Potentiality Of Pulverized Commercially Available Vermiculite As Partial Replacement To Ordinary Portland Cement In Concrete Mix

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Abstract: As the need for concrete continuously increases every year, the necessity and demand for the supply of cement also rise significantly. This study aimed to look for an alternative engineering construction material which can be a potential partial replacement to ordinary Portland cement (OPC). The entire investigation and experiment was based on the established ASTM standards. The physical properties of pulverized commercially available vermiculite (PCAV), namely fineness, specific gravity, and unit weight, were determined via laboratory tests and experiments. The cylindrical concrete specimens were designed for 28 MPa and 24 MPa compressive strengths exposed in a curing period of 28 days. The commercially available vermiculite from Ramgo International Corporation was utilized in the study, and was pulverized using the available pulverizing equipment. As far as the objectives of the study were concerned, the compressive strengths of the samples were determined using the Universal Testing Machine. The results of the experiments and laboratory tests performed showed that only the cylindrical concrete specimen of Class AA (1:1.5:3) with a PCAV – cement proportion of 10% - 90% attained and exceeded the required strength based on the design compressive strength of 28 MPa. Results also showed that PCAV can be used as a partial replacement to OPC in a concrete mix using PCAV – cement proportion of 10% - 90% of Class AA.

Keywords: engineering construction, partial replacement, Portland cement, vermiculite

1. Introduction

As the structural needs increase yearly to meet the demands of the global industrialization phenomenon, the requirement for concrete increases as well to provide instantaneous development [1]. In fact, the worldwide requisite for concrete is twice the need for steel, wood, plastic, and aluminum requirements combined. This is because concrete is generally utilized in the process of giving life to architectural structures, stable foundations, pavements, highways, runways, dams, reservoirs, footings, parking structures, bridges and overpasses, and even for the construction of water transportation means. As mankind has a need for infrastructure, the use of concrete will still rapidly increase in quantities in the near future. And as the quantity of concrete infrastructures continues to increase, the necessity for cement also grows, which requires attention for researchers to find and discover other potential replacements for cement. According to the manual introduced by the University of Iowa, Civil Engineering Materials, these cement replacement materials are known to be special types of naturally occurring materials or industrial waste products that can be used to partially replace some of the Ordinary Portland Cement (OPC) [2]. Numerous benefits can be obtained by utilizing cement replacement materials in the construction industry. Aside from minimizing the needs for cement in the process of constructing concrete structures all over the globe, it can also strengthen properties of cement, like its capacity to resist compression and tension [3]. It may also alter other chemical and physical properties of concrete, and give special features to the product structure like one being sound-proof, fire-resistant or fireproof [4]. In addition, it can aid in the prevention of the continuous extension of environmental threats in the world, and it can also cut the increasing cost of construction [5]. In view of the foregoing, and in order to prove the potentiality of vermiculite as a partial replacement to Ordinary Portland Cement in a concrete mix, certain properties were tested, especially the compressive strength. This property of concrete is the common performance measured by engineers in the process of designing, creating, and constructing structures of different purpose and types. It is used to determine that the concrete mixture as delivered meets the requirements of the specified strength, f'c in the job specification of a certain plan of structure [6]. In light of the above discussion, this paper focused essentially on the behavior of the compressive strength of concrete when vermiculite is used as partial replacement to Ordinary Portland Cement, considering other physical properties like fineness, specific gravity, unit weight, and concrete mix proportions [7].

