefits of PC, it has limited applications. Only low loads can be applied on it and is oftentimes disregarded due to its low strength capabilities.

According to [7], adding acrylic polymer to the concrete increases the compressive strength to a significant degree, with 15% by cement weight having the highest rating. Meanwhile, the study held by [8] showed that the substitution of HDPE for coarse aggregates in the concrete mix increased the compressive strength for both concrete cube and cylinder-shaped specimens which were cured for 7, 14, and 28 days. However, it also showed a decrease in compressive strength for more than 30% replacement of natural aggregates with HDPE. In terms of flexural strength, HDPE substitution with the same specimen also showed increased strength when the mix reached 40% replacement ratio. Compared to the control mix (0% aggregate substitution), there was an improvement of 20% in the flexural strength.

High Density Polyethylene plastics are flexible, translucent or waxy, weather proof, good low-temperature toughness, easy to process by most methods, low cost, and has good chemical resistance. Since HDPE are non-absorbent, they can increase the permeability of pervious concrete because water will just flow through it, unlike the typical coarse aggregates that absorb water [9].

The purpose of this research was to determine the physical properties and mechanical strength of concrete, specifically porosity, and permeability; compressive strength and flexural strength of a pervious concrete utilizing recycled high density polyethylene (HDPE) as partial replacement of coarse aggregate with acrylic as additive. Specifically, this study aimed to know the acceptable percentage replacement (10%, 20%, and 30%) and size (½" or ¾") of HDPE aggregates that would improve the porosity and permeability of a pervious concrete. Permeability was assessed to know the effectiveness of the combination of HDPE and acrylic polymer blend. Also, it determined the effect of the percentage replacement (10%, 20%, and 30%) and size (½" or ¾") of HDPE aggregates in terms of compressive strength and flexural strength. This was done to provide a pervious concrete mix whose strength meets the standards of a typical pervious concrete. Lastly, it also assessed the overall effect of adding HDPE aggregates and determined the optimum mix design using efficiency analysis.

2 Methodology

This study used the crushed aggregate with and without partial replacement of HDPE aggregates which are cut into ½" and ¾" sizes and cement with 15% by cement weight of acrylic polymer as binder mixed with water to produce permeable concrete samples.

The HDPE waste pellets were bought from Plastic Recycling Plant and were softened at a temperature of 165 °C (329 °F) in the furnace. This temperature is the melting point of typical HDPE. The time of melting was 14 minutes. The pellets were softened in a form where it can be compressed. It was necessary to compress the softened HDPE to even out its surface and tighten its bond. The softened pellets were then cooled down. This process was repeated until the desired amount of aggregates was obtained. Afterwards, using a grinder, the HDPE was cut into sizes conforming to the required value for the coarse aggregates in which cutting it into ½" and ¾" sized cubes as shown in fig. 1. It is also intended on this research to use other aggregate size as stated in the study of [7] in order to investigates its effect on physical and mechanical properties of permeable concrete. Other materials such as Portland cement (Type I) and ¾" crushed gravel were acquired at a local hardware store.

Fig. 1 HDPE sample size

A water-cement (W/C) ratio of 0.35:1 by weight was used for this study. And aggregate-cement (A/C) ratios of 4.5:1 by weight were prepared which were based from the results of [7] that resulted to be optimum ratio. HDPE ratios as replacement to coarse aggregates were 10%, 20%, and 30% with 15% acrylic additive. The pervious concrete mixture was cured for 28 days.

