Effects Of Aggregate Shape, Aggregate Size, And Water-To-Cement Ratio on Compressive Strength, Permeability, And Abrasion Resistance of Pervious Concrete Mixture

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Abstract: - Impermeable concrete often contributes to the extent of flooding prevalent in the Philippines, as it prevents natural infiltration of runoffs to the ground. One appealing solution to this problem is the application of pervious concrete, whose high void content allows water to pass through it. However, due to this property, its compressive strength is compromised. Other important properties necessary for pavement, like abrasion resistance, have not been thoroughly studied yet, as well - locally. As part of preliminary studies for the applicability of pervious concrete as part of the pavement system, this paper aims to evaluate the effects of aggregate size, aggregate shape, and water-to-cement (w/c) ratio on the compressive strength, permeability, and abrasion resistance of the concrete mixture. In this study, it was found that the compressive strength and permeability rate are higher for pervious concrete made of angular aggregates, and there is not much difference in the abrasion resistance between the samples made from either angular or round aggregates. An optimized pervious concrete mixture was also obtained, consisting of single-sized 9.5 mm angular aggregates with a w/c ratio of 0.306. This led to a theoretical maximum compressive strength of 22.696 MPa and corresponding permeability of 3.93 mm/s, which is applicable for low-traffic pavements like parking lots. Furthermore, a Spearman correlation value of 0.207 showed that there is a weak, positive relationship between the compressive strength and the percent weight loss of the concrete due to abrasion. This means an inverse relationship between the compressive strength and abrasion resistance exists. However, the finding may not be the actual relationship between the two, as the p-value on the Spearman correlation exceeded the significance value of 0.05.

Key Words: ***Abrasion, Abrasion Resistance, Compressive Strength, Flood, Pavement, Permeable, Permeability, Pervious Concrete.***

I. Introduction

Rainfall in the Philippines is abundant. According to the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), the mean annual rainfall of the country ranges from 965 to 4,064 millimeters [1].

With this amount of rainfall, the country is being susceptible to high flood risk. In fact, the Philippines is ranked eighth in the world among countries with the highest absolute population exposure to flood risk, with 29.1 million people, or 27.7 percent of the national population [2].

One of the reasons for high susceptibility to flood is the pavement. In the Philippines, most pavements are made of impermeable concrete. As this type of concrete prevents the natural infiltration of runoff to the ground, flood risk is increased even more. With the future in sight, a solution to solve this problem is a must.

An appealing substitute to conventional concrete is the use of pervious concrete. Unlike typical concrete, pervious concrete allows water to pass easily from the surface to underlying layers

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as it contains little to no fine aggregate, thus resulting in a high void content [3]. Studies reported that through permeable pavements systems, reductions in storm runoff peak and runoff volume, as well as improvement in water quality, has been observed [4,5].

Pervious concrete is widely used in developed countries like China, Japan, and other European countries. Across the United States. However, this is not the case in the Philippines, where the application of the pervious concrete is very minimal. This limited application of the pervious concrete in the country though can be attributed to the fact that there are hardly any local studies regarding this type of concrete. Existing researches about the pervious concrete in the Philippines are mostly about stormwater management or about its compressive strength. While these are important, especially the latter if the desired application of the concrete is pavement, there is also a need to study several of its properties, including its abrasion resistance.

As defined by the American Society for Testing and Materials (ASTM), abrasion is the physical wear due to hard particles or protuberances forced against and moving along a solid interface. Hence, abrasion resistance is the ability of a surface to resist being worn away by rubbing or friction [6]. Should pervious concrete be applied in pavements, it is necessary to evaluate this specific property as it will be subjected to dynamic loading from traffic.

Of the few local studies about the pervious concrete in the Philippines, one was able to produce a concrete sample of compressive strength 17.94 MPa, which the authors noted as applicable for low traffic pavements such as parking lots, walkways, and school pavement, and a corresponding permeability of 1.35 mm/s. However, the study resulted only to a compressive strength of bare minimum, and other important properties for pavement like abrasion resistance were not tested [7].

Therefore, this study was conducted to evaluate the compressive strength, permeability, and abrasion resistance of pervious concrete. Along with local studies on the compressive strength of the said concrete, this study promotes the benefits of using the pervious concrete as an alternative type of concrete for low-traffic pavements that can help alleviate flooding in the Philippines. This study also serves as part of preliminary studies needed in further research about the applicability of pervious concrete as pavements in the country.

