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Assessment of Waste Crushed Glass as a Partial Replacement for Fine Aggregates in Producing Load-bearing Concrete Paving Blocks

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Abstract:

The construction industry exerts a notable environmental impact, significantly contributing to CO2 emissions, depletion of natural resources, and high energy consumption. Sand is a vital natural resource essential to daily life and the environment. Furthermore, millions of tons of waste contribute to significant environmental challenges worldwide, particularly in the Philippines. A critical issue regarding waste disposal is the lack of proper recycling infrastructure and practices. Wherein, glass is a highly recyclable material that can be melted down and reused indefinitely, most of the glass waste in the country ends up in landfills, contributing to environmental pollution. Due to the shortage of sand, the researchers discovered an idea to generate a way to utilize waste-crushed glass as a partial replacement for fine aggregates in producing load-bearing concrete paving blocks. The primary aim of this research is to assess the appropriateness of waste crushed glass (WCG) as a substitute for fine aggregates, particularly in manufacturing load-bearing concrete paving blocks. Consequently, the study primarily seeks to evaluate the compressive strength of the concrete paving blocks with 7, 14, and 28 of curing days and conduct a cost analysis comparing the standard sample with the simulated sample. To attain the result from the compressive test, the researchers will make paving blocks consisting of a total 36 specimens for the control sample and experimental setups with 15%, 30%, and 45% WCG replacement and 12 specimens allotted for water absorption test. The samples were tested using Universal Testing Machine (UTM), based on the analysis of the findings, the researchers conclude that waste crushed glass (WCG) can be a partial replacement of fine aggregates for load bearing concrete paving blocks. The results revealed that

Experimental Setup B, with 30% of WCG as a partial replacement, obtained higher compressive strength compared to the control sample.

Keywords **—**Load-Bearing, Crushed glass, Fine Aggregates.
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I. INTRODUCTION

Philippines' economy is continuously developing and growing, and many structures and buildings are established that affect the country's natural resources. In the medium and long term, the Philippine government aims to boost investments in human and physical capital to stimulate growth. The Philippines' economy is rapidly improving; in 2022, growth increased to 7.6 percent from 5.7% in 2021 [1]. One of the crucial natural resources is the sand, which has various significant roles and importance in daily lives and the environment. It is a fundamental component used to make concrete and mortar in the construction industry. Unfortunately, according to Recto, there is a "global" shortage of sand, and local demand for building materials is increasing. He continued that it was also past time to reexamine the government's current regulations for the extraction, handling, and retailing of sand and gravel. Recto claims that the lack of building aggregates has increased construction prices and delayed several government projects [2]. Through exploring and intensive analysis, the researchers identified that waste crushed glass (WCG) possessed the quality to partially replace fine aggregates in construction.The use of waste crushed glass (WCG) as a replacement for fine aggregates can greatly increase the mechanical properties of paving blocks. This study aims to reinforce the rectangular concrete paving blocks with waste crushed glass (WCG) as a partial replacement for fine aggregate and make it a load-bearing material that can resist and bear the weight of loads. Through experimentation and analysis, this research aims to enhance the performance and durability of rectangular concrete paving blocks and contribute significantly to the global pursuit of sustainable construction solutions. As we embark on this exploration, the potential to reshape the future of construction practices looms large, promising a greener, more sustainable built environment for generations to come.

A. *Brief discussion of the materials used*

Annually, millions of tonnes of waste glass pose serious problems related to environmental conditions all over the world. The glass is mainly composed of silica [3]. From a performance perspective, crushed glass presents a smooth and angular texture that enhances the workability of concrete, facilitating better mixing and compaction. Its pozzolanic properties can further improve construction materials' long-term durability and resistance, making it an environmentally responsible and economically viable choice. Malik et al., 2013 shared a consensus with these results, affirming that concrete, which integrated glass aggregate at concentrations of up to 30%, demonstrated higher compressive strength than conventional concrete, yet noted that the compressive strength declined with increasing proportions of the mixture [4]. In sum, the adoption of crushed glass as an acceptable aggregate replacement promotes eco-conscious building practices and can elevate the quality and sustainability of construction projects.

