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Investigation of the Effects of Using Pulverized Mussel Sea Shells and Crushed Glass as Partial Replacement of Fine Aggregates in Producing Non-load Bearing Concrete Hollow Blocks

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Abstract:

The study aims to investigate the use of pulverized mussel sea shells (PMSS) and crushed glass (CG) as partial replacements for fine aggregates in non-load bearing concrete hollow blocks (CHB) in terms of compressive strength, water absorption rate, and density compared to commercial CHB in conformance with ASTM and DPWH standard specifications. An experimental research approach was used for the research design, and results were obtained with the aid of universal testing machines. The study consists of one control sample and three experimental samples with varying percentages of 15%, 20%, and 25% CG and 2% PMSS. The experimental results showed optimal strength with 25% CG and 2% PMSS with a compressive strength of 780 psi, or 5.38 MPa, and water absorption of 8.621% and 1866 kg/m3 at the 28th day of the curing period. Therefore, E.S.-3 is the most suitable design mix proportion for the development of non-load-bearing concrete hollow blocks. The use of PMSS and CG as partial replacements for sand increases the compressive strength, decreases the water absorption percentage, and moderately increases the density of masonry units.

Keywords: **Mussel sea shells, Glass, Fine aggregates, Non-load bearing concrete hollow blocks**

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I. INTRODUCTION

Developing countries invest billions of dollars annually in good infrastructure to achieve economic growth and improve the quality of life. In the Philippines, the construction industry contributes significantly to the national economy. According to a recent study, the construction industry of the country is expected to grow by 7% in real terms in 2023, supported by improving economic conditions and public andprivate sector investment in infrastructure, energy, educational, and healthcare facilities, as well as an increase in tourism and leisure and hospitality activities [1]. This is due to the 16thadministration, wherein there is a centerpiece program, Build! Build! Build! (BBB) that aims to aid the massive infrastructure development of the Philippines [2].

Construction materials are now highly in demand in the Philippines, especially concrete hollow blocks (CHB), which are an important part of the global construction industry. This is a fundamental building material that is always required to build large and sturdy structures. Depending on the intended use, this block is typically made from a mixture of cement, sand, and other materials [3]. Given its market prominence, various changes in the mixtures have been made to improve their compressive strength, which has led to the use of additives or the partial replacement of their materials. Boiler slag, broken glasses, and sawdust are some examples of materials that can be used as additives in the manufacturing of CHB [4]. In this study, the researchers will investigate the effects of using pulverized mussel sea shells (PMSS) and crushed glass (CG) as partial replacements for fine aggregates in producing concrete hollow block (CHB).

A. *Background of the Study*

In the Philippines, concrete hollow blocks (CHB) are one of the most often utilized walling materials. This is due, in part, to their low cost in comparison to other materials. The CHB walls are highly susceptible to lateral loads (typhoon or earthquake pushing or pulling forces). The resistance of CHB to lateral loads can be improved by integrating steel reinforcing bars on both a vertical and horizontal axis. Because of the high demand for high-quality raw materials and CHB in the construction industry, obtaining high-quality raw materials and CHB locally can be difficult [5].

The sand mainly acts as the fine aggregate for the concrete hollow block mixture, which enhances properties of concrete such as thermal expansion, compression strength, and tensile strength. Also, sand is required for various purposes; this can be used for fracking, filtration, metal casting, and glass making. Because of its high demand, illegal sand mining became a widespread issue worldwide, resulting in a scarcity of sand [6]. It is possible that similar local groups in the Philippines are involved in trafficking sand materials. In the Senate of the Philippines, it has been discussed that the country is currently experiencing a shortage of six million units due to the scarcity of materials like sand [7]. Hence, various researchers have tried to use bio-waste materials as an aggregate replacement for the mixture and to produce an eco-friendly and cost-effective CHB. In that way, attention will be given to the different environmental problems facing the country.

According to PCAARRD [8], Green mussel shells (Perna viridis) are generated in huge amounts and discarded as waste materials. The PSA reported a total of 19,228.96 MT production for the Philippines in 2020. Western Visayas led the mussel production with 8,534.16 MT, with Capiz producing 7,945.70 MT. Cavite and Samar are two other high-producing provinces, with 5,654.23 MT and 4,077.14 MT, respectively. Farmed mussel production fell from 26,302.77 MT in 2018 to 19,229 MT in 2020. This can be attributed to its low market value and demand as a result of poor sanitary quality and the occurrence of red tides. Furthermore, other issues confronting the industry include poor quality and unsafe mussels.

Another waste materials is waste glass. According to the New Hampshire Department of Environmental Services, it takes one million years for a glass bottle to decompose in the environment. Glass is extremely fragile and easily fractured. When a glass breaks, the shards end up in the dump, trash, or streams. Annually, approximately 130 million tonnes of glass are produced worldwide. Some types of glass cannot be recycled because some bulbs, sheet glass, windshields, car accessories, and windows contain hazardous materials such as mercury, they cannot be recycled[9].

In the study of Jumaday et al. [10], the suitability of the combination of powdered waste glass and powdered mussel shells as bonding material in the mixture of concrete is addressed because the studies show shells have a calcium carbonate content of 95.6% but 0.73% silicon dioxide [11,12]. On the other hand, waste glass, specifically soda-lime glass, has 72.61% silicon dioxide but only 11.42% calcium carbonate [13]. It also said in the study that the design mixture with 5% partial replacement of Powdered waste glass and 5% partial replacement of Mussel Shell Ash had the highest compressive strength. It has been discovered that the percentage of partial replacement has a significant impact on the compressive strength of concrete. It is also observed that as the partial replacement of both materials decreases, the majority of the results obtained higher compressive strength.

Despite the fact that the researchers were aware of the calcium carbonate and silica content of PMSS and CG, the researchers will conduct further research into its potential contribution in the construction industry. Furthermore, one of the goals of this research is to convert waste into functional materials using the least desirable raw materials in order to address the problems of a short life expectancy of current building materials. The finished product, however, must be tested to ensure that the concept is truly efficient.

