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Characterization and Performance Evaluation of Masonry Hollow Blocks (MHB) Mixed with Clay from Two Sites in Bicol, Philippines

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Abstract

Objective: To investigate the impact of the use of local clay in partially replacing cement on compressive strength and physical properties of masonry hollow blocks (MHB) in the Bicol region, Philippines. This is to come up with sustainable and cost-effective materials to be applied in the non-load bearing masonry blocks without jeopardizing the required minimum strength. **Methodology:** Two types of clay (Plasticity Index = 13.95 and 20.65) were used and 0%, 5%, 8%, and 12% of clay substituted by weight with water-cement ratio maintained at 0.5. Molding of three block specimens of each mix were cured at 28 days, and the specimens were tested based on the American Society for Testing and Materials (ASTM) standards as: water absorption, moisture content, dry density and compressive strength. **Results:** As the percentage of clay replacement increased to 12% the percentage of water absorption also increased to 3.70% and the percentage of dry density reduced to 0.672%. Compressive strength revealed that both the control (4.35 MPa) and treatment B with Pulang Daga clay of 5% replacement (4.23 MPa) met the minimum required strength of non-load bearing concrete hollow blocks of 4.14 MPa. Among the varieties of the clay, Pulang Daga clay blends a higher retention of strength at the same level of substitution. **Novelty:** This is the first study to provide empirical region-specific data on the use of Bicol clays in the replacement of partial cement for MHB, as far as the knowledge is concerned. It demonstrates that it can be substituted with clay without violation of the norms. The outcomes demonstrate a more sustainable and cost- efficient construction method that will potentially reduce the cement dependency and carbon footprint of the resource scarce rural regions.

Keywords: Masonry hollow blocks; Lightweight concrete; Clay properties; Concrete blocks performance; Clay substitute

1 Introduction

Geotechnical assessment of soil characteristics is not only an essential field of civil and structural engineering, but also the safety, stability, and functionality of structures erecting on the soil depend on geotechnical behavior. During the last several years, a growing interest is paid to sustainable construction principles, especially the utilization of the local materials which should be used to partially substitute cement in the building parts [1]. Ordinary Portland cement (OPC) production is a leading source of greenhouse gases, so developing feasible alternatives has become a significant research interest in the material science of construction works [2].

Clay-based materials have been reconsidered as one of the possible alternatives due to their availability and pozzolanic properties. Research has shown that partial replacement of cement with either brick or clay powder may help lower the cost of production and carbon emissions, without causing significant structural changes. Indicatively, a 2021 study concluded that, by substituting cement with a maximum of 20 percent of brick and clay powder, the compressive strength of composite materials was not only acceptable, but also thermal resistance was improved [3]. Similarly, an experimental study on hybrid concrete blocks with sawdust and calcined clay, carried out in 2024, claimed that a moderate replacement with clay led to better sustainability without significant effects on the satisfactory mechanical performance of the concrete blocks [4]. Notwithstanding these developments, curing behavior, density, and water absorption properties of most of the research have focused on concrete mixes and not the masonry hollow blocks (MHBs).

Subsequent research on crushed clay brick aggregates and fines recycling highlighted the possibility of the clay-based additives to increase the workability and sustainability of concrete [5]. The findings of these studies are however different in many studies because of differences in soil plasticity, mineral composition and curing conditions hence it is not easy to ensure that the findings can be applicable to particular local situations. In the Philippines, such as, where clay deposits are quite numerous, they differ widely in plasticity and mineral composition. Nevertheless, very little research has been carried out on the effect of locally obtained clays on the geotechnical and structural characteristics of masonry materials. The current literature focuses on agricultural waste or recycled plastics as additives, whereas there is a gap in the knowledge about the mechanics of natural clay aggregates in MHB production.

The study aims at filling these gaps by exploring the geotechnical characteristics and engineering behaviour of MHBs fabricated using locally available clay at two locations within the Bicol Region in the Philippines. In particular, it studies how the levels of different clay contents (0, 5, 8 and 12%) influence compressive strength, water absorption, density, and moisture content. The originality of the study is that the research is region-specific as it finds an empirical correlation between the plasticity of the local clays and the mechanical behaviour of masonry block. The results will offer a viable and cost-effective approach to non-load-bearing construction materials, which will satisfy the national standards in construction strengths and will also encourage green construction activities in the Philippines building sector.

