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Evaluation of the compressive strength of paver blocks with the inclusion of Mangima stone and Eggshell powder

Erna Lou A. Getes

University of Science and Technology of Southern Philippines

*Corresponding author email: amoresernalou@gmail.com

Vera Karla S. Caingles

University of Science and Technology of Southern Philippines

Email: vera.karla@ustp.edu.ph

Abstract--The demands in building infrastructures in many countries require a huge amount of concrete to be used. As such, the construction industry increased its requirement for aggregates and cement. However, quarrying and dredging of aggregates in the river harm the environment. Also, cement production contributes to carbon dioxide emissions. The primary focus of this study is to evaluate the application of Mangima stone (phyllite schist) and eggshell powder (ESP) as fine aggregate and cement additives to the concrete paver, respectively. Laboratory tests such as sieve analysis, absorption, specific gravity, x-ray fluorescence spectroscopy, and compression were performed. The conventional aggregate was replaced with 100% Mangima stones and added with 5%, 10%, and 15% ESP. The samples were subjected to 28 days curing period. Results showed that the samples with 100% Mangima stone and 15% addition of ESP obtained the highest density (2330 kg/m³) and compressive strength (17.09 MPa) but had lowest absorption capacity (0.90%). In general, as the percentage addition of ESP increases, the compressive strength of paver blocks increases. Therefore, incorporating Mangima stone and ESP is a significantly good material in making innovative concrete paver block material.

Keywords---absorption, compressive strength, concrete paver block, eggshell powder, Mangima stone.

Introduction

Paver blocks used in constructing roads manifest the impressive and advanced

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technology of ancient civilizations [1]. These are seen in select thoroughfares in both urban and rural areas in the world [2]. Paver block materials are not only convenient in building footpaths and roads due to their ease of installation but also possess attractive designs as well [3]. Moreover, these have similar components to concrete such as aggregates, cement, and water. Aggregates like sand and gravel is the major feature of paver blocks and concrete. The demands in building infrastructures in many countries require a huge amount of concrete to be used. As such, the construction industry increased its requirement for aggregates and cement. However, quarrying and dredging of aggregates in the river have adverse effects on the environment such as riverbank soil erosion, river beds degradation, and water quality deterioration [4]. In addition, the production of cement increases the emission of carbon dioxide (CO₂) [5], where every 1 ton of cement has an equivalent of 0.9 tons of CO₂ [6].

Researchers explored the use of waste materials in the production of paver blocks. One of the materials studied to replace aggregates in the manufacturing of paver blocks are copper slag, nylon fiber [7], and groundnut husk ash [4], and others. Also, other waste products identified to replace cement in paver blocks are processed waste tea ash [6] and rice husk ash [7]. Over the years, quarrying natural aggregates caused a lot of environmental concern to the construction industry because of the permanent damage inflicted on the river such as river canal destruction. In France, the French Union of Aggregate Producers in 2011 reported that nearly 400 million tons of aggregates are consumed per year. Hence, many studies proposed alternative solutions to address the problem of aggregates. One recommendation is to use Mangima stones as aggregates. The study by [8] showed that Mangima stones could be used to substitute coarse aggregates for structural concrete. Another study by [9] also attested that Mangima stones as fine aggregates with water-reducing admixture would pass the minimum requirement of 3,000 psi.

Cement is the other main component of concrete prevalently used in the construction industry and considered as another source of environmental concern in global warming due to its emission of Carbon dioxide CO₂ into the air [10]. Hence, researchers forwarded other substitutes to cement-like eggshell powder [11]. Eggshell powder is derived from waste materials coming from hatcheries, poultries, and food processors [12]. Based on the report from the Philippine Statistics – Region X, as of November 2020, poultry farms in the region have produced chicken eggs at an estimated of 24,522 metric tons for the period covering the months from July to December 2019. The estimated production is about 3.6 percent higher compared to the results in the 2018 production amounting to 23,748 metric tons. Furthermore, duck eggs production in the same period has also increased by about 4.8% compared to the data in 2018 at 2,002 metric tons. The waste materials from these farms could also pose an environmental and public health hazard.

