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EFFECT OF SHREDDED RUBBER TIRE AS PARTIAL REPLACEMENT FOR COARSE AGGREGATES IN FLY ASH-BASED PERVIOUS CONCRETE

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ABSTRACT: The need to improve traditional concrete practices and the existing waste problem in the Philippines has opened an opportunity for by-products, such as scrap rubber tires and fly ash, as sustainable alternative materials in pervious concrete. This study investigates the effect of shredded rubber tires and fly ash content on the strength and permeability of pervious concrete. A total of 15 mix designs, with varying replacement ratios based on weight, were produced and tested for compressive strength, split tensile strength, and infiltration rate. In particular, the percentage replacements tested in the study were 0%, 10%, 20%, 30%, and 40% for the shredded rubber tires, while fly ash ratios were set at 0%, 10%, and 20%. Two-way ANOVA test and desirability function statistical analyses were conducted to determine the optimal replacement of shredded rubber tires and fly ash. Results showed that the addition of shredded rubber tires produced a decreasing trend, while increasing the fly ash content exhibited an increasing trend, both on the compressive strength and split tensile strengths. On the other hand, the infiltration rate increased with the addition of rubber aggregates. The research findings also indicated that using up to 10% shredded rubber tires, with 10-20% fly ash, yields a more desirable pervious concrete than the conventional mix.

Keywords: Pervious concrete, Shredded tire waste, Fly ash, Strength, Permeability

1. INTRODUCTION

As the Philippine economy progresses, resource consumption and waste generation rates significantly increase. Approximately 21 million tons of garbage in the country is generated annually, 3.5 million tons of which come from Metro Manila alone [1]. Rubber tires are among the residual wastes produced and improperly disposed of through landfill stacking and incineration.

Meanwhile, as the country primarily relies on coal for power generation, large amounts of fly ash are produced. In previous related studies, fly ash had cementitious properties that make it a viable alternative for cement in the concrete mix. Moreover, cement production contributes to more than 7% of anthropogenic greenhouse gas emissions [2]; thus, utilizing fly ash is expected to reduce the need for cement.

In addition, impermeable concrete, or impermeable surfaces in general, are increasingly prevalent, contributing to a reduction in the natural infiltration processes of the land. Santos et al. [3] affirm this trend, reporting a roughly 50% decrease in water infiltration in sub-basins located in Davao City, Philippines, when impermeable surfaces were utilized. Consequently, there is a surplus of surface runoff, posing environmental threats and safety hazards for residents in the country. This issue is particularly conspicuous with the escalating flooding incidents, causing widespread disruption in communities. Igini [4] attests to the frequent flooding in the Philippines. In 2022, the country ranked highest on the World Risk Index due to the increasing sea levels. With this, the researchers aim to explore possible avenues to mitigate the effects of uncontrolled storm runoff through sustainable construction, particularly pervious concrete.

As a potential alternative to coarse aggregates, studies show that incorporating shredded rubber tires in concrete decreases compressive and split tensile strengths [5,6]. This is highly associated with poor adhesion between rubber and cement [7]. However, concrete specimens with rubber could absorb energy to withstand large post-failure loads and deformation after undergoing ductile failure [8]. An increase in rubber aggregates was also noted to increase the permeability rates [9]. A similar study by Bala, Sehgal, and Saini [10], which analyzed the use of smaller shredded tires as a substitute for fine aggregates in concrete composite, yielded the same decreasing trend in compressive strength and an increase in workability with the addition of rubber.

Another material used in concrete mixes is fly ash, produced as waste residue from coal power plants. This is characterized by its cementitious properties, often used as an additive to reduce cost, promote sustainability, and improve concrete strength [11,12]. The use of fly ash as an alternative to ordinary Portland cement has been observed to increase compressive strength, split tensile strength, and permeability up to an optimum amount [13,14]. This trend has been observed in a similar study, which used fly ash as a subsidiary cementitious material for recycled aggregate-based pervious concrete [15]. Additionally, the study of Tripathi, Hussain, and Madhav [16] emphasized the possible influence of compaction on compressive strength values of concrete. It should also be noted that permeability and compressive strength displayed an inverse relationship, which suggests an optimal replacement ratio of admixtures for the ideal mix design.

