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Reusing Inner Lining Tire Strips (ILTS) as Partial Coarse Aggregate Replacement for Sustainable Rubber Paver Blocks (RPB)

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Abstract
The engineering surrounding the usage of concrete continues to evolve with new ideas put forward over the years. New resources emerge among studies to produce more sustainable concrete, although most are not yet established in projects like rubber. Replacing natural coarse aggregate with rubber is a resource-efficient option to avoid further environmental damage. This study aims to assess the sustainability of a Rubber Paver Block (RPB), a paver block with cement containing a certain percentage of coarse aggregates replaced by crumb rubber from Inner Lining Tire Strips (ILTS). Five different cement mixes were produced containing 0%, 10%, 20%, 30%, and 40% of the rubber-replaced coarse aggregate volume that were evaluated using the Absorption, Compressive, and Infiltration Test. Among these cement mixes, only the produced samples of 20% showed favorable results, passing all the physical requirements in all three tests. The characteristics of the rubber present within this mix had specimens with low absorption, adequate strength, and high infiltration that respectively avoid high chances of deterioration, provide durability over time, and add permeability that is mainly useful in flood cases caused by natural or artificial disasters.

Keywords
Inner Lining Tire Strips (ILTS), Rubber Paver Blocks (RPB), Absorption Rate, Compressive Strength, Infiltration Rate

INTRODUCTION

In recent years, the use of concrete pavement has contributed to rapid urban development worldwide. Paver blocks are widely used in pedestrian walkways, roads, industrial areas, parking lots, and low-traffic driveways [1]. However, this practice has created numerous environmental and developmental challenges. Applying impermeable pavers creates a massive, artificial, waterproof surface, increasing surface runoff and flooding [2]. This has long been a known problem in archipelagic countries like the Philippines, where numerous rain calamities and typhoons are reported yearly. Therefore, permeable concrete is becoming an appealing alternative solution for local drainage systems due to its ability to manage water through pavement construction without requiring additional utilities [3].

Due to the many unusable tires from various vehicles, severe environmental problems occur, including rapid land depletion and air pollution [4]. Various organizations worldwide are promoting sustainable development, waste tire recycling, and tire reuse by adding new volumes of recycled materials. One way to reuse rubber waste is by adding it to concrete [5]. The replacement percentage should be limited to specific amounts when using recycled rubber tires as a partial substitute for coarse materials in concrete buildings.

Numerous studies have examined the implications of adding Tire Derived Coarse Aggregate to Portland Cement Concrete (PCC) mixes. In one such experiment, adding rubber up to 30% of the cement mix improved non-structural crack resistance, shock wave absorption, and resistance to acid. Furthermore, crumb rubber concrete is lighter in weight, with a reduced density compared to conventional concrete [6]. One study has shown that adding recycled rubber tires to rubberized concrete significantly increases the slump results and workability [7]. Rubcrete improves not only its mechanical properties but also its hydrological properties. The permeability and water absorption with rubber do not significantly affect the vacuum saturation method applied to cement mortars [8]. The presence of rubber aggregates has provided significant improvement in terms of strain capacity and toughness. A concrete mixture with a rubber content of 60% decreases physical properties to 10% [9]. In a separate experimental analysis [10], using an M15 grade rubber plus concrete mixture provided sufficient strength compared to a standard brick mix, recommending up to a 30% rubber replacement. When the rubber content increases, the water absorption increases while the compressive strength and bulk density decrease. Nonetheless, the study's results highlight the promising outcome of using recycled rubber tires in concrete construction as a partial replacement for coarse aggregates.

Although rubber has several applications and advantages in concrete mixtures, it also has drawbacks. Rubber concrete is limited to non-structural applications due to the lack of cohesiveness and proper bonding between rubber and concrete mix [11]. The weak bond between the rubber surface and paste is primarily caused by rubber particles' hydrophobic nature and extreme external irregularity [12]. It was also found that a significant drop in the compressive strength may be related to the behavior of tire rubber particles as soft aggregate. Using rubber as an aggregate reduces the capacity of the mixture in terms of its rubber content, particle size, and characteristics. However, one way to counter the smoothness of the rubber surface is by utilizing a superplasticizer. This compound admixture is extra in concrete with not more than 0.4% dosage [13] [14] to help produce high workability and can improve its mechanical properties when rubber is added to the concrete mix [5] with a cement mass of 0.8% [14].