2 Methodology

The research work was developed to describe and understand the behavior and application of using clay to produce masonry hollow blocks for non-load bearing masonry walls and partitions. Primarily, the experiment aimed to evaluate the properties of clay aggregate and test its effect on the compressive strength of MHB. Standard laboratory tests were employed to analyze the effects of clay derived from two sites in Bicol, Philippines, on the material composition, water absorption, moisture content, density, and comprehensive strength. The moisture content, specific gravity, grain size distribution, and Atterberg's limits of the clay aggregates collected were also determined.

2.1 Study Site

Clayey soils are common in certain regions of the country including the areas of Tiwi, Albay and Pulang Daga, Balatan, Camarines Sur. Tiwi is located at the northernmost boundary of the province of Albay, Bicol Region, with a total land area of 11,628 hectares and subdivided into 25 barangays. There are two major soil types in Tiwi- the clay soil called Louisiana and the Malinao sandy loam, which is of volcanic origin. The sandy loam which is good for agriculture can be found in 14 barangays, while the clay soil is found in 11 barangays which is suited for bricks, pottery, and other related industries. On the other hand, Pulang Daga is one of the 17 barangays in the Municipality of Balatan, province of Camarines Sur in Bicol where Pulang Daga clay is the dominant major soil type in the area. In-situ clay from these two sites in Bicol Region were utilized as aggregate in producing masonry hollow blocks used in the experiment of this study. The geographical location [6] of the in-situ clay source is shown in Figure 1.

Putsan, Tiwi Albay ***Pulang Daga, Balatan, Camarines Sur***

Fig 1. Clay Sampling Sites Location

2.2 Experimental Design and Standards

The masonry hollow blocks (MHB) with dimensions of 200 mm height, 400 mm length, and 100 mm width, in general use in the Philippines, were used throughout the experimental phase of the work. The web and shell dimensions of the material were 25 mm. Each block contained three cellular holes of 50 mm width. Type 1 Portland cement produced by pulverizing Portland cement clinker and usually contains calcium sulfate used for general purposes defined by ASTM Type 1 C150 (40 kg) was used throughout this study.

Two different aggregates of clay were used as cement replacement in making masonry hollow blocks. The clay aggregate used in the experimental study was obtained from Pulang Daga, Balatan, Camarines Sur, and from Putsan, Tiwi, Albay. Camarines Sur and Albay are two among the six provinces in Bicol, with dominant clay deposits in the region. An experimental design was used to employ design standards for similar experimental units which were grouped into blocks or replicates. The Universal Testing Machine (UTM) was used to perform the test for the compressive strength of the MHB. The data from the experiment were analyzed and compared from standard ASTM specifications, likewise, the Two-Way Anova was also used to determine the significant difference of compressive strength of the blocks with different clay proportions with a 0.05 level of confidence. The Shapiro–Wilk (SW) test was used to verify the normality of distributions. All statistical calculations were carried out using Jamovi software (ver. 2.5, the Jamovi project, 2024).

The clay aggregates were first crushed and then pulverized into a powder form like that of cement and sieved passing through various openings to determine the fineness of clay comparable to the fineness of the cement. Moisture content and specific gravity were determined according to ASTM D2216-10 and ASTM D854-14, respectively.

The compressive strength determination, three MHB compositions were produced using clay, Type 1 Portland cement, the fine aggregate used was Albay sand which is a predominant quarried aggregate found in Albay province in Bicol Region. The sand with grains ranging 0.075 – 2.36 mm in diameter was washed using potable water. The MHB compositions were selected as 0%, 5%, 8% and 12% by weight of clays in substitution for cement as shown in Table 1. The concrete in a fresh state was placed into a mold and tampered evenly distributed over the surface. After being removed in the mold, the specimens were covered with plastic sheets and kept shaded for 7 days to effectively cure and continually immersed them in clean water tanks for 28 days. After 28 days, the material was air dried and tested. Drying shrinkage cracking is eliminated by taking the water ratio as low as possible for low slump lightweight masonry blocks [7]. Three samples were used in each test for water absorption, moisture content, dry density and compressive strength as the required number of specimens in accordance with ASTM technical standards shown in Table 1 for quality control of concrete blocks.