Paving blocks are made from cement, concrete admixture, fine aggregates, and water. Paving blocks have become a popular choice for enhancing the functionality and appearance of outdoor spaces, offering a durable and attractive alternative to traditional pavement solutions. They are designed to be versatile and can be arranged in different patterns, adding aesthetic appeal to landscapes. They are relatively easy to install, requiring a solid base and joint sand to secure them. Paving blocks also allow for efficient water drainage due to the gaps between the blocks, preventing water accumulation and ensuring safety. Simple maintenance, such as cleaning and sealing, can prolong the life of paving blocks, keeping them in good condition for years. Some paving blocks are eco- friendly and made from recycled materials, promoting sustainability in construction practices.

B. ***Objectives of the study***

The general objective of this study is to identify the suitability of waste crushed glass (WCG) as a partial replacement for fine aggregates, especially in the production of load-bearing concrete paving blocks. Hence, it mainly aims to determine the compressivestrength of the concrete paving block and the cost analysis of the standard sample compared to the simulated sample.

Specific Objectives:

1. To determine the compressive strength for the 7-day, 14-day, and 28-day load- bearing concrete paving blocks when WCG is partially replaced for FA.
2. To assess the water absorption percentage for the 28-day load-bearing concrete paving blocks when WCG is partially replaced for FA.
3. To identify the cost analysis of the standard concrete paving blocks compared to the simulated load-bearing concrete paving blocks with WCG.

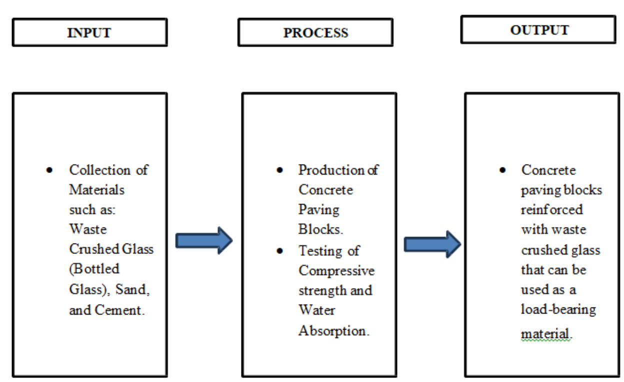
C. ***Scope and Limitation***

This study only focuses on using waste crushed glass (WCG) as a partial replacement for fine aggregates in rectangular concrete paving blocks. The researchers gathered data by testing the proposed product to ensure that WCG is suitable as a partial replacement for fine aggregates in producing load-bearing concrete paving blocks. This study also compared the simulated available concrete paving blocks to determine if waste crushed glass (WCG) is a suitable replacement for fine aggregate. Furthermore, the specimens will be tested in the compressive strength test and the water absorption test only. These tests are chosen to evaluate key performance aspects of the concrete paving blocks containing WCG.

The researchers will collect used clear bottled glass around Pampanga, particularly from their households, neighboring areas, small stores, and potentially designated dump sites. The bottled glass that would be collected is most likely liquor beverages clear bottles. This hands-on approach to crushing allows control over the process and ensures uniformity in the resulting crushed glass material. By incorporating bottled glass from different sources and manually crushing it, the study aims to simulate real-world conditions and obtain a reliable representation of waste glass for subsequent use in concrete paving block production. Additionally, the researchers will conduct sieve analysis to achieve the desired particles of glass specifically, with the mesh sizes of #8 (2.36 mm) and #10 (2.00 mm) only, as per the standard of ASTM C429. Paving blocks reinforced with WCG can only be applied and installed in parking area only, resisting the weight of loads of vehicles particularly cars, tricycles, motorcycles, and bicycles. As per the cost analysis, only the material cost will be computed.

This study aims to assess whether waste crushed glass (WCG) can effectively replace fine aggregates in the context of load-bearing concrete paving blocks.