The specific objective of this study is to incorporate rubber waste into concrete to create a sustainable rubberized pavement block (RPB) that is lighter, more convenient, and eco-friendly. Furthermore, to determine the percentage of rubber content to be mixed into the concrete best suited for low-load bearing applications such as pedestrian streets, low-traffic streets, low-speed areas, overflow parking lots, residential driveways, alleys, and parking lots.

The small-scale research and experiments using tire waste as a partial replacement for coarse aggregate in concrete have been found to have certain benefits. Rubber concrete exhibits a low specific gravity and increased toughness, flexibility, thermal insulation, sound insulation, and energy absorption [10].

This study focuses on the physical properties of RPB, precisely its compressive strength, absorption, and infiltration capacity. The RPBs are tested for their ability to serve non-auto traffic only. It is important to note that other tests, such as fire retardancy, impact, split tensile strength, freeze-thaw durability, and flexural tests, are beyond the scope of this study.

MATERIALS AND METHODS

This study involved experimental phases supported by related studies and utilized materials and methods to assess the sustainability of RPB. This research used ILTS as a partial replacement for coarse aggregate and followed ASTM Standard material testing for concrete guidelines. Five different mixes, including a control mix, are produced and allowed to cure for 28 days.

Conceptual Framework

Fig. 1 shows the study's conceptual framework, which introduces the materials and resources required to create the specimens. It also underwent three tests to determine the desired output of the study. Fifteen samples in each mixture were categorized into five different variations, namely, 0% control mix, 10%, 20%, 30%, and 40% mix. Afterward, these mixtures were fabricated and then tested after curing.

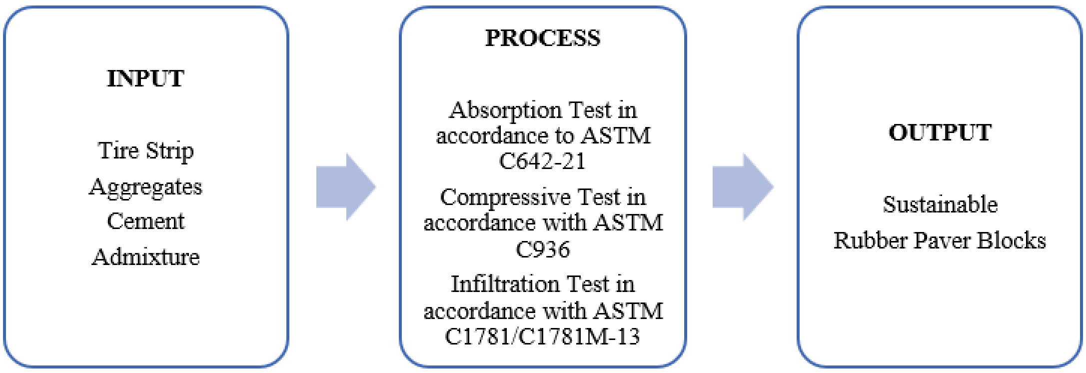

Fig. 1 Conceptual Framework of the Study

Materials and Resources

One material utilized is the tire's inner liner. This specifically formulated compound sits inside the tire and acts as a tube that prevents air escape [15]. Sourced from Filipinas Elastic Rubber Commercial in Davao City, the ILTS were washed, stripped, and dried to be free from any moisture. These were then collected and cut into pieces that were sieved, passing 19mm and retaining 9.51 mm.