Various literatures have elucidated the substantial results of eggshells and Mangima stones as construction materials. The studies explicated that eggshell is rich in calcium carbonate (CaCO₃) which is a compound present in cement. The same study claimed its capacity to be a partial replacement for cement in concrete production like paver blocks [13]. The materials from the eggshells can easily be

acquired from the chicken and duck egg poultry farms in Region X as the PSA inventory has reported an increased production of poultry products each year. Moreover, the studies of [8-9] ascertained the capability of Mangima stones as coarse and fine aggregates. However, there is a dearth of literature about the combined use of eggshell wastes (ESP) and Mangima stones. Consequently, this study attempts to discover the compressive strength of paver blocks using eggshell powder as admixture and Mangima stones as fine aggregates

Methodology

General Procedures

Fig. 1 illustrates the procedures to achieve the objectives of the study. First, the collection and preparation of the materials such as eggshells, Mangima stone, aggregates, and OPC were done. Second, laboratory testing such as sieve analysis, specific gravity, and absorption was performed to determine the properties of the materials after obtaining the materials. Third, the study adopted the ACI standard in the design mix computation. Fourth, all paver blocks were subjected to 28-day curing period. Finally, the samples underwent density, compressive strength, and absorption tests after the required curing days.

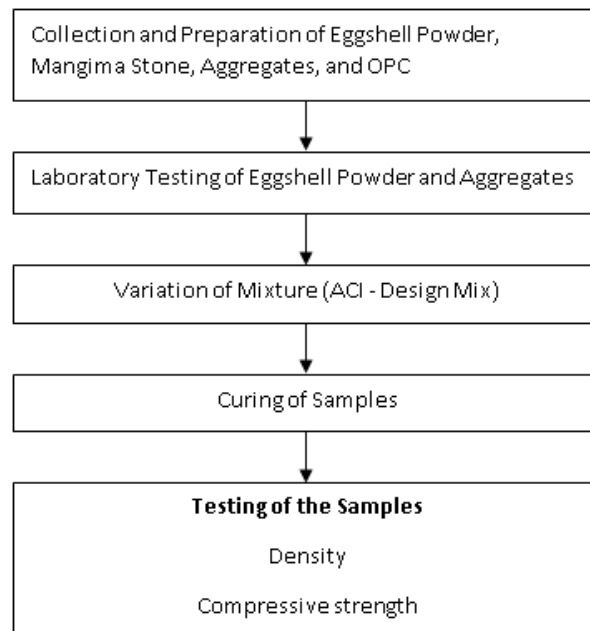


Fig. 1. Flow chart of activities

Collection and Preparation of Materials Eggshell Powder (ESP)

The eggshells were obtained from various Bakeries in Malaybalay City, Bukidnon, and placed in a secured plastic bag for safekeeping. It was then properly washed

with tap water to remove the dirt and other organic particles. The shells were drained and placed in a dry sunny area for 3 days to allow excess water to evaporate naturally and then hand crushed using mortar and pestle before oven-drying. The crushed eggshells were oven-dried and pulverized using a blender to turn into the powder. The powdered eggshells that passed through sieve number 200 (0.20mm) were subjected to a loss of ignition test and chemical analysis using X-ray fluorescence (XRF) analysis.

Crushed Mangima Stone

The Mangima stones were sourced out along the national highway at Barangay Mangima, Manolo Fortich Bukidnon. The Mangima stones are abundant in the area after various road-widening projects were implemented by DPWH. A large amount of Mangima stones fragments were left as waste after the construction activities. The stones are placed in a clean sack and delivered to Malaybalay, Bukidnon. The collected raw stones were washed and then crushed into smaller fragments using a hammer. The stone particles that passed through sieve number 4 (4.75mm) and retained in sieve no. 200 (0.075mm) were used as fine aggregates in this study. Laboratory tests such as specific gravity, absorption, and XRF were performed on the Mangima stones.

Ordinary Portland Cement

The study used type 1 Ordinary Portland cement which was commercially available. The cement was screened using sieve number 200 before mixing with other materials.

Physical and Chemical Tests for Fine and Coarse Aggregates

The fine and coarse aggregates that were used in the study were sourced from a reliable aggregate supplier in Dalirig, Manolo Fortich, Bukidnon. The aggregates were then placed in clean sacks and delivered to the DWPH Material Testing Laboratory in Manolo Fortich, Bukidnon for sieve analysis, specific gravity, and absorption test for coarse and fine in accordance with ASTM C136/C136-19, ASTM C127-15, ASTM C128-15, respectively.