D. ***Conceptual Framework***



The figure above presents the conceptual framework of the study. The input frame consists of the collection of raw materials, namely waste crushed glass (bottled glass), sand, and cement, which are needed to produce concrete paving blocks. After the collection of materials, the process came into view. The collected materials will be made into concrete paving blocks and will be tested for compression and water absorption. The last frame contains the output of the study, which is concrete paving blocks that are reinforced with waste-crushed glass that can be used as a load-bearing material.

II. METHODS FOR PRODUCING SPECIMENS

This research used an experimental design to examine the synergistic effects of crushed glass as a partial replacement for fine aggregates in concrete paving blocks. To answer the research goals, the researchers opted to perform testing to evaluate the compressive strength and water absorption of the developed concrete paving blocks. Through accurate experimentation and analysis, the study aims to compare standard paving blocks and paving blocks mixed with waste crushed glass (WCG).

The researchers collected bottled glass from different households, and the glass used are recycled bottles. After the collection, the researchers wash and manually crush the recycled glass bottle. Lastly, the sample produced are 15%, 30%, and 45% for incorporating waste glass as partial substitution for fine aggregates with a curing period of 7, 14, and 28 days.

The outlined steps for creating and curing the concrete paving block specimens are all based on ASTM C936, also known as "Standard Specification for Interlocking Concrete Paving Units" [5]. The mixture ratio for load-bearing paving blocks is 1:4, with 1 part cement and four parts sand. The dimensions of the pavers are approximately 4 x 8 inches (101.60 x 203.20 mm), and their thickness is approximately 2.4 inches (60 mm) [6]. As per ASTM C936 standards, upon delivery to the construction site, the mean compressive strength of the test specimens should be at least 55 MPa (8000 psi), with no single unit measuring below 50 MPa (7200 psi) [7]. Unfortunately, this ASTM was designed only for heady duty. Thus, this study adopts the Egyptian Standard Specifications (ESS 4382–1/2004) as a support where the average compressive strength of the tested samples shall not be less than 30 MPa with no individual unit less than 25 MPa which has the same criterion for heavy duty of ASTM. This study explores the motivations and critical considerations behind the adoption of waste crushed glass (WCG) in construction and its significance for the construction industry and environmental sustainability.

In this research, the sample specimens with proportions of 15%, 30%, and 45% were subjected to compressive strength testing after curing periods of 7 days, 14 days, and 28 days and water absorption after 28 days. The primary aim was to assess the compressive strength and water absorption at these intervals. Then, the results were compared against the control sample.

A. *PREPARATION OF MIXTURE FOR LOAD-BEARING CONCRETE PAVING BLOCKS*

WCG-PB	WCG	Sand	Cement
Control Sample	0	1.34 kg	0.54 kg
Experimental Setup A - 15%	0.20 kg	1.14 kg	0.54 kg
Experimental Setup B -30%	0.40 kg	0.94 kg	0.54 kg
Experimental Setup C -45%	0.60 kg	0.74 kg	0.54 kg

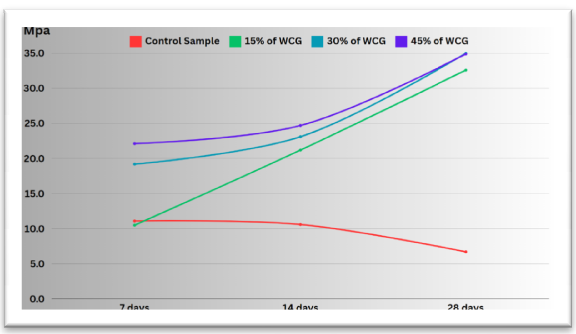
In this study, the designed proportional mixtures 1:4 for Waste Crushed Glass (WCG), cement, and sand respectively and these are:

a. 0 of WCG, 1.34 kg of Sand, and 0.54 kg of Cement
b. 0.20 kg of WCG, 1.14 kg of Sand, and 0.54 kg of Cement
c. 0.40 kg of WCG, 0.94 kg of Sand, and 0.54 kg of Cement
d. 0.60 kg of WCG, 0.74 kg of Sand, and 0.54 kg of Cement