II. METHODOLOGY

The aggregate shape, aggregate size, and water-to-cement ratio were the variables in the study as they are mostly the reasons that affect the properties of pervious concrete [8].

For the aggregate shape, angular and round aggregates were used upon the recommendation of ACI. For the aggregate size, single-sized 9.5 mm and 19 mm were used. Finally, for the w/c ratio, values of 0.25, 0.30, and 0.35 were used based on a study about the compressive strength of pervious concrete [9]. Moreover, the concrete samples did not contain any fine aggregates but were reinforced with Viscosity Modifying Admixture (VMA) as several studies noted that addition of admixture improves the compressive strength of pervious concrete. The samples contained admixtures of 1.5% by weight of cementitious materials. Additionally, it should be noted that the water used in the composition of concrete samples is not potable water. On top of this, the temperature was not also controlled during the production of concrete samples. These may tend to alter some properties of the concrete and may have a significant effect on the data.

In proportioning the mixture, the b/bo method was used, which was presented in Appendix 6 of ACI 211.3R-02 "Guide for Selecting Proportions for No-Slump Concrete". The test cases for the pervious concrete samples are presented in Table 1 and the some of the samples made are shown in Figure 1.

To obtain the needed data to meet the objectives of this study, three different tests were made. These were compressive strength test conforming to ASTM C39/C39M (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens), Constant Head Test, and Surface Abrasion Test. Two samples per test case were tested and their average values were the ones used in the analysis

Table.1. Test Cases for the Pervious Concrete Mixture.

Test Case	Sample ID	Aggregate Shape	Aggregate Size	w/c Ratio
1	SA25	Angular	9.5 mm	0.25
2	SA30			0.30
3	SA35			0.35
4	LA25		19 mm	0.25
5	LA30			0.30
6	LA35			0.35
7	SR25	Rounded	9.5 mm	0.25
8	SR30			0.30
9	SR35			0.35

10	LR25		19 mm	0.25
11	LR30			0.30
12	LR35			0.35

Fig.1. Pervious Concrete Specimens.

After obtaining the data for the compressive strength, permeability, and abrasion resistance of the pervious concrete specimens, bar graphs were utilized to visualize how values obtained for these properties are changing with varying aggregate shape, aggregate size, and w/c ratio. All graphical representations were made with the aid of the software Microsoft Excel.

In addition to the visual graphs of the data, a general factorial design method was performed through the statistical software Minitab to identify whether the variables, namely aggregate shape, aggregate size, and w/c ratio, had a significant factor in the variation of the compressive strength, permeability, and abrasion resistance. This analysis was vital most especially for the compressive strength and the permeability rate of the concrete samples as this determined whether the two can be optimized with respect to the variables.

Since the goal is to produce a concrete sample with high compressive strength and permeability within the 1.35 mm/s minimum defined by the ACI, the bar graphs were used to identify the aggregate shape and the aggregate size that would meet the target goal. For the w/c ratio, points in the form (w/c ratio, compressive strength) and (w/c ratio, permeability) were plotted and the equations of the best-fit curve/line were obtained. After obtaining the equation of the best-fit curve/line, differentiation was performed to get the optimum w/c ratio value and the theoretical maximum compressive strength, as well as the corresponding permeability rate.

Finally, for the correlation between the abrasion resistance and the compressive strength of the pervious concrete samples, the Spearman coefficient was used as it was later found out that the two variables did not relate linearly.

III. Results and Discussion

3.1 Effects of Aggregate Shape

As observed in Figure 2a, the use of angular shape aggregates has vastly improved the compressive strength of the pervious concrete samples. This is due to the fact that angular aggregates have higher surface area, thus requiring higher amount of paste. The rough surface texture of angular aggregates also generates a stronger bond between the paste and therefore leading to a higher compressive strength.