2. Objectives of the Problem

The study attempted to investigate and assess the potential influence of commercially available vermiculite to the most important property of concrete, which is its compressive strength. Specifically, the study had the following objectives:

1. To determine the physical properties of Pulverized Commercially Available Vermiculite (PCAV) in terms of
   - 1.1 Fineness
   - 1.2 Specific Gravity
   - 1.3 Unit Weight
2. To determine the compressive strength of concrete with curing period of 28 days considering the following mix proportions of Pulverized Commercially Available Vermiculite and cement:
   - 2.1 0% of Pulverized Commercially Available Vermiculite and 100% of cement
   - 2.2 10% of Pulverized Commercially Available Vermiculite and 90% of cement
   - 2.3 20% of Pulverized Commercially Available Vermiculite and 80% of cement
   - 2.4 30% of Pulverized Commercially Available Vermiculite and 70% of cement
3. To evaluate and analyze the effects of partial replacement of cement with Pulverized Commercially Available Vermiculite (PCAV), and to recommend the best proportion for concrete mix

3. Materials and Method

3.1. Research Design

An experimental investigation on strength of concrete was conducted by partially replacing cement via 10%, 20%, and 30% of pulverized commercially available vermiculite. All replacement levels were performed once in two different concrete mix proportions: 1:1.5:3 (Class AA) and1:2:4 (Class A). The amount of fine and coarse aggregates was calculated utilizing the proportions based on mass. On the other hand, the water cement ratio (w/c) was fixed with a value of 0.5. Concrete cylinders were subjected to water curing for 28 days to investigate the strength gained depending on the age of curing. For further comprehension of the influence of PCAV on the strength of concretes made with different cement replacement levels, the test for compressive strength was performed.

3.2. Raw Materials

3.2.1. Cement. In this study tests were conducted on cement, such as fineness test, using the sieve method, specific gravity and unit weight determination. In the researchers' study, commercially available Type 1P LAFARGE FORTUNE® cement was chosen in the production of the concrete cylinders.

3.2.2. Aggregates. These are coarse particulate construction materials that are said to be the body of the concrete. These materials must have a good gradation to produce workable concrete cylinder samples. Likewise, good grading implies that a sample fraction of aggregates must have the required proportions such that the sample contains minimum possible voids.

3.2.3. Water. In the study, it was considered to be one of the most important ingredients in the production of concrete cylinder samples because it actually participates in the chemical reaction with cement, which then provides the strength-giving cement gel.

3.2.4. Pulverized Commercially Available Vermiculite (PCAV). In the experimental method, it was utilized as the partial replacement of cement in the production of concrete cylinders. This commercially available vermiculite was purchased from Ramgo International Corporation in Pasig. The purchased material was then crushed using the mill pulverizer available in the chemical laboratory of the Chemical Engineering Department of the university.

Raw materials utilized in the experiment were chosen to provide the most suitable concrete cylinder samples to come up with the best findings possible. Researchers analyzed all existing considerations for the success of the experiment.

3.3. Preparation Stage

Preliminary study was conducted by the researchers through gathering available data and information from various related studies. Different sources were considered such as journals and related articles from different technical reports, books, and internet sources, which were all proven relevant to the study. These sources were analyzed, sorted out, and utilized in order to fortify the foundation of the entire study. Preliminary tests were performed to assess the physical properties of the pulverized commercially available vermiculite (PCAV). The data were required for value calculations of the individual amounts in the concrete mix proportion and the preparation of concrete cylinder specimens [8]. On the other hand, the design of mix proportions was based on the assumption that the concrete was of normal weight. Calculation of concrete mix proportions with the strength of 28 MPa (4000 psi) and 24 MPa (3500 psi) was done using the mass basis method [4]. The researchers used the design mix for Class AA and A. Accepted ASTM standards were considered for the estimation of the required amount of the partial replacement and cement. In addition, the amount of gravel and sand in each batch of concrete mixes was held constant, while the amount of pulverized commercially available vermiculite and the cement proportion were varied as to the amount of each batch of concrete mixture required. On the other hand, the volume of water utilized in the wet mixing was determined using a water cement ratio of 0.5. Cylindrical molds having dimensions of 150 millimeter in diameter and 300 millimeter in height were used to cast the concrete specimens. Two (2) concrete mix proportions (also known as classes) were considered by the researchers in the experimental investigation. Each proportion, consisting of four (4) concrete cylinder specimens, specimens with 0%, 10%, 20%, and 30% of partial replacement, were exposed to 28-day curing. Three (3) trials in each class were produced to limit the scope of the experimental investigation and to ensure the reliability of the study. Thus, there was an overall quantity of 24 concrete cylinder specimens that were formed and tested for compression.