Table 1. ASTM Standards for Clay Properties and Performance of Masonry Hollow Blocks with Clay mixes

Type of Test	ASTM Designation	ASTM Standard Title
Properties of Clay		
1. Moisture Content	D2216-10	Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
2. Specific Gravity	D854-14	Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
3. Particle Size (Grain Size) Distribution	C136-01	Standard Test Methods for Sieve Analysis of fine and Coarse Aggregates
4. Plasticity Index	D 4318-00	Standard Test Methods for Liquid Limit, Plastic Limit and Plasticity Index of Soils
Performance of MHB with Clay mixes		
5. Water Absorption, Moisture Content, Dry Density and Compressive Strength	C140-03	Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units

2.3 Mix Design and Sample Preparation

To analyze the effect of clay aggregate in replacement to cement in masonry hollow blocks, initially, three different mixture proportions 0%, 5%, 8% and 12% by weight shown in Table 2 were adopted for the concrete mixture batches, respectively.

Basically, the MHB was designed with a cement/aggregate (C/A) ratio 1:6 by weight and water/cement (W/C) ratio 0.5 and maintained for all subsequent mixes. This proportion is the commonly used ratio in construction sites for masonry hollow blocks and was used as the control mixtures throughout the experiment. The mixture proportions of trial batches are given in Table 2 in terms of the dry masses of the ingredients. The information and results of these trial batches were used to produce a result on the influence on various parameters to clay aggregate and cement content. The test results of this experiment are given below.

Table 2. Proportion of raw materials for different treatments

Sample Treatment	Mass of Cement and Clay Aggregates (kg)		Clay (%)	Fine Aggregate (kg)	Water (L)
	Cement	Clay			
A	20	0	0	120	10
B	19	1	5	120	10
C	18.4	1.6	8	120	10
D	17.6	2.4	12	120	10

These dimensions used for the material in this study is recommended for non-load bearing walls as prescribed by the National Structural Code of the Philippines (NSCP) and the National Building Code of the Philippines (NBCP). For each mixture, three blocks' specimens were cast and cured for 28 days and air-dried until the time of testing. The samples were then tested in air-dry conditions in accordance with ASTM standard using the Universal Testing Machine (UTM).

3 Results and Discussion

Many recent studies have examined the feasibility and suitability of using clay as aggregate in concrete [8]. This study analyzes the characteristics of clay aggregates moisture content, specific gravity, particle size distribution, and classification type as crucial properties in engineering geotechnical point of view.

Table 3. Moisture Content and Specific Gravity of Clays

Property	Average Values		Specification values
	Pulang Daga Clay	Tiwi Clay	
Moisture Content (%)	16.98	21.46	12 - 24
Specific Gravity	2.69	2.67	2.70- 2.80

3.1 Moisture Content

Table 3 Soil moisture content is one of the most important variables which affect the concrete strength and masonry block strength as it directly influences the cement hydration and cementitious products formation[(9)]. The cement normally has 60-65 percent lime and when mixed with clay soils, pozzolanic reactions take place, and calcium silicate hydrates are developed, which increases the load bearing capacity of the material. Nevertheless, clays (particularly organic ones) are problematic in geotechnology because they can shrink and swell and absorb high amounts of water[(9)]. In this way, moisture content and specific gravity of the in-situ clays were determined according to the ASTM D2216-10 and ASTM D854-14 standards.

Table 3 indicated that the moisture content in Tiwi clay is higher when compared to Pulang Daga clay, and it is 21.46 and 16.98, respectively. The two values are within the inorganic clays range (ASTM D2974-00). The reduced moisture of Pulang Daga clay implies that it will be more compatible with cement, whereas Tiwi clay is highly moist, and thus the hydration process may take longer resulting in higher porosity. This finding is consistent with the results of the article Moisture content effects on the mechanical behavior of cement-stabilized soils[(10)] that found that the compressive strength of stabilized clay blocks reaches a maximum with moisture (up to about 18.20%), but decreases when excess moisture lowers the cohesion between particles. In a similar way, there is one 2024 study that highlighted the fact that moderate moisture improves compaction and bond strength of cement with clay particles, whereas excess moisture undermines the structure and reduces longevity[(11)].

When applied in this research, Pulang Daga clay with moderate moisture content will have a better balance in mixing and curing which will result in better bond formation and mechanical strength than Tiwi clay. The results thus confirm past studies, yet they also further the existing knowledge on the use of naturally occurring clays as an incomplete replacement of cement aggregates in the manufacture of masonry blocks. In contrast to the previous literature who mostly analyzed the use of agricultural or plastic based additives, this study proves the possibility of using indigenous clays as sustainable sources of locally sourced alternatives to maintain the structural performance and minimize the environmental impact.