Mixture Preparation, Casting, and Curing

Mixture proportions were based on the American Concrete Institute (ACI) 211.1-91 to estimate the materials for the paving blocks. From the calculation results, the amount of the Mangima stone as fine aggregates, coarse aggregates, cement, and eggshell powder was carefully weighed using a digital weighing scale. A total of 15 numbers of samples were prepared. Table 1 shows the quantities of materials based on the design mix. The materials were mixed in a stainless basin and then gradually added with water until a homogenous or uniform color mixture was obtained. It was then placed in a 200mm x 100 mm x 70 mm rectangular mold in two layers. Each layer was tamped using a small rod 10 mm (3/8 in.) diameter steel bar subjected to for 25 blows to compact and eliminate the void in the mixture. The samples were cured for 28 days. The curing room was based on ASTM C511 – 19 (2015) and the temperature of the mixing and

curing area is $23 \pm 4^\circ \text{C}$ as per ASTM C511.

Table 1
Design mix proportion

Design Mix	No. of Samples	w/c ratio	Coarse Aggregates (kg)	Fine Aggregates (kg)	Fine Mangima stone (FA) (kg)	Cement (kg)	Water (L)	ESP (Cement additive) (kg)
<i>Mixture A (Conventional sand as fine aggregates with no ESP content)</i>								
Sample A	3	0.57	4.28	4.1	0	1.81	1.03	0
<i>Mixture B (Mangima stone as fine aggregates with no ESP content)</i>								
Sample B (0% ESP)	3	0.57	4.28	0	4.1	1.81	1.03	0
<i>Mixture C (Mangima stone as fine aggregates with additional ESP content)</i>								
Sample C.1 (5% ESP)	3	0.57	4.28	0	4.1	1.81	1.03	0.091
Sample C.2 (10% ESP)	3	0.57	4.28	0	4.1	1.81	1.03	0.181
Sample C.3 (15% ESP)	3	0.57	4.28	0	4.1	1.81	1.03	0.272

Determination of Density, Absorption, and Compressive Strength

After the specified curing period, the samples were removed from the curing area and then air-dried for four hours to drain excess water. The samples were delivered to the accredited Department of Public Works and Highways (DPWH) research laboratory for compressive strength test and absorption test as per ASTM C39/C39-18 (2018), and ASTM C1585, respectively. Prior to the compressive strength test, the paver block samples underwent a density test. The weight and volume of each sample were recorded. The density of the paver block samples was computed as the ratio of the mass to its volume.

Results and Discussion

Loss of Ignition and Chemical Composition of Eggshell Ash

The loss of ignition (LOI) value of the eggshell ash heated at 1000°C is 47.23%. The chemical composition of the eggshell contains high content of Calcium Oxide (CaO) of 56.989% as shown in Table 2. This revealed that eggshell powder has a similar chemical composition to lime and is almost identical to the chemical composition of an ordinary Portland cement.

Table 2
Chemical composition of eggshell powder

Composition	Eggshell Powder (%)
%Ni	0.014
%Al ₂ O ₃	0.007
%Co	1.014
%CaO	56.989
%Cr ₂ O ₃	0.049

% Fe	0.179
%MgO	1.915
%Mn ₃ O ₄	0.032
%Na ₂ O	0.114
%P ₂ O ₅	2.959
%SiO ₂	0.437
%SO ₃	0.338
%TiO ₂	0.041
%V ₂ O ₅	0.050
%ZnO	0.010
%SrO	0.054
%K ₂ O	0.275

Specific Gravity, Absorption, and XRF Results of Mangima stone

The Mangima stone has a specific gravity of 2.38 and absorption value of 661%. Meanwhile, the chemical composition of Mangima stone is shown in Table 3.

Specific Gravity and Absorption values of Coarse and Fine Aggregates

For the coarse aggregates, the specific gravity and absorption values are 2.659 and 1.683%, respectively. Meanwhile, the fine aggregates that were used in this study have a specific gravity of 2.52, absorption of 4.17, and fineness modulus of 1.92.