With all these considered, using fly ash and rubber tire wastes as a partial substitute for cement and coarse aggregates can be a sustainable alternative to how engineers are accustomed to using concrete. However, limited studies have determined the behavior of rubber tire waste when used as an alternative to coarse aggregates rather than fine aggregates. It is also still being determined how both fly ash and coarse aggregates would react when combined in the same pervious concrete design mix.

2. RESEARCH SIGNIFICANCE

The results of this study support the United Nations Sustainable Development Goals, specifically the development of sustainable cities, resilient infrastructure, and responsible consumption and production. Moreover, adopting permeable concrete surfaces and using sustainable alternatives is a potential solution to combat the depletion of natural resources and mitigate the adverse effects of excessive stormwater runoff resulting from impermeable surfaces. Additionally, this approach offers a promising avenue for recycling end-of-life rubber tires, further contributing to sustainable practices in the construction industry.

3. METHODOLOGY

This study employed a quantitative research method that identified the optimal ratio of rubber aggregates and fly ash as a partial replacement for coarse aggregates and cement, respectively. Tests on compressive strength, split-tensile strength, and infiltration rate were conducted to determine the effects of varying the said variables.

3.1 Materials

The materials used to produce the control pervious concrete specimens include Type 1 ordinary Portland cement (OPC), coarse aggregates (gravel), and water. Shredded rubber from end-of-life tires was used as a partial replacement for gravel, the conventional coarse aggregate, while Type F fly ash was used as a partial replacement for OPC.

The coarse aggregates used in this study were gravel and rubber aggregates. Traditionally used in concrete production are gravel aggregates, natural rock fragments.
The rubber aggregates were shredded tire wastes obtained from a local junk shop in the Philippines and hand-cut into cubes, conforming to the size requirements of coarse aggregates. No chemical treatment was applied to the rubber aggregates obtained. The gravel and rubber aggregates are seen in Fig. 1, and their properties are described in Tables 1 and 2.

Fig.1 Coarse aggregates used in the study — rubber (left) and gravel (right)

Table 1 Coarse aggregate properties

Property	GA	RA
Bulk Specific Gravity SSD	2.739	0.597
Particle Shape	Angular	Cubical

Note: GA - Gravel Aggregates, RA - Rubber Aggregates

Table 2 Coarse aggregate grain size distribution

Sieve Size (mm)	Cumulative Percent Passing (%)	
	GA	RA
25.0	100	100
19.0	86	61.34
12.5	51	38.60
9.5	33	0
4.75	15	0

Note: GA - Gravel Aggregates, RA - Rubber Aggregates

3.2 Mix Proportion

A total of 15 mix proportions of pervious concrete were designed and tested in this study. This includes a control mix that did not contain fly ash and rubber aggregates. Table 3 presents the different mix IDs and proportions of binders and coarse aggregates. Consistently for all mix designs, the binder-to-aggregate ratio used was 1:4, and the water-to-cement ratio was 0.34. The ratios used to replace gravel aggregate were 0%, 10%, 20%, 30%, and 40% of rubber aggregate by weight, while the ratios to replace cement were 0%, 10%, and 20% of fly ash by weight.

Table 3 Mix proportions

Mix ID	Binder (%)		Coarse Aggregate (%)	
	C	FA	GA	RA
FA0-RA0	100	0	100	0
FA0-RA10	100	0	90	10
FA0-RA20	100	0	80	20
FA0-RA30	100	0	70	30
FA0-RA40	100	0	60	40
FA10-RA0	90	10	100	0
FA10-RA10	90	10	90	10
FA10-RA20	90	10	80	20
FA10-RA30	90	10	70	30
FA10-RA40	90	10	60	40
FA20-RA0	80	20	100	0
FA20-RA10	80	20	90	10
FA20-RA20	80	20	80	20
FA20-RA30	80	20	70	30
FA20-RA40	80	20	60	40

Note: C - Cement, FA - Fly Ash, GA - Gravel Aggregates, RA - Rubber Aggregates

3.3 Test Procedures

Experiments were conducted to determine the compressive strength, split tensile strength, void content, and infiltration rate of the pervious concrete. The tests' procedures were based on the standards established by the American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO). The specific test standards are tabulated in Table 4.