3.2 Specific Gravity

As in Table 3, the specific gravity between the clays in the two locations, Pulang Daga (2.67) and Tiwi (2.69) is slightly different, both falling within the acceptable range of inorganic clays according to the standards of ASTM D854-14. Although the difference is small, these data indicate that Tiwi clay, with a somewhat higher SG, can have a denser mineral structure, and Pulang Daga clay has a slightly lower value, which can be a sign of its finer texture and, therefore, more favorable tendency to bond with cement.

These results agree with the article Influence of specific gravity on the mechanical behavior of clay-cement composites[(12)], who had stated that specific gravity was positively correlated with compressive strength of soil-cement composites as the higher the value of SG is the less the pore space and the higher the packing density of the particles. On the same note, research[(13)] revealed that addition of SG improves the stiffness and load bearing characteristics of stabilized clay-based materials because the interparticle entrapment is stronger and there is less absorption of water.

In this undertaking, both clays were showing SG values that are favorable to form stable load bearing concrete block. Nevertheless, Pulang Daga clay which has slightly lower SG, but balanced density can provide a more viable compromise between workability and strength as a local aggregate. Through this comparison, the possible potential of the local sourced clays as a viable substitute to the traditional aggregates, the contribution of the study to the development of green materials is highlighted.

One of the most important factors that determine the soil behavior is the grain size distribution, as it determines the permeability, porosity, strength, and bearing capacity. The particle size of both Tiwi and Pulang Daga clays are below 0.075 mm thus making them fine-grained soils, namely, silt and clay[(?)]. This means that it has low permeability and high cohesiveness that influences compaction and water retention during mixing of concrete.

These findings are in line with research carried out in 2021[(11)], which discovered that fine-grained soils are stronger when their stabilization is done properly with cement, and the article named Influence of fine particle gradation on pozzolanic activity and mechanical performance of clay-cement composites. [12], who discovered that smaller particles improve pozzolanic activity and binder adhesion. Therefore, fine texture of both clays can enhance bonding during the production of masonry blocks, but moisture content should be controlled well to avoid shrinkage and stability.