The Porosity Test was conducted first after cured for 28 days. The specimens were air dried, and weighed. Then each of the specimens was weighed again while submerged in water. The submerged weight and the weight in air of the specimens were recorded. The bulk volume of the sample and volume of solids (stone and cementing materials) was determined and used to calculate porosity using the Eq. 1.

$$Porosity\ (\%) = \frac{Volume\ of\ Voids}{Bulk\ Volume}\ x\ 100\% \qquad (1)$$

Permeability is the ability of a material to allow fluids to pass through, and is an important feature of pervious concrete. Pervious concrete allows liquid to pass through it at a higher rate than standard concrete because of its voids. The researchers made an improvised permeability-meter or permeameter in this study. The permeameter was made from thick plastic sheets. It was wrapped around the sample to form a tube that will act as an infiltration ring. Two lines were drawn on the tube just above the sample. The first line was 300 mm from the sample's bottom, and another 500 mm was drawn and designated as the second line. Water was poured into the tube while the sample was in place; the level of the water was higher than the second line. The timer started as soon the water passed through the 500 mm marked line and was stopped once all the water at top has passed through the 300 mm mark. The height of the water that passed through the specimen and the time elapsed was recorded and were used to compute the coefficient of permeability for a constant head in cm/sec by using the Eq. 2.

$$Coefficient\ of\ Permeability\ (k) = \frac{A_o L}{a_o \Delta t}\ \ln\left(\frac{h_o}{h_1}\right) \qquad (2)$$

Where: A_o = the area of the tube
a_o = the cross sectional area of the cylinder
L = the height of the cylinder
t = the time the wate as it passes from ho to h_1

To determine the compressive strength of the cylindrical specimens, the Compression test was performed in accordance with ASTM C39 (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens). On the other hand, the beam specimens were subjected to three point flexural testing in accordance with ASTM C78 (Standard Test Method for Flexural Strength of Concrete Using Simple Beam with Third Point Loading). The specimens were tested using a Universal Testing Machine at the Astec Materials Testing Corporation-Santa Rosa Laboratory.

The efficiency analysis was used as the basis of analysis in this study. To determine the optimal mixture, the Efficiency Coefficient Method was used in the analysis and were utilizing the following variables: compressive strength, flexural strength and permeability. To get the efficiency of the variables, the total efficiency factor (d) is to be assumed as in Eq. 3.

$$d = (d_1 \times d_2 \times d_3)^{\frac{1}{3}} \qquad (3)$$

It is where d_1, d_2, and d_3 are the efficiency factors for compressive strength, flexural strength and permeability, respectively. The efficiency factor was calculated by dividing the value to its maximum value in each data. This method gave the optimum mixture. Thus, the optimum size and ratio was the mixture that obtained the highest efficiency factor value.

3 Results and Discussions

The produced AcPPC and PCHA specimens were examined to compare the physical property for the visual and texture of each type of samples. The specimens produced were also grayish in color as shown in Fig. 2.

For a typical pervious concrete, the density usually ranges from 1600 kg/m^3 to 1900 kg/m^3. For the samples produced, only the controlled mix is within the density for a typical pervious concrete while all the PCHAs are below this range and can be said that it is a lightweight concrete. Table 1 shows the average density of AcPPC and PCHA.

Fig. 2 PCHA produced

Table 1. Average Porosity of AcPPC and PCHA

Type	Average Density (kg/m^3)
CM	1855.23
½ 10%PCHA	1506.79
½ 20% PCHA	1324.89
½ 30% PCHA	1079.13
¾ 10% PCHA	1466.88
¾ 20% PCHA	1254.32
¾ 30% PCHA	1179.51

Porosity and permeability are important properties of a pervious concrete. Porosity is the measure of the voids or empty spaces in a volume while permeability measures the ability of the material to allow the passage of water. While permeability measures the ability of the material to allow the passage of water.

Table 2. Average Porosity of AcPPC and PCHA

Type	Average Porosity	Percent Increase
CM	22.6767	
½ 10%PCHA	26.9323	18.7665
½ 20% PCHA	35.0928	54.7527
½ 30% PCHA	37.4276	65.0488
¾ 10% PCHA	23.3153	2.8160
¾ 20% PCHA	35.3241	55.7726
¾ 30% PCHA	36.2085	59.6726