B. Review of Related Literature and Studies

B.1. Manufacturing of Concrete Hollow Blocks

A study in the Philippines stated that Concrete Hollow Blocks (CHB) are one of the most common material used in the construction industry. The typical mix contains Portland cement, water, sand, and gravel. It is compacted by high pressure and vibration, making it extremely strong and resistant to heavy loads [2]. It is common knowledge in the construction industry that hollow block sizes in the Philippines have one common lateral area, that is, 20 cm. (8 inches) wide and 40 cm. (16 inches) long. They only differ in thickness, which is now commonly up to 10 cm. (4 inches) and 12.5 cm. (5 inch). The 15-cm. (6-inch) thick size is only available by request [14].

According to Koksal, H.O. et. al [15], the compressive strength of concrete block mainly depends on the mix composition (in particular binder content), the degree of compaction, and to a lesser extent on the aggregate type and curing normally used. In general, for a given set of materials, the strength of concrete block will increase with its density. In the ASTM Standards [16], inadequate curing may cause partial moisture, which will reduce the strength of concrete blocks during compression.Surface cracks may result from incorrect curing, which causes the concrete's surface to dry out quickly. Reduced durability is a result of surface cracking, poor strength, and increased permeability. Improperly cured concrete hollow blocks could not be as resilient to loads and environments as properly cured blocks.

The ASTM International [17], stated that the air gaps in the concrete may become trapped as a result of inadequate compaction. These gaps function as weak spots, lowering the total density of blocks and undermining their strength. A non-uniform distribution of aggregates and cement paste due to inadequate compaction may cause variances in the strength of blocks. Weak zones that are prone to breaking and failing can arise from this lack of regularity. The compressive strength of concrete hollow blocks is reduced by the existence of voids and an uneven construction. Weaker blocks might not be able to withstand structural loads and might be more prone to breaking. Insufficiently compacted blocks could be less resilient to external elements such chemical exposure, abrasion, and freeze-thaw cycles. This may jeopardize the long-term resilience of blocks.

In the study of Verdadero [18], there are several factors that can influence the quality of a concrete hollow block (CHB), such as the quality of materials used in the mixture of CHB. Also, the manufacturing process includes the mixing time, compaction pressure, and curing duration. Even the environmental conditions contribute to the quality of CHB, such as the temperature and humidity conditions in production and curing. The type and condition of the equipment and machinery that are used for mixing, molding, and curing influence the condition of a CHB. In addition, the skills and experience of workers involved in the production process are also factors in the quality standards and efficiency of CHB.

B.2. Technical Specification of Materials in making Concrete Hollow Block

In the specifications of the Department of Works and Highways (DPWH), mortar shall consist of sand, cement, and water that meet the specifications of Item 1046 - Masonry Works, 1046.2.5 Series 2018, combined in a ratio of one (1) part cement to three (3) parts sand by volume, plus enough water to provide the necessary consistency [19].The ASTM C144-1 Specifications for Aggregates in Mortar (2017) specify aggregates as one of the ingredients in mortar. Aggregates are made up of sand, either natural or manufactured. The aggregate must not have more than 50% retained between any two subsequent sieves of those specified in 4.1 more than 25% within 300-µm (No. 50) and 150-µm sieve (No. 100) [20].

B.3. Non-load Bearing Concrete Hollow Block Specification

According to Hassan M., et al. [21], concrete hollow block masonry walls have replaced fired clay brick masonry walls in both developed and developing nations, meaning they are now widely used and play a significant role in the modern building industry. They are used for both load-bearing and non-load-bearing walls, and are particularly valued for their energy-saving, raw material-saving, environmentally friendly, fire-resistant, and low maintenance requirements over the course of their lifetime. Non-load bearing hollow blocks shall have a minimum compressive strength of 500psi (3.45 MPa) and they are used as partition, fences, dividers and walls that has a thickness of 7 to 10 centimeters.

B.3.1. Compressive Strength Test (CST)

The compressive strength test is critical for determining the ability of concrete to bear a load and the point at which failure will occur. Concrete compressive stress can be measured using a variety of techniques, including non-destructive and crushing procedures. Since concrete acquires full strength in twenty-eighths (28) days, it is critical to test it at regular intervals after it is originally poured or molded. It is commonly accepted that concrete will reach three-quarters of its ultimate compressive strength after seven (7) days and will then proceed to harden over time [22].

In determining the compressive strength of a CHB, six randomly selected samples from each mix ratio will be evaluated using a uni-axial compressive load. Steel sheets measuring 10 mm will be fastened to the top and bottom to guarantee even loading. The specimens will be tested at a regulated loading rate of 2.5 mm/min [23]. The Department of Public Works and Highways (DPWH) Item 1046 - Masonry Works, 1046.2.5 Series 2018 and ASTM C-129-Non-load bearing Concrete Masonry Units [19][24], provide extensive specifications for non-load bearing hollow block and solid units that are suitable for constructing non-load bearing walls. The minimum required net area compressive strength for a single unit is 500 psi (3.45 MPa), whereas the average for three units should be 600 psi (4.14 MPa).

B.3.2. Water Absorption Test (WAT)

The water absorption test measures the amount of water absorbed under specific conditions. Water absorption is affected by the type of materials used, the additives utilized, the temperature, and the duration of exposure. The results give insights on the materials' performance in water or humid situations. The specimens are dried in an oven for the prescribed time and temperature before being placed in a desiccator to cool. Immediately after cooling, the specimens are weighed. The substance is subsequently immersed in water at the agreed-upon temperature, typically 23°C, for 24 hours or until equilibrium is achieved. The specimens are removed, dried using a lint-free cloth, and weighed [25].