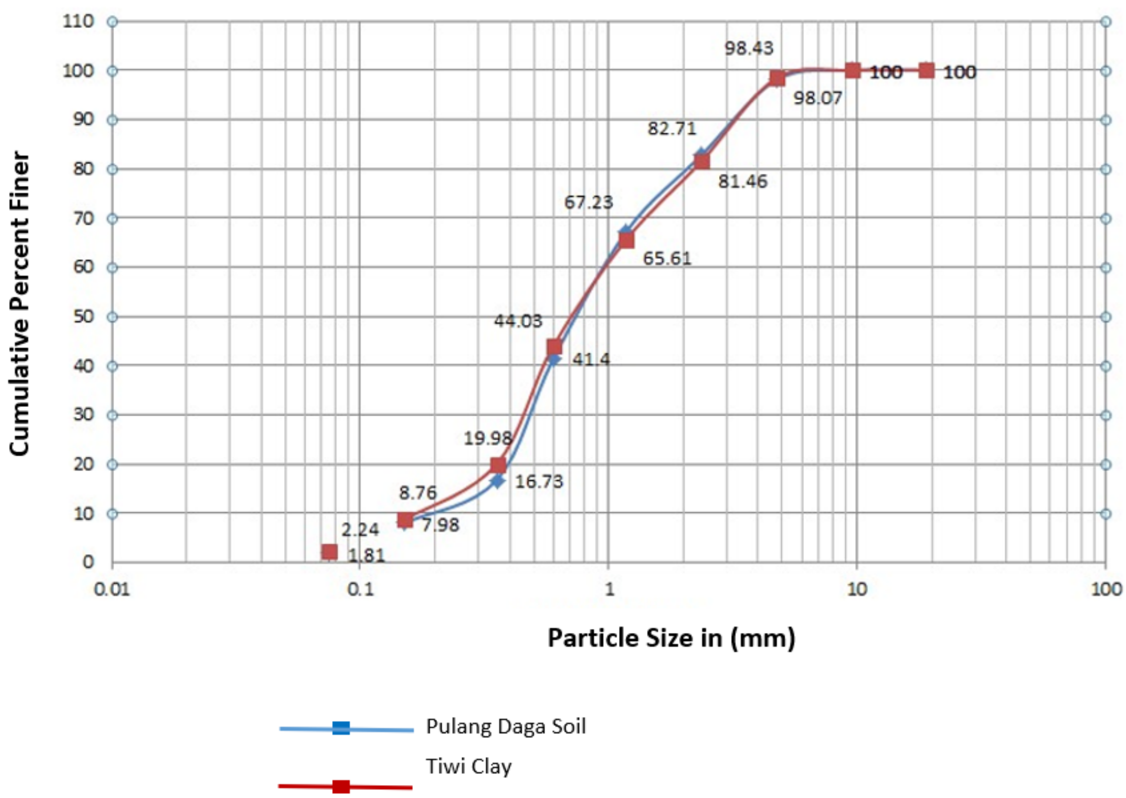

Fig 2. Particle Size Distribution of Clay

To determine the fineness similar to that of cement, the particle size analysis of the samples of the site was conducted by the sieve-sedimentation method by complying with the ASTM C136-01. Figure 2 indicates that Coefficient of Uniformity (Cu) and Coefficient of Curvature (Cc) of Pulang Daga clay were 4.75 and 1.26, respectively, and Tiwi clay had 5.44 and 1.20, which means that both Pulang Daga clay and Tiwi clay are classified as fine-grained soils as per ASTM D2487-11.

The findings show that both clays possess homogenous particle sizes that are characteristic of cohesive soils, which restricts shear strength as a result of low interlocking of particle. This observation has been supported [14], and it was reported that fine, uniformly graded clays have weaker internal force chain, which results in reduced shear resistance without stabilization. There is therefore need to stabilize them so that they can be improved in terms of performance when utilized as aggregates in the manufacture of masonry blocks.

Table 4. Soil Classification of the Collected Clay

Clay	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Degree of Plasticity
Pulang Daga	69.06	55.11	13.95	Medium Plasticity
Tiwi	68.27	47.62	20.65	High Plasticity

Plasticity index or PI is one of the parameters that can be used by engineers to determine the consistency and behavior of the clay at different levels of moisture. It can be explained as the numerical difference between liquid limit and plastic limit which is the extent of plasticity and capacity of soil to withstand deformation. An increase in the PI usually means that it is more compressible and less permeable whereas less PI means that it can work better and shrink less. Tests performed in compliance with ASTM D4318-00 as indicated in Table 5 demonstrate that Tiwi clay is more plastic than Pulang Daga clay which means that it is more compressible with lower permeability. Pulang Daga clay on the other hand which has a higher amount of sand

and silt has a lower PI which prefers less shrinkage effect and stability on the stability of the clay as a constituent in masonry blocks.

These observations are congruent[15] on an experiment that observed that raising the sand content decreases the plasticity index and increases the workability of soil in the mixtures of stabilized clay. Equally,[16] a study found out that soils with moderate PI exhibit superior strength and durability with cement mixture, as a result of reduced shrink-swell characteristics and enhanced cohesiveness. Therefore, the lower plasticity index of the Pulang Daga clay has indicated the possibility of producing masonry blocks, balancing between strength and deformation resistance and reducing the cracking of the block during the curing process.

Table 5. Characteristics of Masonry Hollow Blocks with Clay Mixes

Property	Sample Proportion	Average Value		ASTM Standard Value for Lightweight Concrete Blocks
		Pulang Daga	Tiwi	
Water Absorption (kg/m^3)	A	264.65	264.65	<288 kg/m^3
	B	268.11	269.35	
	C	270.71	272.18	
	D	273.71	274.43	
Moisture Content (%)	A	20.46	20.46	<40% of water absorption of concrete blocks
	B	21.07	21.30	
	C	21.52	21.94	
	D	22.01	22.32	
Dry Density (kg/m^3)	A	1526.36	1526.36	<1680 kg/m^3
	B	1523.74	1522.91	
	C	1520.75	1519.62	
	D	1518.68	1516.10	

3.3 Water Absorption

One property that affects the durability and performance of masonry hollow blocks (MHBs) is water absorption because too much water may undermine internal bonding and decrease the material lifespan. As per the ASTM and DPWH requirements, the water absorption capacity of the lightweight masonry units is 288 kg/m^3.

The water absorption level of MHBs with 5-12 percent clay was greater than the control reflected on Table 6 with 1.31 percent to 3.42 percent and 1.76 percent to 3.70 percent for Pulang Daga and Tiwi clay, respectively. The highest proportion of Tiwi clay was found in proportion D with the highest value of 274.43 kg/m^3 whereas the control concrete had the lowest (264.65 kg/m^3). Despite this growth, all the values that were recorded were acceptable within the ASTM limits.