3.4. Mixing and Casting Stage

This stage of the experimental investigation of the researchers was conducted at the Construction Materials Laboratory of the Civil Engineering Department of Batangas State University-Main Campus II in Alangilan, Batangas City. In the process of mixing each batch of concrete, a mixing pan of sufficient capacity that can allow easy mixing was utilized. Manual mixing using a shovel was preferred. Careful monitoring of the required amount of raw materials was done. Dried mixing of the coarse and fine aggregates, cement, and pulverized commercially available vermiculite was performed to guarantee a well-distributed mixture. Then, a measured volume of water was added and mixed thoroughly until the desired consistency of the mixture was achieved. The fresh concrete paste was then poured, filling one-third (1/3) of the cylindrical molds and was compacted by tamping 25 strokes of steel rod. This step must be done on the two-thirds (2/3) layer and on the last layer of the mold. Using a straight edge, the surface was then levelled and finished into a smooth surface. Samples formed were set aside and were marked with labels to avoid uncertainty. These were allowed to harden for twenty-four (24) hours and were then removed from molds and transferred into a container filled with water, thus allowing the samples to be cured for 28 days until they were ready for testing. These procedure followed the Standard Practice for Making an Curing Concrete Test Specimens in the Laboratory also known as ASTM C 192/C 192M – 6 [9].

3.5. Testing Stage

Standards proposed by the American Society for Testing of Materials (ASTM) were preferred by the researchers for the conducted tests in order to determine the physical properties of the pulverized commercially available vermiculite (PCAV) and cement. The following tests were performed:

3.5.1. ASTM C184-94 – Fineness of Cement by Sieve Method [9]

One hundred grams of cement were accurately weighed and placed on a 75 μm (No.200) sieve. Breakdown any air set lumps in the sample with fingers, without rubbing them on the sieve. The sample was continuously sieved for 15 minutes by holding the sieve in both hands and giving wrist motion. The residue left on the sieve was weighed after sieving.

3.5.2. ASTM C188 – Standard Test Method for Specific Gravity of Cement [9]

The Le Chatelier flask was dried carefully and the kerosene or naphtha was poured to a point on the stem between zero and one milliliter. The level of the liquid in the flask was recorded as initial reading. A weighted quantity of cement (about 60 grams) was put into the flask so that the level of kerosene rises to the 22 milliliter mark. Care was taken to avoid splashing and to see that the cement did not adhere to the sides of the liquid. After putting all the cement into the flask, the flask was rolled gently in an inclined position to expel air until no further air bubbles rose to the surface of the liquid. The new liquid level was noted as the final reading.

Formula:

$$\textbf{Specific Gravity} = \frac{(W_2 - W_1)}{(W_2 - W_1) - 0.79(W_3 - W_4)} \quad (1)$$

where: $\mathbf{W_1}$ – weight of empty Le Chatelier Flask
$\mathbf{W_2}$ – weight of Flask + Cement Replacement
$\mathbf{W_3}$ – weight of Flask + Cement Replacement + Kerosene
$\mathbf{W_4}$ – weight Flask + Kerosene
0.79 – specific gravity of Kerosene

3.6. Concrete Mix Proportion

Each series of concrete was designed with constant water volume of 1.6 liters. A control mix was considered, which is a sample of plain concrete paste composed of cement, water, coarse, and fine aggregates without cement replacement (0% of PCAV). Two (2) concrete mix proportions were considered by the researchers with PCAV as cement replacement. Samples were composed of unconventional mixes of 10%, 20%, and 30% of the total mass of Ordinary Portland Cement (OPC) in each concrete proportion. The PCAV concretes were labelled according to the percent of the partial replacement utilized in a certain sample.