Table 3. Average Permeability of AcPPC and PCHA

Type	Average Permeability (cm/s)	Percent Increase
CM	1.1460	
½ 10%PCHA	4.3746	281.7452
½ 20% PCHA	4.7890	317.9082
½ 30% PCHA	6.4281	460.9352
¾ 10% PCHA	4.3670	281.0813
¾ 20% PCHA	5.6239	390.7583
¾ 30% PCHA	5.1888	352.7895

Table 2 and table 3 shows the values of porosity and permeability that was obtained in this study. The controlled mix (CM) obtained the lowest permeability and porosity. While, it was the ½" 30% HDPE modified Pervious Concrete with 15% Acrylic Additive (PCHA) that obtained the highest permeability and porosity with a value of 6.4281 cm/s and 37. 4276%, respectively. The ½" 30% PCHA had an increase in permeability of 460.9352% and 60% increase in porosity.

It can be stated that the addition of HDPE aggregates in the mixture, increases the permeability and porosity of a pervious concrete. The higher percentage replacement results to higher value of porosity and permeability.

The conventional PC used in the industry has a porosity that ranges from 15% to 30% by volume [10]. All the samples achieved a value of porosity that ranges from 22% to 38%. The ½ sized 20%, ½ sized 30%, ¾ sized 20% and ¾ sized 30% PCHA specimens exceeded the 30% porosity value that is commonly used in the industry. The typical value of permeability of a pervious concrete is ranging from 0.135467 to 1.2192 cm/s [11]. The values of permeability obtained in this study exceeded the typical values of permeability of a pervious concrete.

Compressive strength is the stress in which a material can sustain without fracture. Comparing the values of the controlled mix or AcPPC and HDPE modified Pervious Concrete with 15% Acrylic Additive (PCHA), in general the overall compressive strength decreases as the percentage of HDPE aggregates replacement increases as shown in Fig. 3. The AcPPC specimen obtained the optimum strength with an average value of 11.590 MPa. The specimen that obtained the second highest value was ½"-sized 10% PCHA with an average value of 4.147 MPa followed by the ¾"-sized 10% PCHA with an average value of 3.183 MPa. While the ½"-sized 30% PCHA has the lowest value of compressive strength with an average value of 1.445 MPa.

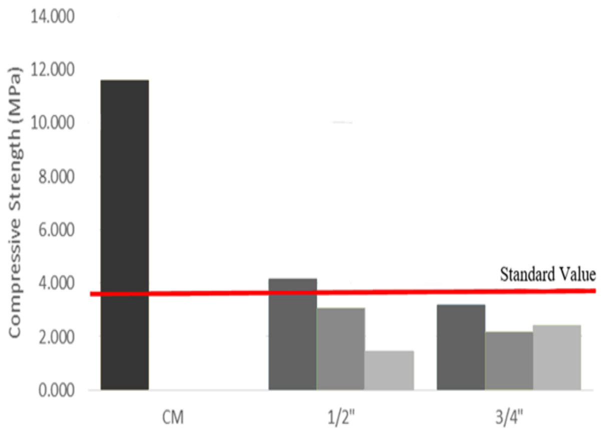

Fig. 3 Compressive Strength of AcPPC and PCHA (1st color: 10% HDPE, 2ND color: 20% HDPE and 3rd color: 30% HDPE for both ½" and ¾" aggregate size)

The CM obtained the highest compressive strength with an average value of 11.590 MPa. It is followed by the ½" 10% PCHA with an average value of 4.147 MPa. On the other hand, it was the ½" 30% PCHA that obtained the lowest compressive strength of 1.445 MPa.

It was also the CM that obtained the highest flexural strength of 1.1533 MPa, and again, followed by the ½" 10% PCHA with an average flexural strength of 1.1177 MPa as shown in Fig. 4. There was only a 3.08% decrease in flexural strength from the CM to the ½" 10% PCHA. ½" 30% PCHA also obtained the lowest flexural strength with an average value of 0.2891 MPa.