The experimented tendency is consistent with a report[7] that fine clay particles enhance water absorption because of their porous characteristics and large surface area. Likewise, 2022[17] authors discovered that absorption rates increase with the inclusion of clay in concrete composites because it can be addressed by a reasonable proportion and sufficient cement content. The present research is however different as it shows that both Tiwi and Pulang Daga clays up to 12 percent retain absorption within acceptable limits making them viable as substitute of cement in producing MHB at least partially. This highlights how this study will be special in terms of maximizing the use of local clay in the production of eco-efficient and sustainable construction materials.

3.4 Moisture Content

The content of moisture plays a significant role in concrete performance and concrete durability in terms of workability, hydration, shrinkage, and strength. As shown in Table 6, the lowest moisture content (20.46% was registered in control mix and addition of Pulang Daga and Tiwi clays led to incremental increases in all the levels of replacement. The growth percentage was observed to be 2.98-7.58% Pulang Daga and 4.11-9.10% Tiwi clay and therefore the greater the clay content the better the water retention. This pattern is consistent with one study in 2021[6] which found that clay-rich aggregates increase water retention through their fine particle size and hydrophilic characteristics increasing internal moisture and slowing the drying process. On the same note, a study[8] has determined that soils with increased indexes of plasticity such as Tiwi clay in this case is more likely to retain more moisture leading to slower curing that may have a better bond in the long-term. Nevertheless, the current results indicate that Pulang Daga clay with lower ability to hold moisture can be more stable in its dimensions and less prone to shrinkage and thus can be used in applications with the minimum amount of water-induced deformation.

This comparison proves the originality of this research by showing that despite the fact that both local clays raise the moisture content of concrete, they possess different mineral compositions that lead to different effects, that is, Tiwi clay contributes to higher retention and bonding potential, whereas Pulang Daga clay contributes to greater stability and lesser swelling, helping to select the appropriate material in regard to particular engineering requirements.

3.5 Dry Density

The dry density (the ratio of dry solids to the total volume) determines the degree to which the cement and aggregates as well as the clay fines are packed. Dense packing is also important as it normally results to increased strength, reduced permeability, and improved durability. Table 6 indicates that with increase in clay replacement, dry density of MHBs reduces in both Pulang Daga and Tiwi clays. Pulang Daga clay was slightly denser than Tiwi in similar mixes: e.g. the lowest density (1516.10 kg/m^3) was in a mixture with 12 per cent. Tiwi clay, with the control mix showing 1526.36 kg/m^3.

A current 2022 study[9] supported this trend when it was found that as the dry density of silty clay was increased, so did the overall volume of the particle arrangement as well as the shear strength in direct shear testing. On the same note, the researchers[18] reasoned that incorporation of recycled brick powder in high-plasticity clay reduced the proportion of maximum dry density when the additive was added, which was associated with increasing the ratio of void.

Through this, the researcher put forth that Pulang Daga clay is somewhat harder to compress since it has slightly higher dry densities than Tiwi clay which is more plastic and finer. This implies that where density (and strength) is more of an issue, Pulang Daga clay is a better choice; but where Tiwi clay is less dense but could otherwise have other useful properties (e.g. thermal performance or bonding), it will need special mix design to overcome the losses of density.

Table 6. Compressive Strength of Masonry Hollow Blocks mixed with Clay

Sample Treatment	Compressive Strength (MPa)		Required Compressive Strength Minimum Psi (MPa)	
	Pulang Daga Clay Average	Tiwi Clay Average	Individual Unit	Average of 3 units
A	4.35	4.35	600 Psi (4.14 MPa)	500 Psi (3.45 MPa)
B	4.23	4.10		
C	3.80	3.64		
D	2.69	2.55		

It has been established that the compressive strength of the masonry hollow blocks (MHBs) is significantly affected by the presence of clay in the concrete mix[19]. The compressive strength declines gradually as the clay content increases as illustrated in Table 7. The highest strength was obtained in the control mix which was 4.35 MPa, and blocks with 12 percent clay content gave Pulang Daga and Tiwi clay 2.69 MPa and 2.55 MPa, respectively. In case of clay content minimized to 8%, the strength grew to 3.80 MPa and 3.64 MPa. Only the 5% Pulang Daga clay mix and the control achieved the minimum required of 4.14 MPa of non-load-bearing concrete blocks as required by the DPWH meaning that moderate replacement of clay does not affect the strength, but heavy replacement of clay reduces strength.