To determine the water absorption rate of a CHB, three (3) full-sized concrete hollow blocks must be thoroughly immersed in clean water at the ambient temperature for 24 hours. The blocks will then be withdrawn from the water and allowed to drain for one minute before being placed on a 10 mm or coarser wire mesh, with visible surface water removed using a damp towel. The submerged and surface dry concrete hollow blocks will be weighed immediately. After weighing, all blocks must be dried in a vented oven at 100 to 1150 degrees Celsius for at least 24 hours and until two subsequent weighing at 2-hour intervals demonstrate an increment of loss of no more than 0.2 percent of the specimen's last previously calculated mass [2]. Furthermore, according to Table 1046.2 of the DPWH, the highest allowable water absorption rate of CHB is 240 kg/m³ [19]. The American Society for Testing and Materials (ASTM) standard for maximum water absorption tests is 24.01% [26].

B.3.3. Weight Classification Test (Density)

The unit weight of concrete, or the weight of a given volume of concrete, is an important factor that determines the material's strength and performance. The unit weight must be determined in order to compute the self-weight of construction material and the quantity necessary for quality control purposes. The unit weight of concrete is mostly determined by the unit weight of the aggregate used, including fine particles, which might vary geographically and affect the overall density of the concrete. A larger unit weight of concrete often leads to a higher compressive strength. Furthermore, denser concrete with a higher unit weight has fewer voids and porosity, making it less susceptible to water penetration and deterioration. However, the unit weight of concrete has no direct impact on its workability because it is governed by parameters such as the water-cement ratio, aggregate grading, and additive inclusion [27].

To determine the density of a CHB, three (3) blocks must be dried to a consistent mass in a suitable oven at around 1000 degrees Celsius. After the blocks have cooled to room temperature, the dimensions of each block must be measured to the closest millimeter, and the overall volume calculated in cubic centimeters [23]. According to DPWH Specifications Item 1046.2.11.2, Table 1046.3, for the non-load bearing CHB, the oven dry density of concrete (kg/m³) for the average of 3 units determines the density classification for lightweight masonry units. Lightweight masonry units have a density less than 1680 kg/m³, whereas medium weight unit classified within the range of 1680 kg/m³ to less than 2000 kg/m³ [19].

C. Costing of Concrete Hollow Blocks

According to ConstructPH, the use of a variety of CHB-making equipment, depending on the output, can produce concrete hollow blocks. The materials areusually Portland cement and aggregate, sometimes sand and fine gravel, that are available in the market. There are also materials such as industrial waste and biodegradable waste. The cost of a CHB varies depending on the materials used, the location of the manufacturers, the ratio of the CHB mixture, equipment and labor costs, and mass production and demand. The updated price of a CHB per piece in the Philippine market ranges from Php 14.00 to Php 55.00, depending on its strength and size [28].

D. Sand Utilization

Sand mining is a widespread but often overlooked issue worldwide, causing a scarcity of sand due to its high demand. In the Philippines, this problem persists, with illegal black sand mining being prevalent, driven by the desire to obtain valuable magnetite iron ore. Such activities, like sand mining, heighten the dangers and scale of threats, including land subsidence from erosion, and leave coastal communities vulnerable to rising sea levels and typhoons. [6]. Moreover, sand is acquired and mined for various purposes; this material can be used for fracking, water treatment (filtration), metal casting, and making glass, silicon chips, and ceramics [29], but the greatest use of sand is for fine aggregate in concrete [7] [29], in which countries like China, India, Singapore, Malaysia, Thailand, Vietnam, and the Philippines are characterized by significant demands for construction, which naturally translates to substantial requirements for sand [29]. As the demand for such resources continues to rise, the supply of sand is dwindling, leading to the emergence of "sand mafias" in various parts of the world. It's possible that similar local groups in the Philippines are involved in trafficking sand materials. In the press release in the Senate, Senator Recto points out the misconception that sand is abundant everywhere and therefore cannot be depleted. This belief is erroneous because sand is not infinite. He highlights that the country is currently experiencing a shortage of six million units due to the scarcity of materials like sand. Hence, he proposes implementing a policy against sand exports to prioritize the use of local sand resources within the country [7].

Waste Materials

E. Pulverized Mussel Sea Shell as Construction Material

According to Eziefula et al. [30], utilizing calcined mussel sea shells in construction helps to maintain the environment in addition to preserving natural resources. Costs are decreased when materials are reused because there is no need to landfill, dispose of rubbish, or purchase new resources. It indicates that when the expenses of transportation, storage, and processing are lower than those of using standard aggregates, employing by-products of sea shell as recycled materials in concrete is more cost-effective.

According to El Biriane & Barbachi [31] Due to the significant amount of waste generated by bivalve aquaculture and the related waste management challenges, sea shell waste, particularly mussel shells, has been recognized as a viable substitute for traditional concrete components. Researchers have studied the viability of employing sea shell waste as a replacement for standard aggregates or cementitious materials in concrete design as a means of decreasing the concrete industry's environmental effect. They also discovered that utilizing mussel shell can lower the amount of air in the created combinations while increasing their tensile and compressive strength.

In the study of Ismail et al. [32], Green mussel shell ash (GMSA) has a lower specific gravity than ordinary Portland cement (OPC), therefore it presents the potential of being an additive to the concrete mixture. The study was tested by trial and error setting the quantity of the addition of the GMSA into percentages of 1%, 2%, 3%, and 4%, which are compared to OPC. All the added GMSA attained the target compressive strength of 30 MPa, however, the 2% admixture achieved a significant result of 42.75 MPa, 52.6 MPa, and 54 MPa for 7, 28, and 60 days respectively, exceeding the compressive strength of OPC. Adding GMSA also reduced the setting time formation of carboaluminate in the cement particles. The research also determined the particle size distribution of the GMSA and OPC. GMSA size was discovered to be finer than an OPC, having a size of 8.284μm compared to OPC that have 18.187μm. This means that GMSA will offer a quicker reaction of the hydration process to a more focused surface area, which will lead to a rapid increase in concrete strength. The tensile strength and capillary water absorption of the mixture with 2% GMSA offered significant results compared to the OPC. As the GMSA % increases, the workability of the mixture decreases. Concluding the use of further water to preserve their pre-determined workability.