ASTM C39 – Standard Test Method for Compressive Strength of Cylindrical Concrete Specimen [9]

This test method consists of applying a compressive axial load to molded cylinders or cores at a rate which is within a prescribed range until failure occurs. In this study, the compressive strength of the specimen was calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen.

3.7. Determination of Compressive Strength

Considering the procedures and guidelines of ASTM C39, the compressive strength of the concrete cylinder specimens was determined. Twenty - four (24) samples were tested for compressive strength. The maximum compressive load of each specimen was determined with the use of a Universal Testing Machine. This value was then divided by the cross-sectional area of the specimen to determine the compressive strength.

Formula:

$$\textbf{Compressive Strength} = \frac{F}{A} \quad (2)$$

where: **F** – the maximum load indicated by the UTM (lbs-f, N)
A – cross-sectional area subjected to load (in^2, mm^2)

4. Results and Discussion

Properties of Pulverized Commercially Available Vermiculite (PCAV)

4.1. Fineness.

Tables 1 and 2 present the data for the determination of the fineness of the cement and PCAV as partial replacement to ordinary Portland cement by sieve method (ASTM C184-94)[9]. This implies that Ordinary Portland Cement has finer particles, which offers a greater surface area for hydration and faster development of high strength [7] compared to the Pulverized Commercially Available Vermiculite.

Table 1. *Fineness of Cement Sample*

Trial	Weight of Cement Sample (grams)	Weight of Residue on Sieve No. 200	Fineness of Cement (percentage)
1	100	4.3	95.7
2	100	4	96
3	100	4.4	95.6
		Average	95.77

Table 2. *Fineness of PCAV*

Trial	Weight of PCAV Sample (grams)	Weight of Residue on Sieve No. 200	Fineness of PCAV (percentage)
1	100	85.4	14.6
2	100	85	15
3	100	85.2	14.8
		Average	14.8

4.2. Specific Gravity.

Table 3 shows the average specific gravity of Ordinary Portland cement (OPC) sample and pulverized commercially available vermiculite (PCAV). The corresponding values obtained denote that the OPC can almost certainly provide a higher compressive strength compared to PCAV because it is demonstrated that the value of specific gravity of cement is directly proportional to the maximum compressive strength that a concrete specimen can possibly attain.

Table 3. *Specific Gravity of Cement Sample and PCAV*

Trial	Specific Gravity	
	Cement Sample	PCAV
1	3	2.98
2	3.05	2.95
3	3.12	2.91
Average	3.06	2.95

4.3. Unit Weight.

The three specimens of the cement sample (OPC) and the PCAV have a reported average unit weight of 29.99kN/m^3 and 28.91kN/m^3, respectively. These values obtained from the tests conducted imply that OPC has a higher unit weight, which in turn can provide a concrete specimen with higher maximum compressive strength compared to the specimen with PCAV.

4.4. Compressive Strength of PCAV Concrete.

Tables 4 and 5 show the compressive strength test results of the cylindrical concrete specimens of Class AA and Class A with varying proportions of PCAV, which were exposed to 28 day – curing. On the Table 4 shown, the average compressive strength of the conventional concrete specimen of Class AA cured at 28 days is 27.63 MPa, while the sample with a PCAV – Cement ratio of 10% - 90% has a compressive strength value of 28.67 MPa. For a PCAV – Cement ratio of 20% - 80%, an average compressive strength value of 24.47 MPa has been computed. Lastly, for the PCAV – Cement ratio of 30% - 70% , the computed average compressive strength was equivalent to 20.7 MPa. The corresponding values acquired from the laboratory tests imply that the PCAV – Cement ratio of 10% - 90% exceeds the standard compressive strength of Class AA which is 28 MPa.