Table 3
Chemical composition of Mangima stone

Composition	Mangima Stone, %
%Ni	0.006
%Al ₂ O ₃	0.013
%Co	18.020
%CaO	2.381
%Cr ₂ O ₃	0.032
% Fe	2.952
%MgO	5.995
%Mn ₃ O ₄	0.106
%Na ₂ O	0.013
%P ₂ O ₅	0.437
%SiO ₂	57.917
%S	0.154
%TiO ₂	0.633
%V ₂ O ₅	0.048
%CuO	0.006
%ZnO	0.004

Density and Absorption Values of the Paver Blocks Samples

Table 4 shows the average density and absorption values of Mixture C, the samples with 5%, 10%, and 15% ESP as a cement additive. There was a gradual increase in average density values with an increase in ESP that was added to the

mixture. The Density of the paver ranges from 2.16 – 2.33 kg/m³. The results revealed that the sample with 5% ESP is lighter than samples with 10% and 15%. Thus, the density of the paver increases as the percentages content of the ESP to the paver increases. Additionally, the absorption values are 2.34%, 1.84%, and 0.90% for samples with 5%, 10%, and 15% ESP, respectively. This implies that the samples become less absorptive as the percentage addition of ESP increases.

Compressive Strength of the samples

Table 4
Density values of mixture C

Mixture C	No. of Samples	Average Density (kg/m ³)	Average Absorption (%)
C.1	3	2160	2.34
C.2	3	2220	1.84
C.3	3	2330	0.90

After 28 days of curing samples, the samples were subjected to a compression test. The results for the compressive strength are shown in Table 5. Sample A displayed lowest the compressive strength compared to Samples B, C.1, C.2, and C.3. This revealed that replacing the conventional fine aggregates with Mangima stones and the addition of ESP contribute to the strength of the paver block. Hence, the compressive strength obtained from the samples with Magima stone as fine aggregates and 15% addition of ESP is 44.22% higher than the samples with conventional fine aggregates and no ESP content. Fig.2 showed the graph of the compressive strength of the samples with Mangima stones and ESP content. It can be observed an increasing strength of the paver block. Further, the addition of ESP to the paver block with Mangima stone as fine aggregates leads to an increase in strength.

Table 5
Compressive strength

Design Mix	Sample No.	Individual Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
Sample A	1	11.96	11.85
	2	11.89	
	3	11.70	
Sample B	1	10.03	12.71
	2	14.73	
	3	13.36	
Sample C.1	1	12.72	15.17
	2	15.58	
	3	17.20	
Sample C.2	1	17.16	16.57
	2	17.56	
	3	14.99	
Sample C.3	1	17.62	17.09
	2	17.18	
	3	16.46	

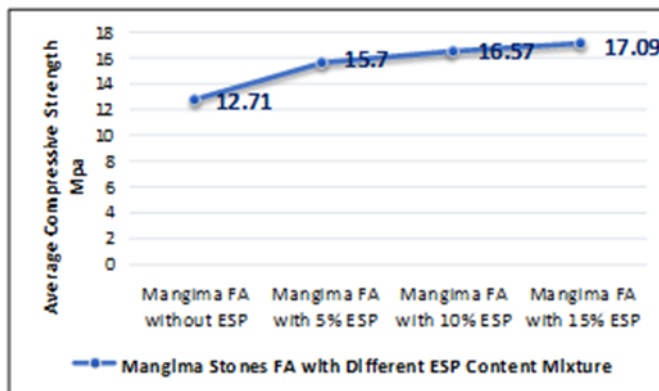


Fig.2: Graph of compressive

Conclusion

This experimental study investigated the potential application of Mangima stone as fine aggregates in paver blocks with additional ESP content. The XRF analysis showed that the dominant component in Mangima stone is SiO_2 while in ESP is CaO . This high amount of calcium oxide on ESP proved that it is an effective cementitious material. Adding ESP to the concrete mixture as cement additive improved the compressive strength of the paver blocks. The results also showed that the use of crushed Mangima stone is acceptable to be an alternative fine aggregate. The concrete mixture with the use of 0.57 water-cement ratio with crushed Mangima stone as fine aggregate and 15% ESP content as cement

additive displayed the highest compressive strength on paver blocks.

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