The identified movement was reported in 2022 that[19] said that cement-stabilized lateritic blocks with more than 10% of clay proportion will yield significantly less compressive strength because of increased water absorption and weaker interfacial bonding between clay and cement paste. It has been discovered that the substitution of clay up to 5 percent was tolerable without compromising the level of strength, but in addition, substitution beyond that point, decreased the strength of compaction and cement hydration, causing a decline in mechanical performance[20].

Such comparisons support the findings of the current research, which implies that the proportion of clay negatively correlates with compressive strength, mostly due to the presence of higher porosity and decreased density. But Pulang Daga clay showed a little better performance than Tiwi clay and most probably this is because of the fact that the former has lower plasticity and higher dry density which makes it form a denser and more unified block form. In general, the research indicates that maintaining a balance between workability, sustainability, and strength in MHB production at 5 percent to 8 percent of clay is achievable.

Table 7. ANOVA for Compressive Strength

	Sum of Squares	*df*	Mean Square	F	*p*
Proportion	7.6257	2	3.8128	4515.204	<0.001
Clay Type	0.0910	1	0.0910	107.789	<0.001
Clay Type * Proportion	7.44e-4	2	3.72e-4	0.441	0.654
Residuals	0.0101	12	8.44e-4		

Significant level at p < 0.05

The study aims to determine which among the two clays (Pulang Daga and Tiwi) is the most effective when mixed with cement and sand to produce masonry hollow blocks (MHB) by comparing its compressive strength. The compressive strength was measured using the Ultimate Testing Machine (UTM). Prior to conducting the analysis, the test of normality was examined using Shapiro-Wilk statistics which showed that the assumption of normality was followed, $W = 0.975,\ \ p = 0.883$. Thus, the two-way ANOVA test was performed to analyze the effect of clay type and proportion on the compressive strength of MHB.

The results revealed that there was statistically significant main effect of clay type on compressive strength, $F\ (1, 12) = 107.789,\ \ p = 0.000$. Simple main effects analysis also showed that proportion on compressive strength was statistically significant, $F\ (2, 12) = 4515.204\ \ \ p = 0.000$. On the other hand, the interaction between the clay type and the treatment proportion on compressive strength did not have a statistically significant effect, $F\ (2, 12) = 0.441,\ p = 0.654$.

Post-hoc tests using Tukey HSD test revealed significant differences between all different treatment proportions mixed with two different clay types. Further, the Tukey HSD test also revealed significant differences between Pulang Daga and Tiwi clay.

The findings suggest that both Pulang Daga clay $(M = 3.57\ MPa)$ and Tiwi clay $(M = 3.43\ MPa)$ draws some effect on the compressive strength of masonry hollow blocks, however Pulang Daga clay was found be produce higher compressive strength than the Tiwi clay. Moreover, in terms of treatment proportion, $A\ (M = 4.35),\ B\ (M = 4.17),\ C\ (\ M = 3.72),\ D\ (M = 2.62)$, proportion A (controlled) displayed the highest compressive strength, while proportion B obtained the highest compressive strength for the MHB with proportion of clay mixes. This result conforms to the test conducted on the compressive strength of concrete with up cycled plastics replacement that strength decreases with increasing proportion of replacement in concrete hollow blocks. Likewise, this further revealed that concrete strength is inversely proportional to quantity of clay particles contained in aggregates.

The findings further revealed that as the proportion of clay increases the strength decreases for both clay types. These findings also manifest that interaction between clay type and treatment proportion did not have significant effect on the compressive strength. However, it can also be deduced that proportion B can be effective and a good replacement for commercial masonry hollow blocks. This product can be used in building construction such as wall partitions and fences. This material may lessen the cost of masonry hollow blocks while maintaining its allowable strength prescribed by the ASTM standards.