In the study of Lejano et al. [33], Green mussel shell (GMS) has a lower specific gravity than ordinary Portland cement (OPC), therefore it presents the potential of being an partial replacement of cement for the concrete hollow blocks mixture. The study was tested by trial and error setting the quantity of the addition of the GMS into percentages of 10%, 20%, 30%. All the added GMS attained the target compressive strength of 3.24 MPa, 3.14 MPa, and 3.61 MPa respectively, therefore, the 30% partial replacement achieved the highest compressive strength

According to Sainudin et al. [234], Mussel Shell Ash (MSA) has the potential to be a portion replacement in Ordinary Portland Cement (OPC) due to its physical properties. The MSA has a size of 9 μm to 43 μm and is significantly lower than OPC. MSA has a 10.48% lower specific gravity compared to OPC. MSA also contains 71.5% calcium oxide compared to OPC which has 57.2%. This indicates that MSA can reduce porosity, performing a higher hydration reaction process for a shorter setting time and increase strength and durability. The evaluation processed 4 different tests varying their percentages of 0%, 3%, 5%, and 7%. The more MSA dosage the concrete receives, the lesser the compressive strength attained, however in 28 days of curing all the tests reached the target strength of 35MPa. On 60 days of curing, the mixture that has 3% MSA achieved the highest results from compressive strength and split tensile strength.

According to the findings of Punthama et al. [35], sea shell waste can be used to substitute cement in mortar mixes because all mortars containing sea shell waste produced appropriate strength, reduced shrinkage with drying, and lower thermal conductivity than traditional cement. Waste from green mussels and cockles, glass, and cement scraps were used as ingredients needed to produce concrete bricks by partial substitution of Type Portland cement 1 using leftover cement, sea shells, and substituting some of the sand with glass scrap.

F. Crushed Glass as Construction Material

According to Yang et al. [36], due to its physical and chemical properties, glass is regarded as the most acceptable alternative among the numerous types of industrial waste as an aggregate. In addition, prior research has demonstrated that recycled glass may be appropriate for use in various applications, such as concrete, bricks, and highway engineering projects.

It stated in the study of H.A. Safarizki et al. [37], in determining the optimal composition of glass powder as a partial replacement for sand in relation to concrete compressive strength, the glass powder mixture used has a content of 10%, 15%, 20%, and 30% of the amount of sand in the concrete mixture. At 28 days, concrete compressive strength testing is performed. The results of the concrete compressive strength test revealed that the optimum value is 22.8 MPa with a 15% variation in glass powder content. At 15% coarse glass powder, glass powder works well as a partial sand substitute, because the addition of glass powder variations to the weight of the sand increases the compressive strength of the concrete. The increase occurred at 15% variation in coarse glass powder by 22.8 MPa and 30% in mixed glass powder by 21.12 MPa.

According to D. B. Eme and C. Nwaobakata [38], the powdered glass was used as admixture, replacing cement in the concrete production process. The result showed that workability increases with an increase in admixture content. It further revealed that the compressive strength increases with admixture addition to about 4% powdered glass addition. The compressive strength at 6% addition of powdered glass was also higher than that of the conventional concrete. Thus, replacement can be done to about 6% addition of powdered glass by weight of cement.

In the study of Afshinnia and Rangaraju [39], they compared the workability of concrete with plain Portland cement and with an incorporated cement mix with pulverized glass. Glass powder was used to replace a portion of 20% as concrete aggregate improving the mechanical and fresh properties of the concrete. They stated that the glass powder has the potential to improve the splitting tensile and compressive strength and also reduce the air content of the homogeneous mixture to its negligibly limit compared to a plain Portland mixture.

According to Guatam S.P. [40], when waste glass is used as a partial replacement for fine aggregate, 28 days strength is found to increase marginally up to a 20% replacement level. At 30 days to 40% replacement level of waste glass with fine aggregate, there is a marginal decrease in strength. Waste glass can be used effectively as a fine aggregate replacement. The optimal level of waste glass replacement as fine aggregate is 10%.

G. Synthesis

The strength capabilities of a concrete hollow block mixture, particularly its compressive strength, can be significantly altered by replacing portion of fine aggregates. In addition to other components being included in the mixture, it can vary in terms of curing time, partial replacement or additive, and mixing ratio that can be managed in different tests. The utilization of PMSS and CG in concrete and concrete hollow blocks in earlier research provides guidance for future research and clarification of recorded adjustments. With this resource available, more research on the benefits of utilizing PMSS and CG in the production of building materials can be modified and developed. Furthermore, because a concrete hollow block with a combination of PMSS and CG as a partial replacement for fine aggregates has yet to be published and it opens up the opportunity to new discoveries and knowledge improvements.

II. METHODOLOGY

A. Research Design

This study will use a scientific experimental research design to make concrete hollow blocks with Pulverized Mussel Sea Shells (PMSS) and Crushed Glass (CG) as a partial replacement for sand. To achieve a successful result, the researchers will collect data and testing materials by investigating the properties of each material.

B. Raw Materials

B.1. Mussel Sea Shell (Perna Viridis)

Mussel Sea Shell is one of numerous invertebrates in the class Bivalvia of the Phylum Mollusca. They are bivalve mollusks with an asymmetric and elongated shell form and they are vivid green to dark brownish-green periostracum and pearly white to iridescent blue internal shell valves. The mussel sea shells will be pulverized and sieved before being collected as the major materials for the experimental sample mixture.

Fig. 1 Mussel Shell [42]

B.2. Glass

Soda lime glass or Flint glass is a clear glass that is used as containers, bottles, and jars for beverages and food. This is one of the main raw materials used in this study for the reinforcement of sand in producing concrete hollow block.

Fig. 2 Glass [43]

C. Preparation of Raw Materials

This study used waste materials as a partial replacement for sand in producing concrete hollow blocks, and the materials were obtained within Pampanga. The Mussel Sea shells will be cleaned and washed to separate the excess flesh or meat from the shell. On the other hand, alcoholic glass will also be washed and cleaned to remove the plastic and paper that are attached to it. Afterwards, these materials are set to dry in a sun-drying process in preparation for crushing and pulverization.