Table 4 Testing methods

Concrete Property	Test Standard
Compressive strength	ASTM C39
Split tensile strength	ASTM C496
Density and void content	ASTM C1688
Infiltration rate	ISO 17785-1

To evaluate the compressive strength, split tensile strength, and infiltration rate, a total of 180 cylindrical specimens measuring 100mm in diameter by 200mm in height (4 inches x 8 inches) were cast and cured in accordance with ASTM C192. Each test and mix proportion were performed on four specimens to ensure the accuracy and reliability of the results. In the case of the void content test, fresh concrete was utilized. The testing setups used for compressive and split tensile testing are in Figures 2 and 3.

Fig.2 Compressive test setup

Fig.3 Split tensile test setup

4. RESULTS AND DISCUSSION

The compressive strength, split-tensile strength, and infiltration test results of the 15 mix designs were gathered and analyzed. In addition, this section presents the graphical representation of results, an analysis of the two-way ANOVA tests, and desirability function calculations performed using the results obtained. Sample batches of the specimens tested are presented in Figure 4, specifically FA0-RA10 and FA0-RA20.

Fig.4 FA0-RA10 and FA0-RA20 specimens

4.1 Strength Properties

Table 5 presents the average initial results obtained from compressive and split tensile testing. The weight of the concrete specimens tested varied depending on the mix design, with the lightest average weight recorded as 2060.1 grams and the heaviest as 3457.5 grams. Furthermore, increasing the percentage of rubber aggregate replacements resulted in lighter concrete specimens. This can be attributed to the lower unit weight of rubber aggregates than gravel.

The average compressive strengths were determined for each mix design, with values ranging from a minimum of 0.00 MPa to a maximum of 10.64 MPa. The average split tensile strength values range from a minimum of 0.00 MPa to a maximum of 1.82 MPa. Additionally, it can be observed that the obtained compressive strengths were much higher than the split tensile strengths, indicating that the concrete is more resistant to compression than tension.

Table 5 Initial compressive and split-tensile strengths test results

Mix ID	Compressive strength		Split-tensile strength	
	Weight *g*	Pressure *MPa*	Weight *g*	Pressure *MPa*
FA0-RA0	3107.2	5.36	3207.7	1.06
FA0-RA10	2962.6	2.29	2920.6	0.68
FA0-RA20	2760.2	1.24	2646.3	0.33
FA0-RA30	2483.3	0.21	2431.9	0.09
FA0-RA40	2110.8	0.00	2060.1	0.00
FA10-RA0	3263.7	7.41	3198.7	1.56
FA10-RA10	2974.2	3.55	2959.5	0.71
FA10-RA20	2708.1	1.08	2633.5	0.23
FA10-RA30	2521.5	0.20	2390.7	0.09
FA10-RA40	2072.0	0.00	2223.3	0.00
FA20-RA0	3457.5	10.64	3454.6	1.82
FA20-RA10	2860.2	2.14	2965.7	0.93
FA20-RA20	2646.5	1.15	2615.9	0.25
FA20-RA30	2394.6	0.00	2367.0	0.05
FA20-RA40	2246.2	0.00	2199.8	0.00

Upon loading, specimens with rubber aggregates were observed to undergo ductile failure attributed to horizontal deformation. This was similar to the study of Gesoğlu, Güneyisi, Khoshnaw, and Ipek [5], which correlated the replacement with rubber aggregates to ductility and damping capacity. Moreover, prominent cracks were observed along rubber aggregates, as shown in Figures 5 and 6, which are more cubical in shape than gravel. Additionally, cracking in the outermost cement coating was observed on rubber aggregates throughout testing. Strength reduction can be attributed to the elasticity of rubber, which accelerates failure between the rubber-cement interface and the lack of adhesion between the rubber surface and cement [17].