Crushed stone and fine aggregates were sourced from A's Sand & Gravel Supplier Belisario, Davao City, following the M15 mix grade standard. Moreover, the Ordinary Portland Cement Type I-based concrete, widely used worldwide for a century where structures were proven safe and durable [16], was utilized. Lastly, TibayMix Super Concrete, a powder admixture, acted as a superplasticizer and water-retarder. This improved the properties of fresh concrete, such as its workability and compressive strength [17]. As recommended, one sachet (140 g) of TibayMix superplasticizer admixture was used in every bag (40 kg) of cement. This admixture was sourced from a leading e-commerce website in the Philippines.

Methods and Procedure

Five series of concrete mixtures (0%, 10%, 20%, 30%, and 40%) of rubber paver blocks (RPB), including a conventional mix, were made using a custom-made steel mold that creates RPB with dimensions of 8 x 4 x 2 inches per ASTM C936/C936M-13. Three experimental tests were conducted to determine the characteristics of rubber paver block samples, specifically tests on absorption, compressive strength, and infiltration. Following the M15 grade standard, 15 samples per mixture per test were made and tested after 28 days of curing for compressive and infiltration tests and 24 hours after for absorption test. A total of 225 paver block specimens were produced in the study.

Mix Proportion and Aggregate Properties

The design mix for M15-grade concrete was developed based on IS 10262:2009. With 0.6 water-to-cement (w/o) ratio and 1:2:4 RPB ratio by volume, RPBs were composed of natural coarse aggregates with 10%, 20%, 30%, and 40% ILTS partial replacement. The dosage of the superplasticizer was kept constant at its recommended use. When rubber was utilized to replace aggregates with equal volume and the rubber dosage at 0%, 10%, 20%, and 30%, the compressive strength of concrete decreased by about 50% as the rubber dosage increased from 0% to 30% [18]. Table 1 shows different mixes of RPBs with their coarse aggregate partially replaced with specific amounts of ILTS.

Table 1 Mix Design of Rubber Paver Blocks (RPB)

Rubber Content	Water (L)	Cement (L)	Sand (L)	Admixture (g)	Crushed Stone (L)	Rubber Strip (L)
0%	18	21	42	140	84	-
10%	18	21	42	140	75.6	8.4
20%	18	21	42	140	67.2	16.8
30%	18	21	42	140	58.8	25.2
40%	18	21	42	140	50.4	33.6

Test Procedures

The selected properties of the prepared concrete mixture were evaluated on three different tests.

a. Absorption Test

The Absorption test was carried out using ASTM C642-21 to assess the water penetrating when immersed into concrete samples. The lower the absorption, the better the results, as high-water absorption levels lead to deterioration because of thawing and periodical freeing during cold seasons. Fifteen samples per variation were used with dimensions of 8 x 4 x 2 in. per paver block. The value of Water Absorption was calculated using Eq. 1.

$$\text{Water Absorption, (WA)} = \frac{Ws - Wd}{Wd} \times 100 \qquad (1)$$

Where W_s is the weight of saturated water and W_d represents the dry weight

For the computation of the water absorption, the value of the water absorption rate of each paver was divided by the difference between the saturated and dry weight over its dry weight.

b. Compressive Test

The compressive test was carried out per ASTM C936 to see whether there was an increase or decrease in the samples' strength with the presence of ILTS in the concrete mixture. Fifteen samples per variation were used with dimensions of 8 x 4 x 2 in. per paver block. The compressive strength (in kN) value was calculated using Eq. 2.

$$\text{Compressive strength} = \frac{Maximum\ Compressive\ Load}{Area\ of\ Specimen} \qquad (2)$$

The maximum compressive strength values were obtained and recorded in kilonewtons (KN). The value of each block was calculated by dividing the maximum load over the cross-sectional area of each block.

c. Infiltration Test

This test was carried out based on ASTM C1781/C1781M-18 using Eq. 3 by pouring a fixed volume of water on a 4" x6" infiltration ring through the pavement samples and recording the time to discharge a fixed amount of water. This test was conducted on every mixture of 0%-control, 10%, 20%, 30%, and 40% after 28 days of curing.

$$\text{Infiltration Rate, (I)} = \frac{KM}{D^2 t} \quad (3)$$

Where I is the infiltration rate in mm/h, M is the weight of infiltrated water in kg, D is the inside diameter of the infiltration ring in mm, T is the time required for a measures amount of water to infiltrate and K is 4583666000 in SI Units.