Table 4. *Compressive Strength of Specimens at 28 Days Curing of Class AA*

Percent Replacement	Trials	Actual Load (kN)	Compressive Strength	
			psi	MPa
0	1	514.46	4032	27.8
	2	526.45	4047	27.9
	3	512.26	3945	27.2
Average		517.7233	4008.00	27.63
10	1	531.78	4206	29
	2	527.66	4163	28.7
	3	529.87	4105	28.3
Average		529.77	4158.00	28.67
20	1	449.78	3539	24.4
	2	450.76	3510	24.2
	3	460.74	3597	24.8
Average		453.76	3548.67	24.47
30	1	381.42	3017	20.8
	2	397.06	3104	21.4
	3	371.63	2886	19.9
Average		383.37	3002.33	20.7

Table 5 shows the compressive strength of the specimens being cured for 28 days using Class A. It was shown on the table that the average compressive strength of the conventional concrete specimen of Class A cured at 28 days is 23.73 MPa, while the sample with a PCAV – Cement ratio of 10% - 90% has a compressive strength value of 21.50 MPa. For a PCAV – Cement ratio of 20% - 80%, an average compressive strength value of 19.90 MPa has been computed. Lastly, for the PCAV – Cement ratio of 30% - 70%, the computed average compressive strength was equivalent to 17.67 MPa. It is noted that the computed average compressive strength on any of the PCAV – Cement ratio does not meet the designed compressive strength of 24 MPa.

Table 5. *Compressive Strength of Specimens at 28 Days Curing of Class A*

Partial Replacement	Trials	Actual Load (kN)	Compressive Strength	
			Psi	MPa
0	1	431.76	3437	23.7
	2	437.72	3408	23.5
	3	438.37	3481	24
Ave		**435.95**	**3442**	**23.73**
10	1	408.7	3162	21.8
	2	407.26	3118	21.5
	3	389.77	3075	21.2
Ave		**401.91**	**3118**	**21.50**
20	1	367.13	2915	20.1
	2	363.61	2857	19.7
	3	370.67	2886	19.9
Ave		**367.14**	**2886**	**19.90**
30	1	323	2582	17.8
	2	318.3	2495	17.2
	3	337.02	2611	18
Ave		**326.11**	**2562.67**	**17.67**

These average values of the compressive strengths were then used in the next section for a broader investigation and assessment of the potentiality of the PCAV as a partial replacement to OPC in a concrete mixture.

4.5. Relationship of PCAV to the Concrete Compressive Strength

Figure 1 presents the influence of the PCAV - cement ratio to the compressive strength of the cylindrical concrete specimens of Class AA and Class A exposed at 28 days of curing.

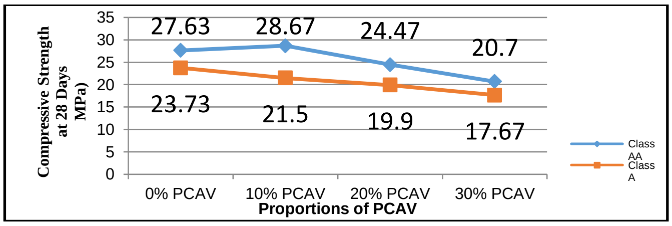

Figure 1. *Behavior of Compressive Strength in Different PCAV Proportions*

In comparison to the conventional concrete (based on ASTM Standard), the best pulverized commercially available vermiculite to cement ratio was observed to be the 10% - 90% proportion of Class AA, which was exposed to a curing period of 28 days. This proportion of PCAV – cement having a compressive strength of 28.67 MPa passes the designed compressive strength of Class AA (1:1.5:3), which has a value of 28 MPa. Other proportions, including those of Class A, did not attain the designed compressive strength.