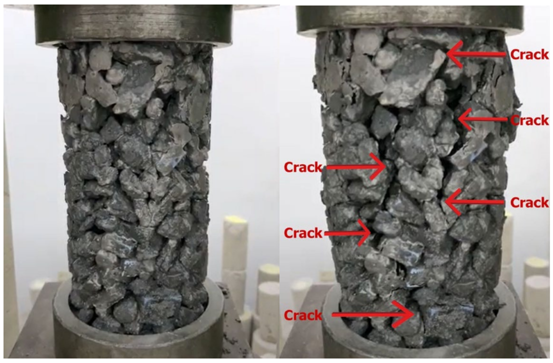

Fig.5 FA10-SR10 during compressive testing

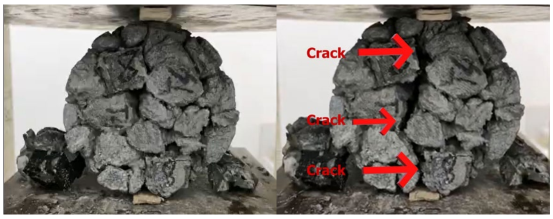

Fig.6 FA10-SR10 during split tensile testing

The lack of adhesion between the rubber aggregates and binder can be further observed in Figure 7. Several shredded rubber aggregates were found to be exposed and were not coated by the hardened binder upon failure during compressive and split tensile testing.

Fig.7 Exposed shredded rubber post testing

4.2 Strength Projection

Due to unforeseen testing restrictions, several mix designs were tested past this study's prescribed 28-day curing period. The curing periods for these specific mix designs were 34 and 35 days. Strength prediction models were employed to project the experimental results to their equivalent values on the 28th-day to account for the strength development during the additional curing period.

4.2.1 Compressive Strength

The prediction model used to project the 28th-day compressive strength was developed by the American Concrete Institute (ACI) and shown in Eq. (1) [18].

$$(f_c')_t = \frac{t}{\alpha + \beta(t)}(f_c')_{28} \tag{1}$$

where $(f_c')_t$ in MPa is the compressive strength with a curing age of t in days, α and β are constants set to be 4.00 and 0.85, respectively, and $(f_c')_{28}$ in MPa is the 28th-day compressive strength.

4.2.2 Split Tensile Strength

A similar process was applied to determine the 28th-day split tensile strength equivalent. The formulas were based on the study of Li, Wang, Deng, Li, and Zhao [19] and are illustrated in Eq. (2) and (3).

$$\beta_{CC}(t) = exp\{s\left[1 - \left(\frac{28}{t}\right)^{0.5}\right]\} \tag{2}$$

$$f_{st.t} = f_{st.28}[\beta_{CC}(t)]^{\frac{2}{3}} \tag{3}$$

where $\beta_{cc}(t)$ is a coefficient dependent on curing age t in days, s is a coefficient dependent on the type of cement, $f_{st.t}$ is the split tensile strength in MPa with a curing age of t in days, and $f_{st.28}$ is the 28th-day split tensile strength in MPa.

4.3 Infiltration Rate

Eq. (4) was used to consider the individual properties of each of the four specimens to determine the average infiltration rate for each mix design.

$$K_{ave} = \frac{V_{water}}{A_{ave}(t_{ave})} \tag{4}$$

where V_{water} is the volume of water and is equivalent to 2,000,000 mm^3, t_{ave} is the average recorded time in seconds, and A_{ave} is the average cross-section area of the specimens in mm^2.

Furthermore, Table 6 presents each mix design's average weights and infiltration rates. The average weights per mix design varied from 2064.0g to 3354.9g. The average infiltration rates were determined and ranged from the lowest value of 5.28mm/s to the highest value of 23.66mm/s.