Statistical Analysis

T-test, a statistical method used in the testing of hypothesis for comparison of means between the groups [19], was used to determine the significant difference of hardened concrete containing five series of rubber content (0%-control mix, 10%, 20%, 30%, and 40%) in terms of absorption, compression, and time of infiltration. Considering the recommended requirements for each test, physical requirements for water absorption should be 7% for individual use. They shall not exceed 6% for average use, compressive strength of solid interlocking paving units shall be not less than 15 MPa and record the fastest elapsed time taken for water to infiltrate through the sample pavements among all conducted trials.

RESULTS AND DISCUSSIONS

In this portion, the gathered data from tests on absorption, compressive, and infiltration, along with the analysis of results, were analyzed in coordination with the study's statistician and adviser and were tested in an ASTM-accredited testing center.

A. Aggregate Characterization

Pavers are one example of small precast material with a required maximum size of about 10 mm for coarse aggregates [20]. This study used crushed stones as coarse aggregates passing 19 mm and retaining 4.75 mm with a nominal size of 9.5 mm. Tables 2 and 3 further exhibit the test reports of aggregate characteristics utilized in making the RPB samples.

B. Absorption Test

Comparing the mean absorption rate between the four mixtures and the ASTM standard, it was observed that while the rubber content increased, the water absorption didn't exceed the required rate, as shown in Fig 2. It also revealed that the 20%, 30%, and 40% rubber mixture falls within the physical requirements of not exceeding 6% for average use for water absorption, unlike the 10% mixture.

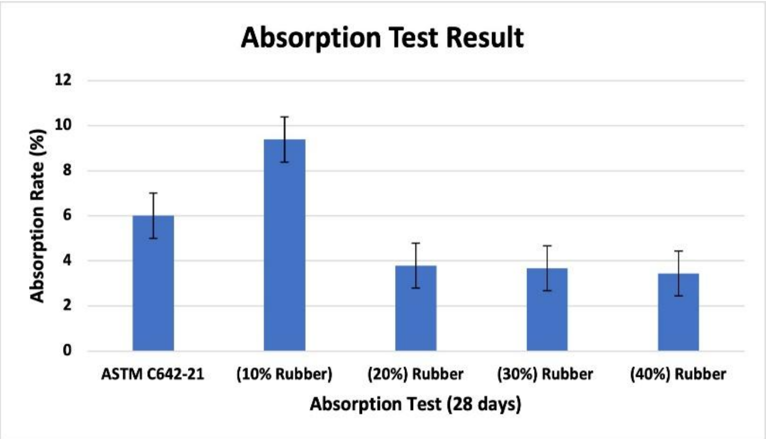

Fig. 2 Absorption Test Result

By also utilizing the t-test performed in 4 batches of comparison, it was found that there was no significant difference between the standard and 10% mix with average mean values of 7.0 and 10.00, indicating that both variations performed similarly. On the other hand, batches 20%, 30%, and 40%, with average mean values of 3.79, 4.07, and 3.73, respectively, had significant differences, each compared with the ASTM standard. Thus, the addition of rubber limits the ability of the paver block to absorb moisture.

Understandably, the mix containing 10% rubber had the highest absorption rate among the four batches of produced mixes. Following the observed data trend, 20% had a lower absorption rate than the percentage mixes beforehand, so 30% and 40% mixes to the ones that came before it. Although 20%, 30%, and 40% were getting lower as the percentage went on, the three mixes only had slight minor differences within each other. Moreover, the absorption rate is lower when rubber is mixed with cement due to the rubber particles' hydrophobic characteristics [16]. The samples could repel water, thus lowering their absorption rate. These samples have a higher concrete workability, reducing the risk of substantial deterioration. Therefore, the lower the absorption rate, the more acceptable the paver blocks are. With a 6% maximum required absorption rate for a paver block, 20%, 30%, and 40% mixes were the only samples that fell within the criteria. The concrete mix containing 40% rubber-replaced coarse aggregates gave the most satisfactory absorption rate and was the lowest among all the five batches.