D. Pulverization and Crushing of Waste Materials

After gathering and cleaning the materials needed to create the hollow blocks, the researchers will locate the best area to crush and heat the mussel sea shells and collected glasses. In the crushing of glass bottles, the researchers will wear protective eyeglasses and gloves throughout the process to prevent accidents and injuries, and then they will place the glass bottles in a sack and re-insert another bag to ensure that no one gets injured during the procedure. The other participants in this experimental study will begin breaking the bottles with a mallet, and once cracked, they will be placed in another sack bag to be crushed further by the researchers using a hammer. The next thing that the researcher will do is to sieve the crushed glass in a No. 30, (0.60mm) sieve mesh screen to filter and separate the refined glass from the big chunk glass, then put the refined crushed glass in a container.

On the other hand, the mussel sea shells will be calcined before pulverizing, as mussel shells become brittle when heated. After heating the mussel shells, they will be placed in a sack and smashed into pieces with a hammer, similar to how glass bottles are crushed. They are then placed back into the sack to be crushed even further until they form into powder. The remaining shells that have not gone to powder will be reheated until brittle, and then crushed again by the researchers.

E. Production Process of CHB

E.1. Proportioning

The researchers will set a ratio and proportion for the concrete hollow block (CHB) mixture. In Table 4, shows the ratio and proportion of the 4 different samples, conforming to the DPWH Standard Specification for Masonry Works, Item 1046.2.5. Series of 2018 which is the 1:3 ratio. The control sample mixture contains a 40kg of cement and 120kg of fine aggregates. The ratio and proportion in sample E.S.-1 is 40kg of cement, 99.6kg of sand, 2.4kg of PMSS, and 18kg of CG. In E.S.-2, the ratio and proportion are 40kg cement, 93.6kg of sand, 2.4kg of PMSS, and 24kg of CG. Lastly, the ratio and proportion of E.S.-3 is 40kg of cement, 87.6kg of sand, 2.4kg of PMSS, and 30kg of CG. All the samples of CHB will be cured on different days, which are seven (7), fourteen (14), and twenty-eight (28) days.

TABLE 1: Ratio and Proportion

RAW MATERIALS	DESIGN PROPORTIONING BY WEIGHT (KILOGRAM)			
	CONTROL	E.S.-1	E.S.-2	E.S.-3
SAND	120kg	99.6kg	93.6kg	87.6kg
CEMENT	40kg	40kg	40kg	40kg
PMSS	0	2.4kg	2.4kg	2.4kg
CRUSHED GLASS	0	18kg	24kg	30kg

E.2. Mixing and Molding

After measuring the PMSS and CG by following the designed ratio and proportion, the constituents will be thoroughly mixed until they achieve a homogeneous mixture. There will be three different mixture proportions of blocks, wherein CG has a varying percentage of 15%, 20%, and 25%, while PMSS has a distinct percentage of 2%. There will be no definite water-cement ratio since it will only be needed to provide the necessary consistency. The homogeneous mixture will be placed in a 4" CHB molder machine and will be manually vibrated to ensure that the specimen is fully compacted and to avoid air pockets with mortar, which will result in a good-quality product. After molding, the CHB will be transferred to a cool area for curing.

E.3. Curing

The molded CHB will be cured to determine the maximum strength of the block that will be achieved. In this study, the curing days of CHB will be in a span of 7, 14, and 28 days. Water will be sprinkled on the specimen blocks for at least twice (2) a week. Twelve (12) blocks will be carried out to the testing center to test their compressive strength within the said curing days.

F. Testing of Concrete Hollow Blocks (CHB)

To accurately produce the necessary data, the researchers will manufacture three (3) test samples for each type of specimen within the curing time. The total number of samples needed to produce and assess is forty-eight (48) CHB; thirty-six (36) samples for the Compressive Strength Test (CST), twelve (12) samples for the Water Absorption Test (WAT). These samples will be cured in seventh (7th), fourteenth (14th), and twenty-eight (28th) days. The following table shows the number of samples needed based on the designated type.

TABLE2: Research Sample

Sample	PMSS & CG	Curing Time	CST & WAT	No. Of Sample
CTRL	0%	7	4	12
		14	4	
		28	4	
E.S.-1	2%-15%	7	4	12
		14	4	
		28	4	
E.S.-2	2%-20%	7	4	12
		14	4	
		28	4	
		7	4	

E.S.-3	2%-25%	14	4	12
		28	4	
TOTAL NUMBER OF SAMPLES				48

F.1. Compressive Strength Test

Hollow blocks are widely used worldwide and are required to have the property to withstand different loads and to appropriately function for distinct uses. Compressive strength is the major characteristic that a hollow block must have. Concrete compressive strength test will determine the behavior of any concrete materials that will satisfy the American Society for Testing and Materials (ASTM) standards C129-11. For non-load bearing hollow blocks, the minimum required strength is 600 psi for an average of three units and 500 psi for individual units [24].

a) The researchers will prepare 4 sets of CHB with 3 specimen per set to the testing center.
b) The 12 specimens will be tested individually on the compression testing machine.
c) The maximum compressive strength of the CHB specimens were evaluated by following the formula.

$$\text{Compressive Strength} = \frac{\text{Maximum load of failure}}{\text{Net Area}}$$

Eq. 1: Compressive Strength formula (PSI or MPa)

F.2. Water Absorption Test

According to Table 1046.2 of the DPWH Standard Specification, the maximum water absorption for lightweight masonry materials is 288 kg/m³ for average of three units and 320 kg/m³ for individual units, while the maximum water absorption for medium-weight masonry materials is 240 kg/m³ for average of three units and 272 kg/m³ for individual units, whereas the maximum water absorption for normal weight masonry materials is 208 kg/m³ on average and 240 kg/m³ for individual units [19].