Table 6 Average infiltration test results

Mix ID	Weight *g*	Infiltration Rate *mm/s*
FA0-RA0	3221.2	13.88
FA0-RA10	2978.2	10.64
FA0-RA20	2692.5	12.59
FA0-RA30	2535.3	12.87
FA0-RA40	2064.0	23.66
FA10-RA0	2616.5	15.27
FA10-RA10	3252.2	11.01
FA10-RA20	2944.7	10.18
FA10-RA30	2335.1	18.20
FA10-RA40	2159.5	18.68
FA20-RA0	3354.9	5.28
FA20-RA10	3015.0	10.08
FA20-RA20	2685.7	14.99
FA20-RA30	2342.9	18.25
FA20-RA40	2211.6	21.21

4.4 Trend Analysis

Figures 8 and 9 present the trends of projected compressive and split tensile strengths with the replacement percentages of rubber aggregates and fly ash, respectively. Regarding the compressive and split tensile test results, an increase in the replacement percentage of rubber aggregates led to a decrease in the maximum resisted forces before failure. A higher fly ash content also increased compressive and split tensile strengths, particularly for mix designs with 0% rubber aggregate replacement. Notably, when 10% of rubber aggregate was replaced, the strengths only reached about 50% of the strengths of their respective mix designs, with constant fly ash content and 0% rubber aggregate replacement. The decrease in strength relative to the replacement of aggregates can be attributed to the grain size variation between rubber and gravel. Other similar studies also showed that the increase in grain diameter resulted in strength reduction [20].

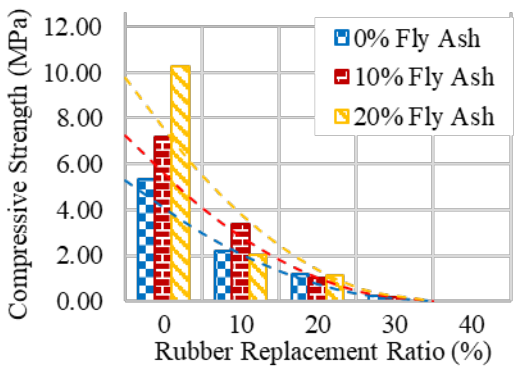

Fig.8 Compressive test trend analysis.

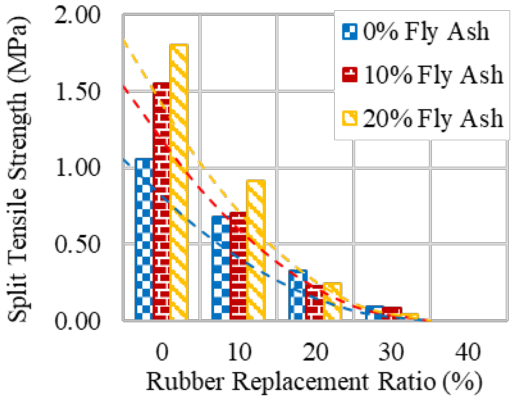

Fig.9 Split tensile test trend analysis.

Figure 10 presents the trend for infiltration rate with respect to the density of specimens. Overall, the infiltration test results produced a decreasing trend as the density increased. The densities of the specimens were found to be inversely correlated to the replacement percentage of rubber aggregates, indicating that an increase in rubber content corresponds to a decrease in density. In line with this, it can be observed that increasing the amount of rubber aggregates results in higher infiltration rates. This is possibly due to the cubical shape and grain size distribution of the rubber aggregates, leading to increased voids throughout the specimen. These voids allow easier water passage, facilitating a faster infiltration rate. The exact relationship between aggregate size and infiltration rate was observed by Mulyono and Anisah [21] when they compared the performance of gravel and crushed stone with varying sizes.