C. Compressive Test

As shown in Fig. 3, comparing the mean values of each mixture's compressive strength revealed the highest compressive strength is 10%, followed by the 20% mixture, which met the 15 MPa requirement. Moreover, the 30% and 40% mixture's mean strength almost met the required strength requirement. It is observed that the compressive strength decreased as the rubber volume was increased. For example, samples 10% and 20% had a compressive strength of approximately 16 MPa and 15 MPa, respectively. However, samples from the 30% and 40% mixture had the lowest compressive strength, containing the most rubber-replaced coarse aggregates.

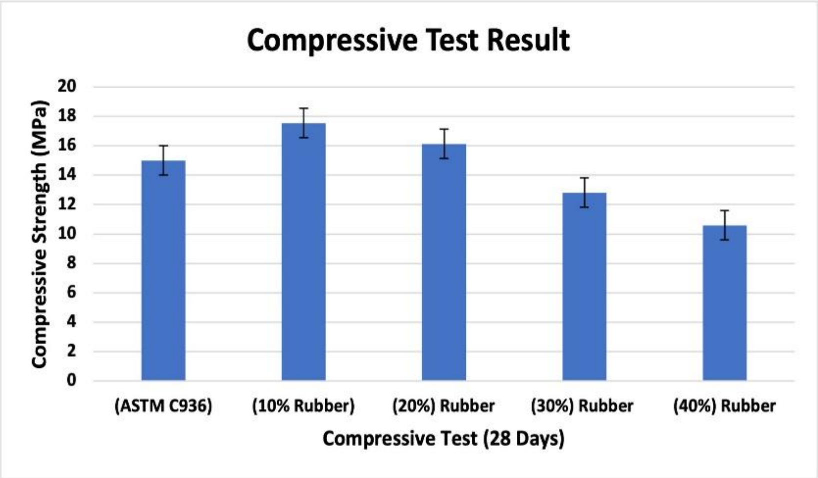

Fig. 3 Compressive Test Result

The t-test found no significant difference between the 10% and 20% ASTM standard mix with an average mean of 16.04 and 15.02, respectively, compared with the ASTM standard with an average mean of 15. MPa. On the other hand, there was a significant difference between the 30% and 40% mix, with an average mean of 12.89 and 11.29 compared with the standard mix.

It was observed that the addition of rubber weakens the compressive strength of RPB. The significant drop in the compressive strength may be related to the behavior of tire rubber particles as soft aggregate [17]. The recommended compressive strength is 15 MPa for non-auto-traffic use; thus, the 10% and 20% mixes are satisfactory as per ASTM C936.

In line with this, the types of cracking after compressive testing were analyzed as shown in Fig. 4. Samples (a) 10% mix showed signs of toothed vertical cracks. Vertical cracks were also observed in samples (b) 20%, (c) 30% mix, and (d) 40% mix showed a small sign of toothed cracking. By analyzing these samples, the widths of the cracks of the treated samples were thinner. It can be observed that the more significant the amount of rubber volume present in the mixture, the lesser the gaps were.