Similarly, Figure 2b shows that permeability rates in samples using angular aggregates are higher compared to those of using round aggregates. With irregularity in shapes and having a higher surface area, the amount of paste intended to fill the

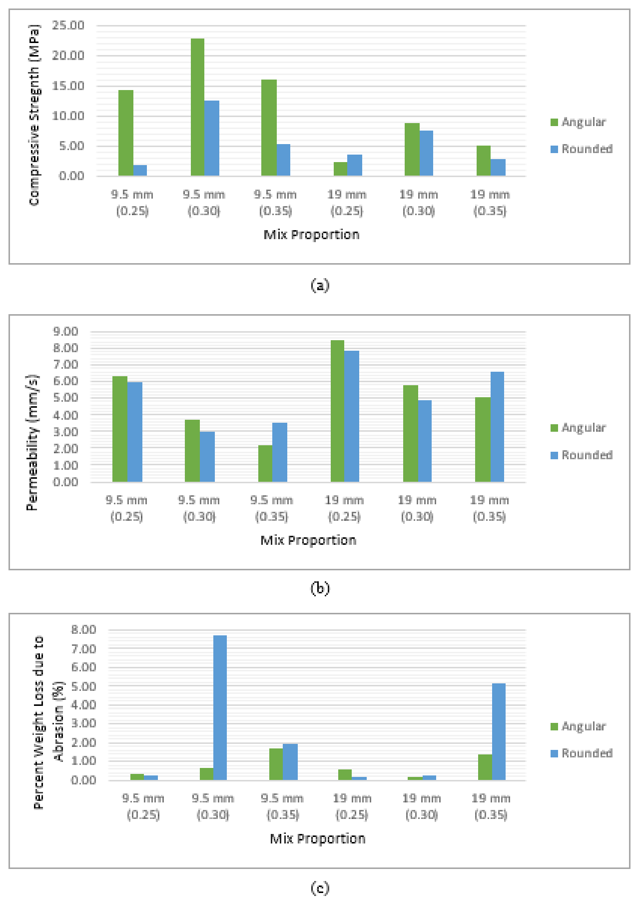

Fig.2. Effects of Aggregate Shape on the (a) Compressive Strength, (b) Permeability, and (c) Abrasion Resistance of Pervious Concrete Samples.

voids between the aggregates is lower compared to those of round aggregates, thus resulting to higher permeability rates.

Finally, as illustrated in Figure 2c, there is not much difference between the abrasion resistance of the samples using angular aggregates and the samples using round aggregates except for the 9.5 mm (w/c ratio of 0.30) and 19 mm (w/c ratio of 0.35) using round aggregates, where the percent weight loss due to abrasion are 7.683% and 5.178%, respectively.

3.2 Effects of Aggregate Size

The size of the aggregates has also played significant role in the compressive strength, permeability, and abrasion resistance of the pervious concrete samples. As shown in Figure 3a, samples using 9.5 mm aggregates are generally stronger than those samples using 19 mm aggregates in terms of their resistance to compressive force. Smaller aggregates require little amount of paste compared to larger aggregates to be entirely covered, hence some of the excess paste occupies the voids, leading to stronger bonds.

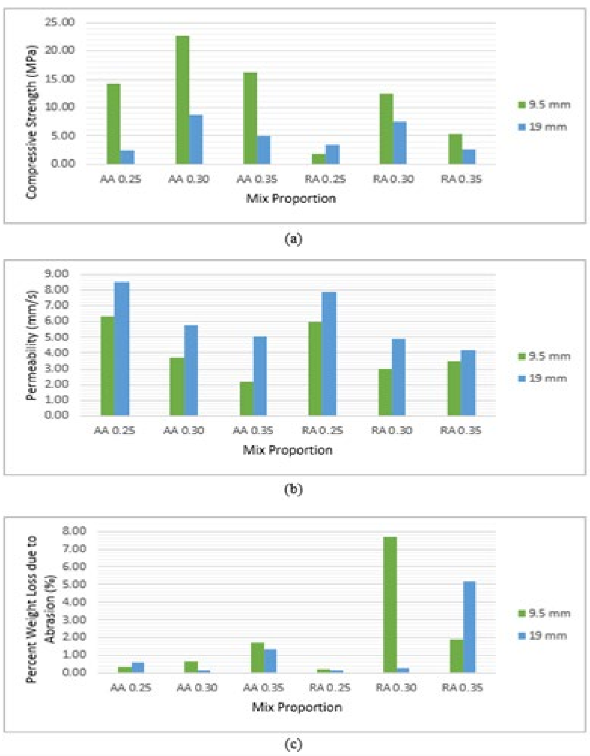

Fig.3. Effects of Aggregate Size on the (a) Compressive Strength, (b) Permeability, and (c) Abrasion Resistance of Pervious Concrete Samples.

In contrast, Figure 3b shows that samples using 19 mm aggregates have higher permeability rates than the ones using 9.5 mm. This can be explained easily as larger aggregates often lead to higher void content, and smaller aggregates to smaller void content.