The water absorption rate of the exterior and interior concrete surfaces is ascertained by the water absorption test. The American Society for Testing and Materials (ASTM) standard for maximum water absorption tests is 24.01% [26]. All the samples will be compared to the standard mixture. The researchers used the following formula to obtain the absorption rate of the samples:

$$\text{WAR} = \frac{\text{Wwet} - \text{W} - \text{dry}}{\text{Wdry}} \text{x100}$$

Eq. 2: Water Absorption Rate (WAR) formula (%)

Wwet = weight of the soaked sample
Wdry = weight of initial/dry sample

F.3. Weight Classification of Concrete Hollow Blocks (Density)

The researchers will investigate the effects of Pulverized Mussel Sea Shells (PMSS) and Crushed Glass (CG) on the weight of CHB. The weight of the four (4) CHB will be measured using a digital weighing scale for each day of curing. The researchers will calculate the volume by measuring the length, height, and dimensions of the holes in centimeters and converting them to meters to determine the volume of CHB. To calculate the gross area in square meters, multiply the length and width of the blocks measured in meters. The researchers will calculate the Net Area by subtracting the gross area from the area of the holes in the CHB. Finally, the bulk density of the CHB will be determined by dividing each block's observed weight by its dimensional volume.

a) Dimensions to be measured:
Conversion Factor:

1m = 100 cm

Length of CHB (cm), Width of CHB (cm) and Height of CHB (cm)

b) The formula for solving the Gross Area of CHB will be expressed as:

$$\textbf{Gross Area of CHB } (\mathbf{m^2}) = \textbf{Length of CHB (m) x Width of CHB (m)}$$

Eq. 3: Gross Area of CHB formula (m^2)

c) The formula for solving the Net Area of CHB will be expressed as:

$$\textit{Net Area of CHB} = \textit{Gross Area of CHB} - 3\,(\textit{Area of Inner Hole}) - 2\,(\textit{Area of Outer Hole})$$

Eq.4: Net Area of CHB formula (m^2)

d) The mathematical formula will be expressed as:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Eq. 5: Density of Concrete Hollow Blocks formula (kg/m^3)

The researchers will classify the weight of a CHB conforming to the DPWH Standard Specification Item 1046 - Masonry Works. An Oven-Dry CHB with a density of less than 1680 kg/m^3 will be classified as lightweight CHB. An Oven-Dry CHB with a density of 1680 kg/ to less than 2000 kg/m^3 will be classified as medium-weight CHB. Lastly, an Oven-Dry CHB with a 2000 kg/m^3 or more density will be classified as normal-weight CHB [19].

G. Costing

To determine the cost of the experimented CHB, the researchers will calculate the price of CHB based on the market prices of the materials used in the control and experimental samples. Thereby, the researchers will differentiate the definite cost of the standard CHB under the DPWH standards from the modified CHB in this study excluding the cost of the equipment and labor in the manufacturing process.

a) A total of 400.8kg of sand, and 4 sacks of cement that weighed 40kg per sacks, will be purchased in the market.

b) The sand that can be sold in the hardware is measured by cubic meters. Therefore, the researchers will convert the cubic meter into kilogram.

Conversion factor:

$$1\text{m}^3 \text{ of sand} = 1680\text{kg}$$

The formula for solving the Cost of Sand per kilogram for each experimental sample will be expressed as:

$$\text{Cost} = \frac{\text{Cost of Sand}}{1\text{m}^3} \times \frac{1\text{m}^3}{1680\text{kg}}$$

Eq. 6: Cost of Sand per kilogram formula (Php)

c) The researchers will determine how many will be able to produce CHB using the mixture ratio of DPWH Standard Specification 1046-4, which is the 1:3 ratio.

d) The equation that will be used to obtain the cost of CHB per piece will be expressed as:

$$\text{Cost of CHB} = \frac{\text{Sand} + \text{Cement}}{\text{No. of CHB}}$$

Eq.7: Cost of CHB per piece formula (Php)

III. RESULTS AND DISCUSSION

This chapter presents the results obtained from the mechanical operations conducted in the study. The results are displayed through tables and graphs, which include data analysis and interpreted outcomes in alignment with the objectives of the study. Three (3) mechanical tests were conducted during the preparation of this paper: the Compressive Strength Test, Water Absorption Test, and Weight Classification Test.