III. RESULT AND DISCUSSION

A. *Summary of Average Compressive Strength on 7th Day, 14th Day, and 28th Day*

Description	No. of Days	Average (Mpa)	ASTM C936 Standard	Remarks	ESS 4382-/2004	Remarks
Control Sample	7	11.1	The average compressive strength of the tested samples shall not be less than **55 MPa** with no individual unit less than 50 MPa.	*All specimens didn't reach the required standard.*	The average compressive strength of the tested samples shall not be less than **30 MPa** with no individual unit less than 25 MPa	FAILED
	14	10.6				FAILED
	28	6.7				FAILED
Experimental Setup A – 15% of WCG	7	10.5				FAILED
	14	21.2				FAILED
	28	32.6				PASSED
Experimental Setup B – 30% of WCG	7	19.2				FAILED
	14	23.1				FAILED
	28	35.0				PASSED
Experimental Setup C – 45% of WCG	7	22.13				PASSED
	14	24.7				FAILED
	28	34.9				PASSED

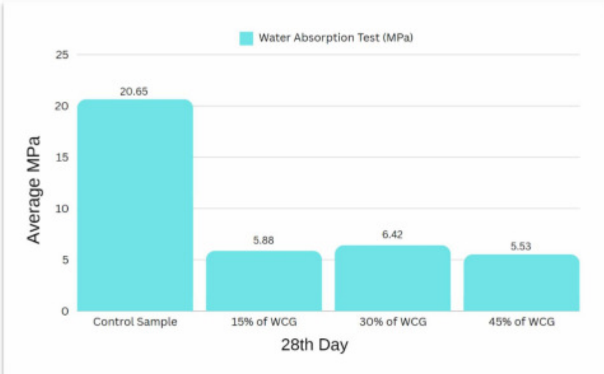


The result shows that as per the Control Sample, the more the curing period increases the more its compressive strength decreases. All the average strength of Control Samples were not able to reach the required strength of ASTM C936 and ESS 4382–1/2004. Consequently, Experimental Setup A incorporated 15% of WCG gained its strength as the curing period increases, it reached the required strength of ESS 4382–1/2004 at a curing period of 28 days. Also, the Experimental Setup C incorporated 45% of WCG reached the required strength of ESS 4382–1/2004 at a curing period of 7 and 28 days. Lastly, Experimental Setup B incorporated 30% of WCG which gained the highest average amount of compressive strength of 35.0 MPa at a curing period of 28 days.

Guatam et al (2012) found that while adding up to 4% of waste glass to concrete as a substitute for fine aggregate did not significantly alter its strength, concrete with up to 30% of fine glass aggregate develops its compressive strength more quickly than regular concrete [8]. According to Weru (2018), Since concrete typically reaches about 99% of its compressive strength within 28 days, it's nearly at its ultimate strength, which may fully develop over 1 or 2 years. Consequently, engineers often base their design calculations on the compressive strength test results obtained after this initial 28-day period [9]. Crushed glass particles larger than 0.6 mm in size might enhance the compressive strength of concrete through the pozzolanic reaction (Lee et al., 2013) [10]. The pozzolanic reaction involves the combination of calcium hydroxide with pozzolanic material, resulting in the formation of secondary C-S-H. This process enhances the mechanical properties and durability of the hydrated cement paste even further (Mehta PK &Monteiro PJM, 2014) [11].