Figure 3c shows that, in general, there is only a little difference in the abrasion resistance of the pervious concrete samples made from 9.5 mm coarse aggregates and 19 mm coarse aggregates. However, four of the six cases have shown that the percent weight loss due to abrasion of the samples using 9.5 mm coarse aggregates are a little higher, hence have less resistance compared to the samples using 19 mm. This can be attributed to the size of the aggregates and their weights themselves as they are easier to be moved compared to the larger aggregates when acted upon by a load.

3.3 Effects of Water-to-Cement Ratio

The impact of the water-to-cement ratio on the compressive strength of the pervious concrete samples is quite variable, as seen in Figure 4a. But emerging pattern based on the illustrations is that the compressive strength has its peak strength around the w/c ratio of 0.30.

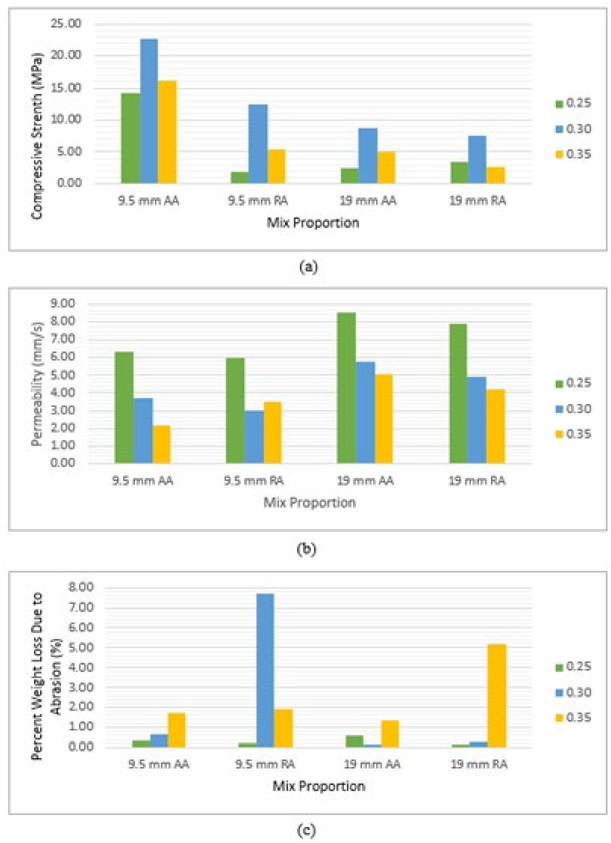

Fig.4. Effects of Water-to-Cement Ratio on the (a) Compressive Strength, (b) Permeability, and (c) Abrasion Resistance of Pervious Concrete Samples.

On the other hand, Figure 4b shows that as the w/c ratio increases, the permeability rate of the pervious concrete is decreasing.

Lastly, Figure 4c exhibits the effects of the w/c ratio on the abrasion resistance of the pervious concrete samples. As seen in the figure, samples with w/c ratio of 0.25 have the lowest percentage of weight loss due to abrasion. Although there is a slight variation, samples with w/c ratio of 0.30 are second, and the samples with w/c ratio of 0.35 have the least resistance to abrasion among the samples.

3.4 Interaction of the Variables

Using general full factorial design method of analysis, the interactions of the factors (aggregate shape, aggregate size, and w/c ratio) on the compressive strength, permeability, and abrasion resistance of the pervious concrete samples were quantified.

Considering the compressive strength as the response variable, none of the p-values of the factors exceeded the significance level of 0.05, hence they all have statistically significant effects on the compressive strength. Moreover, only the interaction of the aggregate shape and the aggregate size has significant effects on the response variable (p-value of $0.01458 < 0.05$), while the rest of the combinations do not significantly affect the latter at a 95% confidence level.

In addition, a Pareto chart of the standardized effects of the factors on the compressive strength indicates that among the factors with significant effects, the aggregate size has the largest effect, followed by the aggregate shape, w/c ratio, and the interaction of the aggregate shape and aggregate size.

Meanwhile, the aggregate size, w/c ratio, and the interaction between the aggregate shape and aggregate size have p-values that are less than the significance level of 0.05, therefore they have significant effects on the permeability rates of the pervious concrete samples. However, unlike when the compressive strength is the response variable, the w/c ratio has the largest effect on the permeability rates.