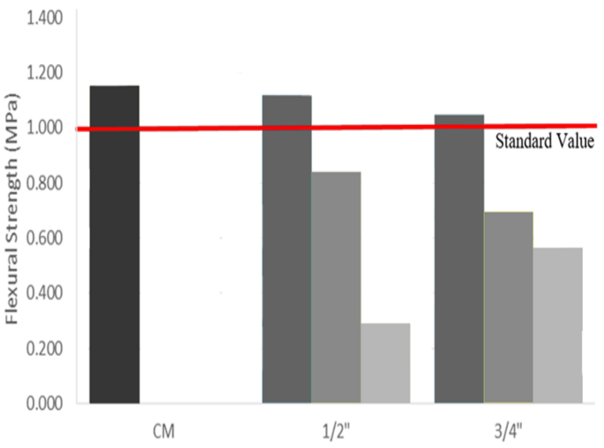

Fig. 4 Flexural Strength of AcPPC and PCHA (1st color: 10% HDPE, 2ND color: 20% HDPE and 3rd color: 30% HDPE for both ½" and ¾" aggregate size)

According to [12], a typical pervious concrete mixture can produce a compressive strength of up to 3.5 MPa to 28 MPa. Only the ½ sized 10% PCHA achieved a compressive strength within the typical values of a standard pervious concrete.

The flexural strength of a typical pervious concrete is ranging between 1 MPa up to 3.8MPa. Only the controlled mix, the ½ size 10% PCHA, and the ¾ sized 10% PCHA obtained a value within the acceptable range.

Based on the efficiency analysis, the ½ sized 10% PCHA obtained the highest efficiency as compared to the other mixtures. The average value of d_t obtained in the ½ sized 10% PCHA is 0.5126. It has a percent difference of 8.5436 with the controlled mix. The mixture with the lowest d_t obtained was ½ sized 30% PCHA sample. The optimum mix design is the ½ sized 10% PCHA based from the efficiency analysis. All computed values were tabulated in the table 4.

Table 4. Efficiency Analysis of AcPPC and PCHA

Efficiency Analysis	dt Average	Percent Change
CM Beam	0.4723	--
½ 10%PCHA Beam	0.5126	8.5436
½ 20% PCHA Beam	0.4452	-5.732
½ 30% PCHA Beam	0.2719	-42.428
¾ 10% PCHA Beam	0.4722	-0.008
¾ 20% PCHA Beam	0.3870	-18.066
¾ 30% PCHA Beam	0.3753	-20.532

4 Conclusions

All of the HDPE-modified Pervious Concrete with 15% Acrylic Additive (PCHAs) exceeded the porosity and permeability of the controlled mix (CM). The addition of HDPE aggregates caused an increase in permeability as compared with a typical pervious concrete which has permeability ranging from 0.135467 to 1.2192 cm/s. The average value of porosity that was obtained in this study was within the range of 23.3152% to 37.4276%, passing the acceptable industry standard. The PCHA's porosity and permeability are directly proportional to each other. With regard to the mechanical strength, no PCHA exceeded the strength of the controlled mix.

Additionally, HDPE aggregates can be used as a replacement for aggregates without compromising the mechanical strength, porosity, and permeability of a typical pervious concrete, whether it be ½" or ¾" in size. However, it is the percentage of substitution that affects the said properties. Over all, the ½"-sized 10% PCHA was the optimum mix design. The said mix design has increased in terms of porosity by 18.77% and 281.75% in terms of permeability. Also, the value of the porosity was within the standard while the permeability exceeded the typical maximum value of a pervious concrete. For the mechanical strengths, lower compressive strength compared with the controlled mix but the value was within the acceptable compressive strength according to the standard. On the other hand, in terms of the flexural strength the ½"-sized 10% PCHA has an insignificant change as compared to the controlled mix but has also achieved a value within the acceptable flexural strength according to the standard.

Lastly, based from the efficiency analysis, the ½"-sized 10% PCHA obtained the highest efficiency, while it was the ½"-sized 30% that obtained the lowest efficiency. It can be said that the ½"-sized 10% PCHA is a better mix design compared to all the specimens considering the values obtained from permeability, compressive strength and flexural strength.

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