Table 8. Performance comparison between the present study and the State-of-the-art Clay-Cement Composite

Parameter	Previous Studies	Current Study	Improvement Achieved
Optimal Clay Replacement (%)	5% Maximum	8% Tolerable	+3% Replacement while maintaining strength
Water Absorption (kg/m3)	290-310	264-274	Within ASTM limit, better water stability
Moisture Control	Higher retention→ Shrinkage	Balanced retention (16.98%)	Minimized Cracking & Shrink-swell effect
Compressive Strength (MPa)	3.0-3.8	3.8-4.35	Higher at the same replacement
Sustainability Impact	Additives often Imported	Locally Sourced Clay	Lower Carbon Footprint

As highlighted in comparative table, the novelty of this study is in showing that Pulang Daga clay that is locally obtained can be used as a high-performing and sustainable replacement material in the production of masonry hollow blocks (MHB). In contrast to the past where replacement of clay was restricted to 5% because of significant reduction in compressive strength, this work succeeded in attaining a maximum replacement of 8% and still maintained a strength level of 3.8-4.35MPa which is well within the ASTM requirements of non-load-bearing blocks. This enhancement brings to the fore a new optimization of clay properties, especially in relation to the control of moisture (16.98%), specific gravity (2.69), and the plasticity index (13.95), which contributed to cement hydration and reduced internal porosity. A smaller microstructure with less water absorption (268.11 kg/m^3) is obtained, which is better than the earlier results which had higher absorption and lower bonding. This type of optimization offers a new understanding of the fact that the mechanical and durability performance of concrete blocks can be greatly impacted by the natural composition of clay and pre-characterization.

In addition to mechanical efficiency, the new study is novel by the fact that it is sustainable, and context based. Although the previous research relied on industrial by-products or imported pozzolanic materials, this research used native Pulang Daga and Tiwi clays which can be obtained easily in the Bicol region thus instead of increasing the cost of production, reducing carbon emission, and self-reliance on local materials. The paper presents a localized material engineering paradigm in which the environmental appropriateness, financial viability, and technical functionality are balanced. Such combination of geo-material characterization, eco-efficiency and performance validation is a new step in development of region-specific and green construction materials. Therefore, the current study is important as it improves the knowledge about clay cement composites and creates a new pattern of sustainable construction that could be implemented in other developing areas with similar geological opportunities.

4 Conclusion

This study provides valuable data for improving masonry hollow blocks by highlighting the influence of clay found in two sites in Bicol on the mechanical performance of the MHB. This experiment can help in choosing the appropriate mix or applying corrections to the right quantity of clay to be added to the cement mixture to achieve certain values on important parameters of engineering applications. The following points are drawn based on the laboratory test results used in this study:

Since consistency, strength, and density parameters are affected by moisture content which varies with different types and its corresponding volume change characteristics, it is essential to critically analyze the effect of clay on engineering material. In this study, the average value moisture content of clay in Tiwi is approximately 4.48% higher than that of clay in Pulang Daga, while the specific gravity has almost the same value.

Pulang Daga clay with medium plasticity is classified as clay loam, while Tiwi clay with high plasticity is classified as silty clay with 6.7% difference in terms of their plasticity index (PI). Both soil types contain percentage of clay, but they differ in composition. The addition of clay in the concrete mix had varying effects on the masonry hollow blocks in terms of water absorption, moisture content, and dry density of the material.

The results of the experiments with different clay percentages from the two sites were seen that the increase of the percentage of clay increased the water absorption, water content, while decreased the dry density of the masonry hollow blocks and this was due to the decrease in plasticity index of the clay aggregate.

The study established that compressive strength of masonry hollow blocks for controlled, and treatment B met the allowable standard for compressive strength for non-load bearing material prescribed by ASTM standards with minimum of 4.14MPa (average of 3 units). It can be gleaned from the result that Pulang Daga clay produced higher strength than Tiwi clay since clay loam has higher proportion of sand and silt particles and gives better aeration compared with silty clay.

The MHB with 5% clay is acceptable for exterior walls below and above grade that may or may not be exposed to moisture penetration with minimum compressive strength of 4.14 MPa, however, adding 8% clay limits its use for exterior walls with weather-protective coatings and in walls not exposed to the weather with allowable minimum compressive strength of 2.83 MPa.

The results revealed that there was a statistically significant main effect of clay type and proportion on compressive strength of masonry hollow blocks. However, the interaction between the clay type and the treatment proportion on compressive strength did not have a statistically significant effect.

4.1 Intellectual Merit

Results from this research will be useful for analyzing the geotechnical structure of clay soil, such as moisture content, specific gravity, grain size distribution, and Atterberg limits of in-situ clays found in Pulang Daga, Balatan, Camarines Sur and Tiwi, Albay. The method developed in this research can help reduce the future risks of failures and develop a more robust design for construction methodologies and materials. Therefore, results from this research have potential benefits to the construction industry. The results and activities of this research are incorporated into courses on soil mechanics which pushes forward the integration of continuum engineering education and research.

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