Finally for the abrasion resistance, the aggregate shape, w/c ratio, and the interaction between the aggregate size and w/c ratio are the only factors that have significant effects to the response variable, with p-values of 0.0099, 0.03962, and 0.00503, respectively, which are all lower than the significance level of 0.05. Among these three, the interaction between the aggregate size and w/c ratio contributes the largest effect, followed by the aggregate shape, and the w/c ratio.

3.5 Optimization of Pervious Concrete

It was observed that pervious concrete samples made from 9.5 mm angular coarse aggregates have undoubtedly resulted to higher average compressive strengths at any values of w/c ratio as compared to the other samples – with the permeability rate not being compromised. With the goal of optimizing the strength of pervious concrete while maintaining the permeability rate above the ACI requirement of 1.35 mm/s, it can be inferred that the pervious concrete must be made from angular aggregates of size 9.5 mm.

Moreover, based on the interaction of the factors and variables, it was shown that the w/c ratio has the most consistent significant effect on the response variables, thus the response variables can be optimized with the w/c ratio as the independent variable.

Using the compressive strengths for samples made from 9.5 mm angular aggregates obtained through the Compressive Strength Test of the pervious concrete samples, a quadratic model for the strength versus the w/c ratio was generated and is shown in Figure 5. The model has resulted to a R-squared value of 99.7%. Through optimization of the obtained equation for the relationship between the w/c ratio and the compressive strength, it was found that the theoretical maximum compressive strength is 22.696 MPa at an optimum w/c ratio of 0.303.

Furthermore, using the obtained data for the permeability rate of the samples made from 9.5 mm angular aggregates, a linear

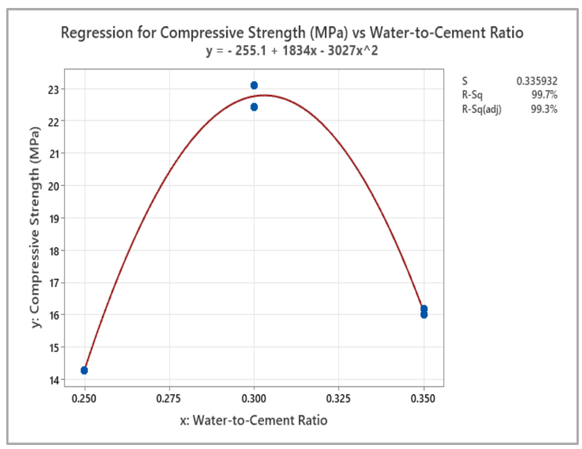

Fig.5. Regression for Compressive Strength: Quadratic Model.

model was found to relate the w/c ratio to the permeability rate. With an R-squared value of 95.8%, it is shown in Figure 6 that as the w/c ratio increases, the permeability rate decreases, which totally makes sense as impermeable conventional concrete usually has w/c ratios above 0.40.

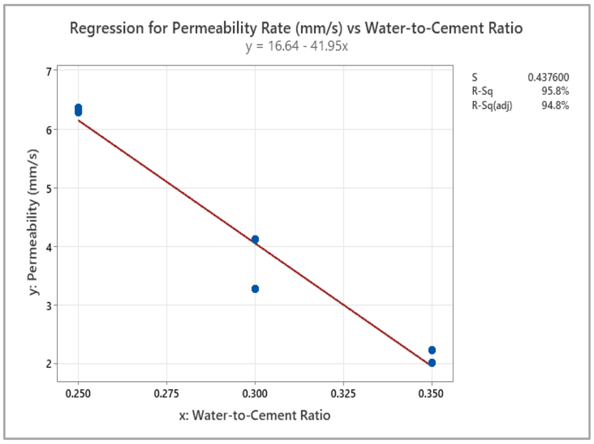

Fig.6. Regression for Permeability: Linear Model.

Using the obtained linear model, it was found that at the optimum w/c ratio of 0.303, the theoretical permeability rate is 3.93 mm/s. This permeability rate is well above the minimum value of 1.35 mm/s set by the ACI.

Based on its theoretical values, the pervious concrete mixture can be used for pedestrian paths or sidewalks and low-traffic pavements such as parking lots and walkways, permeable bases, shoulders, and edge drains, which require at least 17 MPa of compressive strength.

3.6 Correlation Between Compressive Strength and Abrasion Resistance of Pervious Concrete

Figure 7 shows the scatterplot of the compressive strength and the corresponding percent weight loss due to abrasion of the 24 pervious concrete samples. As depicted in the figure, there are two outliers from the plotted data thus the compressive strength and the abrasion resistance cannot be related linearly.