A. *Compressive Strength Test*

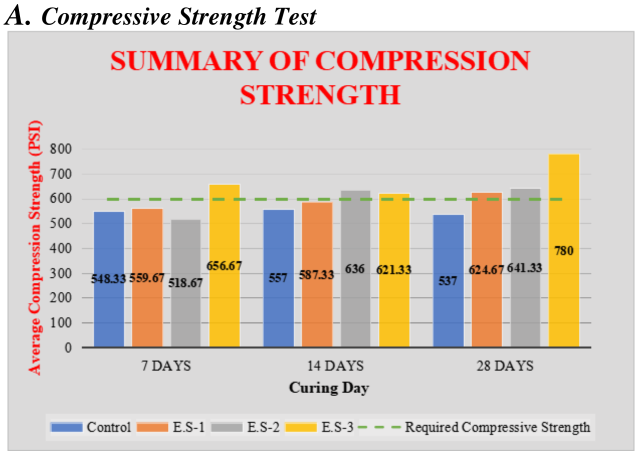

Fig. 3 Bar Graph Summary of Compressive Strength Results

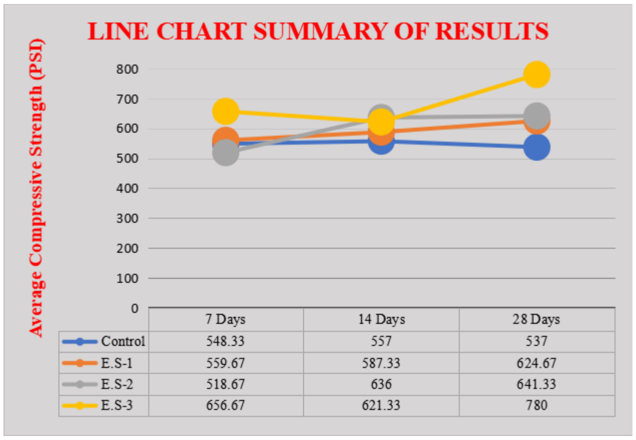

Fig. 4 Line Graph Summary of Compressive Strength Results

The results showed that the E.S.-1 and E.S.-2 on the seventh(7th) and (14th) days of curing have a big difference in compressive strength. However, the E.S.-3 which contains 2% PMSS and 25% CG dominated all the data in the curing days of seven (7) and twenty-eight (28) days of curing time with an average of 656.67 psi or 4.53 MPa and 780 psi or 5.38 MPa respectively. The remaining experimental samples are also consistent in increasing compressive strength exceeding the control samples. It is also noticeable that the average of the control sample on the twenty-eight(28th) day of curing is the lowest among all the data including its two curing periods. In conclusion, the E.S.-3 which has 2% PMSS and 25% CG is the optimum ratio in terms of compressive strength test conforming to the DPWH specifications.

Both studies, one by H.A. Safarizki et al. [37] and the study of the researchers examine the effect of material composition on concrete strength by looking at the compressive strength data of CHBs. H.A. Safarizki et al. discovered that the concrete reached an optimal compressive strength of 22.8 MPa at a 15% variation in glass powder content, indicating the usefulness of glass powder as a partial sand substitute. Similar findings were foundin this study, where researchers found that E.S.-3, which contains 25% CG and 2% PMSS, has a higher compressive strength than other formulations; values reached 5.38 MPa, or 780 psi, after 28 days of curing. The importance of material proportions in improving concrete strength—whether by optimizing PMSS and CG ratios or by adding glass powder—is highlighted by both investigations.

With the exception of a few CHB samples, the results were satisfactory. Same results for the control sample used in the study; despite the fact that the researchers followed the standard ratio and proportion for the CHB mixtures, it still did not pass the required compressive strength based on the DPWH standards. As stated in the study by Verdadero [18], there are several factors that can affect the quality of CHB during the production process. The failure may have been brought on by inconsistencies in the vibration-assisted molding process, gaps in the curing process, or the uneven surface of the CHB samples.

B. Water Absorption Test Results

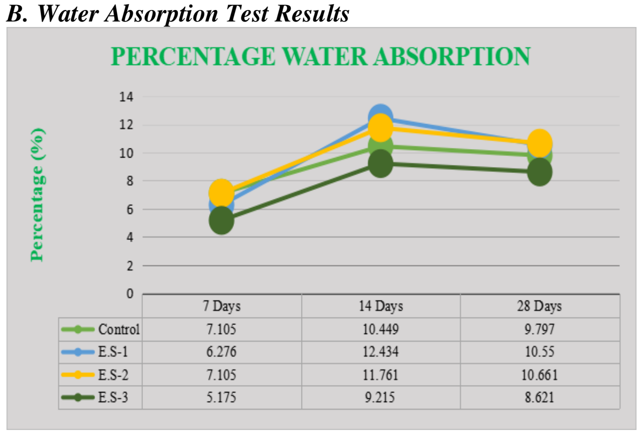

Fig. 5 Line Graph Summary of Water Absorption Test Results

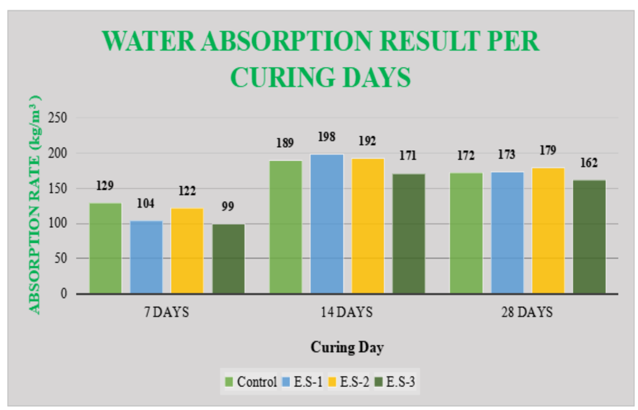

Fig. 6 Water Absorption Test Results (kg/m^3) Per Curing Days Conforming to the DPWH Standard Specification Table 1046.2 - Masonry Works

SAMPLE	RAW MATERIALS	WEIGHT (kg)	PRICE (Php)	TOTAL PRICE (Php)	PRICE OF CHB PER PIECE
CONTROL	SAND	120	0.268/kg	32.16	Php 10.659
	CEMENT	40	213/ sack	213	
	PMSS	0	0	0	
	CG	0	0	0	
E.S. - 1	SAND	99.6	0.268/kg	26.693	Php 10.421
	CEMENT	40	213/ sack	213	
	PMSS	2	0	0	
	CG	24	0	0	
E.S. - 2	SAND	93.6	0.268/kg	25.085	Php 10.352
	CEMENT	40	213/ sack	213	
	PMSS	2	0	0	
	CG	24	0	0	
E.S. - 3	SAND	87.6	0.268/kg	23.477	Php 10.282
	CEMENT	40	213/ sack	213	
	PMSS	2	0	0	
	CG	30	0	0	

TABLE3: Cost of CHB per piece for each Experimental Sample

The results showed that the control and the three (3) experimental samples of CHB in all curing days passed the required water absorption rate of ASTM and DPWH standard specifications. However, the results showed that the CHB on the fourteenth (14th) day garnered the highest water absorption rate. On the fourteenth (14th) day of curing, concrete hollow blocks might exhibit higher water absorption percentages due to several factors. One major reason is that although the concrete has undergone initial hydration and gained some strength during the first two weeks of curing, it has not fully reached its maximum strength or density yet. This means there are still more pores and capillaries in the concrete matrix that can absorb water. Additionally, inadequate curing conditions, such as insufficient moisture or temperature fluctuations, can hinder the concrete's ability to develop optimal strength and density, leading to higher water absorption rates.