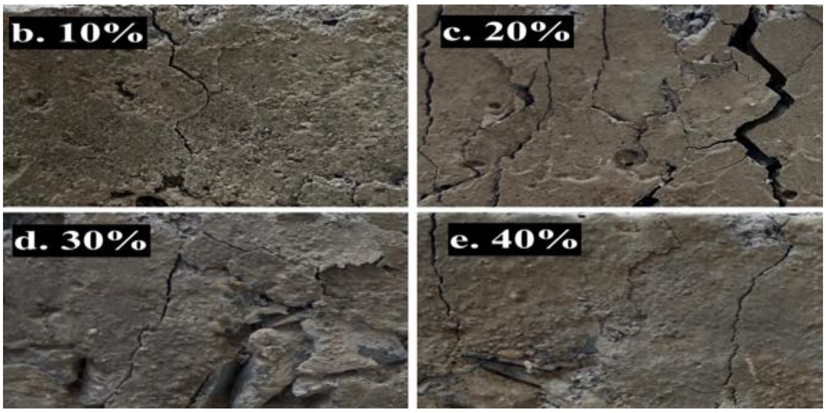

Fig. 4 Formed cracks after Compressive Testing: a) 10% mix, b) 20% mix, c) 30% mix, d) 40% mix

D. Infiltration Test

As shown in Fig. 5, it was observed that there was an increasing trend in infiltration rate when more rubber was added to a concrete mix. The 40% mix had the highest infiltration rate since it contained the most rubber content. This was followed by the 30% mix that showed a high infiltration rate and unrestricted water movement, which is desirable for a rubber paver block. The 20% and 10% had less infiltration rate.

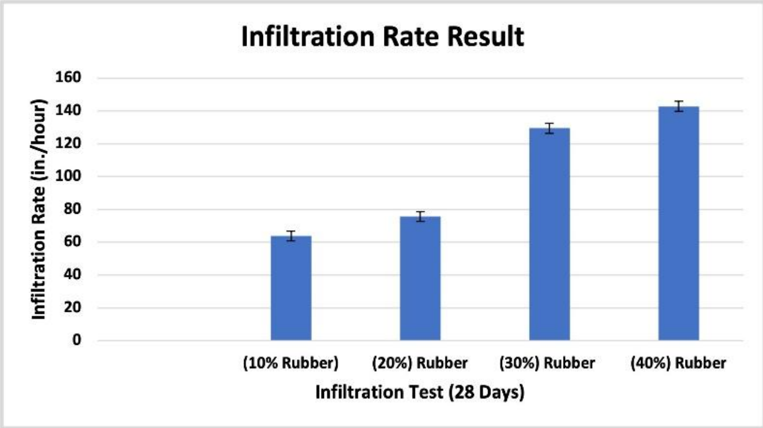

Fig. 5 Infiltration Rate Result

The t-test for storing water through infiltration was performed in 4 batches of comparison, respectively, 10%, 20%, 30%, and 40%, with average means of 12.79, 15.13, 25.89, and 28.57. Paver blocks with 40% rubber content recorded the highest with an average mean value of 28.57. Thus, adding rubber as coarse aggregates increased the permeability of concrete mixes. This happens due to the weak bond between recycled rubber and cement mix, which leads to interfacial gap voids [15]. Therefore, it was easier for water to flow through the said sample.

CONCLUSIONS AND FUTURE WORKS

The proposed Rubber Paver Blocks (RPB) showed significant changes in results throughout the entire test process of absorption, compressive strength, and infiltration by adding crumb Inner Lining Tire Strip (ILTS) to the M15-grade concrete design mix. With the proponents' initial goal for this study of showing compatibility with the ideal sustainable permeable blocks, this study concludes that the concrete mix of 20% rubber aggregate volume content for Rubber Paver Blocks (RPB) showed the most favorable results. It is the only variation that met the required absorption rate of 3.79 and compressive strength of 15.02 MPa while still having a reasonable infiltration rate of 15.13 with bearable crack occurrence, making it the most sustainable among the four cement mix series.

Overall, the study shows that it is possible to use recycled rubber, specifically Inner Lining Tire Strips (ILTS), in concrete mixture as a partial replacement for coarse aggregate. However, the researchers recommend that the percentage replacement should be limited to a specified amount, as discussed above, preferably with the application of superplasticizer admixture, and the application should be limited to non-auto traffic only.

FUNDING INFORMATION

No funding involved.

DECLARATION OF CONFLICT

We have no personal, financial, or other interest that could, or could be seen to, influence the decisions or actions we are taking or the advice we are giving during my research for this study.

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