Since the two variables cannot be related linearly, a Spearman correlation was run to determine the relationship between 24 pairs of compressive strength and percent weight loss due to abrasion. Through the analysis, a Spearman correlation of 0.207 was obtained, which indicates that there was a weak, positive relationship between the variables. This also means that as the compressive strength increases, the percent weight loss due to abrasion increases as well (abrasion resistance decreases). However, the obtained p-value of 0.332 is greater than the significance level of 0.05, therefore the data are not statistically significant and they may not show the true relationship between the two variables. Hence, further tests relating the compressive strength and the abrasion resistance of pervious concrete samples are needed.

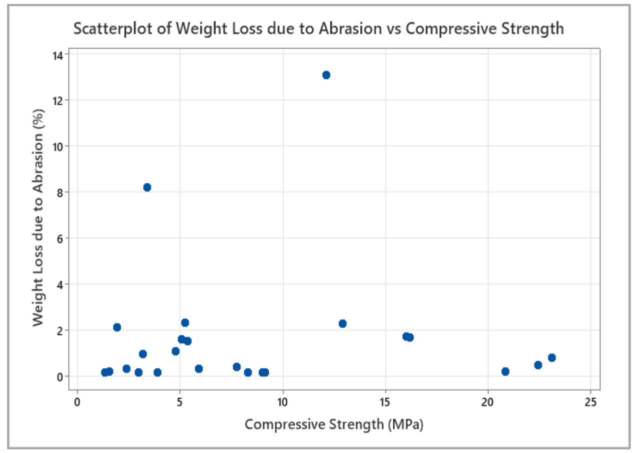

Fig.7. Scatterplot of Weight Loss Due to Abrasion vs Compressive Strength.

IV. Conclusion And Recommendation

4.1 Conclusion

Overall, the study was able to examine that between the angular and round aggregates, it was the angular aggregates that would give the pervious concrete a better compressive strength with an acceptable permeability and with high abrasion resistance. Moreover, it was also proved that as the aggregate size used for the coarse aggregates gets smaller, the compressive strength increases and the permeability decreases – although results obtained in the tests are still well above the acceptable permeability of 1.35 mm/s.

The study also showed that the w/c ratio has the most consistent significant effect on the compressive strength, permeability, and abrasion resistance of the pervious concrete at a 95% confidence interval. With this, the compressive strength was optimized with respect to the w/c ratio. The optimization through differentiation of the best fit curve resulted in a pervious concrete with theoretical maximum compressive strength of 22.696 MPa and corresponding permeability of 3.93 mm/s. This concrete could be achieved using single-size 9.5-mm angular coarse aggregates with a w/c ratio of 0.303. Furthermore, this concrete can be used for low-traffic pavement applications such as parking lots and walkways.

Finally, the Spearman correlation between the compressive strength and the abrasion resistance of the pervious concrete samples obtained a correlation coefficient of 0.207.

This indicates that there is a weak, positive relationship between the two variables and that as the compressive strength increases, the percent weight loss due to abrasion increases as well – which means abrasion resistance decreases. However, further tests conforming to ASTM standards must be conducted as the p-value of 0.332 exceeded the significance level of 0.05, which means the data are not statistically significant and they may not show the true relationship between the two variables.

4.2 Recommendations

This study was limited to evaluating the effects of aggregate shape, aggregate size, and w/c ratio on the compressive strength, permeability, and abrasion resistance of pervious concrete samples. Since this study has met the said goal and has also produced a pervious concrete mixture applicable for low-traffic pavements, further studies on its feasibility, as well as market viability, concrete grading, and life cycle analysis, as a pavement system is recommended.

As the current restrictions due to the pandemic limited the use of laboratories in this particular study, it is also recommended to conduct another similar one to further verify the conclusions made. Temperature control, use of potable water, as well as the handling of concrete, could be considered as these may be the factors that resulted in little inconsistencies in the data obtained during the tests. Moreover, an assessment of the properties of concrete for 7 days, 14 days, 21 days, and 28 days of curing can be carried out to gain further insights on pervious concrete, in general. Other properties such as angularity number can also be taken into consideration.

Although it was shown from the test results in this study that the pervious concrete has good abrasion resistance, its relationship with the compressive strength was found to be not significant, as per the Spearman correlation, and it may not represent the actual relationship. Thus, it is also recommended to conduct further tests on this specific property using different ASTM standard tests.

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