B. *Water Absorption Test Results on the 28th Day*

Description	Dry Weight -M1 (lbs)	Weight of Sample after Immersion in water -M2 (lbs)	Water Absorption at 28 days (%)	Average	lbs/ft2	ASTM C140 Standard	Remarks
Control Sample	3.265	3.951	21.01	20.66	0.65%	The mean absorption of the test specimens should not exceed 5%.	PASSED
	3.276	3.993	21.89				
	3.247	3.867	19.09				
Experimental Setup A – 15%	4.394	4.634	5.46	5.88	0.18%		PASSED
	4.524	4.815	6.43				
	4.568	4.830	5.74				
Experimental Setup B – 30%	4.336	4.623	6.62	6.42	0.20%		PASSED
	4.557	4.846	6.34				
	4.612	4.903	6.31				
Experimental Setup C – 45%	4.780	4.982	4.23	5.53	0.17%		PASSED
	4.733	5.071	7.14				
	4.817	5.068	5.21				



As shown in the figure, as the percentage of crushed glass in the mixture increases, its water absorption level decreases. Based on ASTM C140, the mean absorption of the test specimens should not exceed 5%. This indicates that all the experimental setups and the control sample met the required standards. Thus, the highest water absorption percentage was observed in Control Sample, reaching 0.65 %. In comparison, Experimental Setup B showed a slightly lower percentage of 0.20 %, the Experimental Setup A had 0.18 % and lastly, Experimental Setup C showed the lowest percentage at 0.17 %.

C. *Cost Analysis*

Computed Cost per Setup

MATERIALS	CONTROL SAMPLE	EXPERIMENTAL SETUP A	EXPERIMENTAL SETUP B	EXPERIMENTAL SETUP C
CEMENT	PHP 42.12 (6.48 kg)	PHP 42.12 (6.48 kg)	PHP 42.12 (6.48 kg)	PHP 42.12 (6.48 kg)
FINE AGGREGATES	PHP 16.25 (16.08 kg)	PHP 13.82 (13.68 kg)	PHP 11.40 (11.28 kg)	PHP 8.98 (8.88 kg)
TOTAL (12 samples)	PHP 58.37	PHP 55.94	PHP 53.52	PHP 51.10
Price per Piece	PHP 4.86	PHP 4.66	PHP 4.46	PHP 4.26

Table displays the projected expenses for both the control sample and the experimental setup incorporating waste crushed glass (WCG) as a partial substitute for fine aggregates. The experimental setup C, featuring a 45% replacement of waste crushed glass (WCG) for fine aggregates, emerges as the most economical option, priced at just PHP 51.10, compared to the Control Sample, which is priced at PHP 58.37. As shown in the previous data, the compressive strength of all the experimental setups is much larger compared to the control samples. The setup where 30% of waste crushed glass (WCG) partially replaced fine aggregates and underwent a 28-day curing period surpassed the compressive strength achieved by the control sample that was cured for 28 days. Therefore, experimental setup B is strongly suggested as a substitute for the conventional concrete paving blocks mixture. In the control sample, the projected cost amounted to PHP 58.37, whereas experimental setup B amounted to PHP 53.52, indicating a difference of PHP 4.85 between the two setups. Hence, there exists a notable contrast in the cost of formulating concrete paving blocks with WCG as a partial replacement for fine aggregates compared to the standard concrete paving block mixture.

IV. CONCLUSIONS

In conclusion, the “Assessment of Waste Crushed Glass as Partial Replacement for Fine Aggregates in Producing Load-Bearing Concrete Paving Blocks” at varying percentages (15%, 30%, and 45%) revealed several key findings:

1. The experimental setup B with 30% of WCG as a partial replacement for fine aggregates resulted in increased compressive strength.
2. The water absorption level of the experimental setup A, B, and C falls significantly compared to the control sample, indicating that the paving blocks with WCG absorb considerably less water than the conventional paving blocks. This characteristic is beneficial as it reduces the risk of cracking, spalling, and other forms of deterioration.
3. Substituting fine aggregates with WCG results in cost savings, which is particularly beneficial for the efficient production of paving blocks on a large scale. Furthermore, this environmentally friendly approach reduces the ecological impact of glass disposal, contributing to sustainability.
4. The study has determined that it is feasible to utilize WCG as a partial replacement for fine aggregates in producing concrete paving blocks.

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