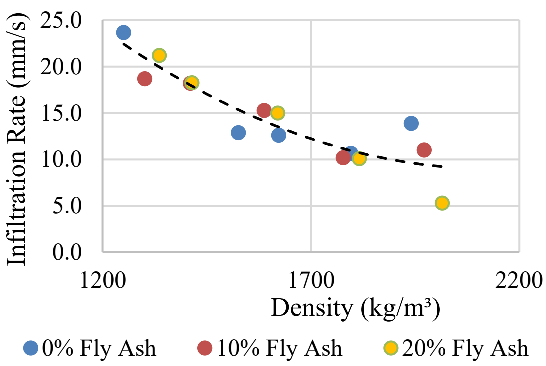

Fig.10 Infiltration test trend analysis

4.5 Statistical Analysis

4.5.1 Two-way ANOVA with Repetition

A two-way analysis of variance with repetition was performed to examine the statistical significance of rubber aggregates and fly ash replacements on the compressive strength, split tensile strength, and infiltration rate of concrete. The results, presented in Table 7, showed that the replacement of rubber aggregates significantly affected the values obtained from each test. The combined effect of fly ash and rubber aggregates significantly impacted the tested concrete properties. However, the fly ash replacement percentage variation did not significantly affect the infiltration rate.

Table 7 Two-way ANOVA with repetition

	Compression			Split Tensile			Infiltration Rate		
	FA	RA	FR	FA	RA	FR	FA	RA	FR
f	5.32	157.05	7.53	5.78	175.77	4.95	0.236	14.98	3.27
p	0.008	<.001	<.001	0.006	<.001	<.001	0.791	<.001	0.005

Note: FA - Fly Ash, RA - Rubber Aggregate,
FR - Fly Ash and Rubber Aggregate

4.5.2 Desirability Function

The determination of the optimum mix design is based on the desirability maximization of compressive strength, split tensile strength, and infiltration rate, as seen in Eq. (5). Normalized average values of test results were first obtained by dividing individual values by the total per test. The desirability for each mix design was quantified by getting the cube root of the product of normalized test results using Eq. (6) [22,23].

$$d_n = \frac{a_n}{\Sigma a_n} \tag{5}$$

$$D = (d_1 x\, d_2 x\, d_3)^{\frac{1}{3}} \tag{6}$$

Upon using the desirability maximization function on normalized test values, the most desirable mix designs are shown in Table 8. Generally, mix designs with lower rubber replacement were more desirable.

Table 8 Desirability ranking

Mix ID	Compression *MPa*	Split Tensile *MPa*	Infiltration *mm/s*	Rank
FA10-RA0	7.16	1.54	15.27	1
FA20-RA0	10.25	1.80	5.28	2
FA0-RA0	5.36	1.06	13.88	3
FA10-RA10	3.40	0.70	11.01	4
FA20-RA10	2.14	0.93	10.08	5
FA0-RA10	2.29	0.68	10.64	6

5. CONCLUSION

This study investigated the potential of utilizing shredded rubber tires and fly ash as sustainable alternative materials in pervious concrete, aiming to improve traditional construction practices and address one of the waste problems in the Philippines. The research incorporated different replacement ratios of shredded rubber tires and fly ash to determine their impact on pervious concrete's strength and permeability properties. In particular, the percentage replacements of shredded rubber tires to gravel were limited to 0%, 10%, 20%, 30%, and 40%, while cement was partially substituted by fly ash at 0%, 10%, and 20% replacements.

Results showed that the addition of rubber tires in the mix had a decreasing effect on compressive and split-tensile strengths but yielded lightweight concrete with higher infiltration rates. On the other hand, increasing fly ash content resulted in higher compressive and split-tensile strengths. This was further supported by the results of the two-way ANOVA test and desirability maximization function. Findings also showed that incorporating up to 10% rubber aggregates with 10-20% fly ash yields a more desirable pervious concrete mix with regards to compressive strength, split-tensile strength, and infiltration. These findings offer a promising solution to improve concrete practices, reduce mismanaged waste, and promote sustainability in construction projects.

Considering the significantly low strengths for mix designs with 30% and 40% replacement of shredded rubber tires, it is suggested to investigate smaller intervals of replacement percentage of shredded rubber tires, such as 0%, 5%, 10%, 15%, and 20%. This range would provide a more comprehensive understanding of the effects of different replacement percentages and determine whether shredded rubber has a more optimal replacement percentage.

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