Nonetheless, in this study, it can be concluded that the efficacy of the E.S.-3 sample in reducing water absorptionconsistent with both sets of criteria, despite variations in the defined limitations and testing protocols of the ASTM standards and DPWHstandard specifications.

C. Weight Classification Test Results

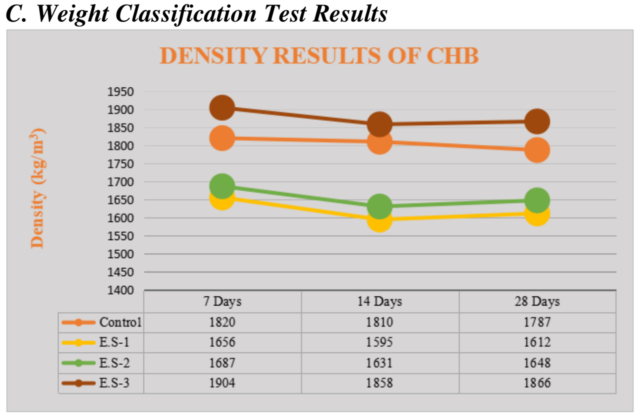

Fig. 7 Density Results of CHB Per Curing Days

The results showed that the control and the three (3) experimental samples of CHB in all curing days passed the required weight for non-load bearing concrete hollow blocks conforming to the DPWH Specifications Item 1046.2.11.2, Table 1046.3. The E.S.-1 in all curing days was classified as lightweight CHB, while the E.S.-2 was classified as medium-weight CHB in 7 days of curing and lightweight CHB in 14 and 28 days of curing. The control sample and E.S.-3 were classified as medium-weight CHB in all curing days. Therefore, the E.S.-1 is the lightest CHB among the experimental samples, while the heaviest is the E.S.-3 among the experimental samples in all curing days.

D. *Costing of CHB*

The researchers purchased the raw materials in the hardware, such as cement, which cost Php 213.00 per sack and weighed 40kg, and sand, which cost Php 450.00 per cubic meter and Php 0.268 per kilogram. On the other hand, the bio-waste materials used in this study, such as the pulverized mussel sea shells (PMSS) and crushed glass (CG); are obtained within the vicinity of Pampanga for free, which cost the researchers Php 0.00 for the bio-waste.

The results showed that all of the experimental samples were more cost-effective than the control samples. Also, conforming to ConstructPH, which shows the price of CHB [28], it showed that the three (3) experimental samples are approximately Php 2.00 cheaper than the ordinary 4" CHB in the market. Based on the compressive strength, the E.S.-1 and E.S.-2 throughout the duration of curing with a 500 psi to 600 psi compressive strength are approximately Php 14.00 cheaper than the 500 psi 4" CHB in the market. While the E.S.-3 in its 7th and 14th days of curing with a strength of 600 psi is Php 14.00 or more cheaper than the 500 psi 4" CHB in the market, Moreover, the E.S-3, on its 28th day of curing with a strength of 700 psi, showed that it is approximately Php 19.00 cheaper than the 700 psi 4" CHB in the market.

IV. CONCLUSION

The researchers observed changes in the compressive strength of non-load-bearing CHB samples over seven (7), fourteen (14), and twenty-eight (28) day curing periods. All experimental samples surpassed the control sample in compressive strength, despite using just 2% PMSS. Notably, E.S.-3 consistently outperformed other experimental samples, achieving the highest compressive strength on the seventh (7th) and twenty-eighth (28th) days of curing with 2% PMSS and 25% CG. Although E.S.-3's strength slightly decreased on the fourteenth (14th) day, it still met DPWH standard specification criteria. Furthermore, E.S.-2 with 20% CG and 2% PMSS outperformed the control sample in compressive strength on day fourteen (14). After summarizing the data, E.S.-3 emerged as the ideal ratio for compressive strength, meeting DPWH requirements. Overall, the results were satisfactory, demonstrating the efficiency of experimental combinations in increasing compressive strength, except for a few CHB samples.

The water absorption of all CHB specimens over seven (7), fourteen (14), and twenty-eight (28) days revealed its significant impact on durability and compactness. E.S.-3 outperformed the control and other experimental samples on the seventh (7th) day, exhibiting the lowest water absorption percentage at 5.175%. All samples adhered to the ASTM standard's maximum water absorption of 24.01%. Similarly, E.S.-3 continued to meet ASTM criteria on day fourteen (14) with a water absorption rate of 9.215%. By day twenty-eight (28), E.S.-3 maintained its superiority, absorbing water at a rate of 8.621%. Moreover, E.S.-3 demonstrated efficiency in a water absorption test conforming to DPWH Standard Specification (Table 1046.2) requirements of a 240 kg/m³ water absorption limit. E.S.-3 exhibited the lowest water absorption in the seventh (7th), fourteenth (14th), and twenty-eight (28th) curing periods: 99 kg/m³, 171 kg/m³, and 162 kg/m³, respectively. These results confirm E.S.-3's effectiveness in reducing water absorption and improving CHB durability, aligning with both DPWH and ASTM standards. The consistent performance of E.S.-3 across multiple testing periods underscores its potential to successfully reduce water absorption and meet industry standards, even amidst varying standards and testing techniques. However, the compressive strength and water absorption rates of the blocks did not uniformly improve as the curing period progressed. Various outcomes could be attributed to the curing and handling of the blocks.

In the density test, E.S.-1, which contained 2% PMSS and 15% CG as a partial replacement of sand, exhibited the lowest density in all curing periods, while E.S.-3, with 2% PMSS and 25% CG, demonstrated the highest density across all periods, yet still classified as medium-lightweight CHB based on the DPWH standards. These results indicate that an increase in CG replacement correlates with higher CHB density. Analyzing the cost of all CHB specimens revealed that the experimental samples were slightly more cost-effective than the control samples. Specifically, E.S.-3 had the lowest cost among the experimental samples, priced at PHP 10.282. This suggests that higher CG substitution for sand leads to lower CHB production costs.

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