Summary of Findings

The study was conducted to assess the potentiality of the pulverized commercially available vermiculite (PCAV) as a partial replacement to ordinary Portland cement (OPC) in a concrete mix. Furthermore, the following is the summary of findings from the experiments performed by the researchers and from the results of laboratory tests:

1. Properties of Pulverized Commercially Available Vermiculite (PCAV)
   1.1 The average particle size of the PCAV is 14.8%, while the ordinary Portland cement's sample fineness is 95.77%.
   1.2 The reported specific gravity of the PCAV and the OPC is 2.95 and 3.06, respectively.
   1.3 The unit weight of the PCAV and the OPC is 29.99kN/m^3 and 28.91kN/m^3, respectively.

2. Compressive strength of the PCAV concrete

2.1 For the PCAV – cement proportion of 0% - 100%, the average compressive strength of the cylindrical concrete specimen of Class AA at 28 days of curing was reported to have a value of 27.63 MPa (4000 psi), while that of Class A of the same age has a value of 23.73 MPa (3440 psi).

2.2 For the PCAV – cement proportion of 10% - 90%, the average compressive strength of the cylindrical concrete specimen of Class AA at 28 days of curing was reported to have a value of 28.67 MPa (4160 psi), while that of Class A of the same age has a value of 21.50 MPa (3120 psi).

2.3 On the other hand, for the PCAV – cement proportion of 20% - 80%, the average compressive strength of the cylindrical concrete specimen of Class AA at 28 days of curing was reported to have a value of 24.47 MPa (3550 psi), while that of Class A of the same age has a value of 19.90 MPa (2890 psi).

2.4 For the PCAV – cement proportion of 30% - 70%, the average compressive strength of the cylindrical concrete specimen of Class AA at 28 days of curing was reported to have a value of 20.70 MPa (3000 psi), while that of Class A of the same age has a value of 17.67 MPa (2560 psi).

3. Based on the designed compressive strengths of 28 MPa and 24MPa, with a curing period of 28 days, the required strengths were not attained by the cylindrical concrete specimens utilized in the laboratory tests, except for the sample Class AA with a PCAV – cement ratio of 10% - 90%.

5. Conclusions

In light of the foregoing findings, the following conclusions were formulated by the researchers:

1. The particle size of PCAV does not meet the values given by the tests conducted on the ordinary Portland cement. On the other hand, the specific gravity and unit weight of PCAV meet the values reported and calculated from the laboratory experiments conducted. These properties were proven to have significant influence to the concrete specimens' compressive strength.
2. The best PCAV – cement proportion is 10% - 90% of Class AA.
3. The pulverized commercially available vermiculite (PCAV) can be used as a partial replacement to ordinary Portland cement using a concrete mix proportion of 1:1.5:3 (Class AA) at PCAV – cement ratio of 10%-90%.
4. Since PCAV is more expensive than commercially available Portland cement, its use as partial replacement is not economical though it can partially replace OPC in a concrete mix.

6. Recommendations

With regards to the findings and conclusions of the study, the researchers recommend the following:

1. Use pulverized commercially available vermiculite (PCAV) as partial replacement to ordinary Portland cement at a PCAV – cement proportion of 10% - 90% using Class AA.
2. Use other equipment or other means of pulverizing the commercially available vermiculite to provide a sample with a particle size almost equal to the fineness of ordinary Portland cement.
3. Test other concrete mix proportions (Class B and Class C) for the assessment of the potentiality of PCAV as partial replacement to OPC.

For future researchers, the following recommendations are given:

1. Test the fire – retarding property of the concrete samples with partial replacement of PCAV using Class AA with PCAV – cement proportion of 10% - 90% to prove its economical feasibility.
2. Determine the behavior of the samples with OPC partially replaced by PCAV in varying amounts regarding the attainment of compressive strengths of the specimens exposed to 14, 45, and 60 days of curing period.

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9. Author Profile

Engr. Oliver S. Dimailig received the degree of B.S. in Civil Engineering and Master of Engineering major in Civil Engineering from Batangas State University in 2006 and 2016, respectively. Engr. Dimailig is practicing the profession as a registered civil engineer for more than 10 years. His first job was in the Philippine Ports Authority as an

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Department. During his term as department chairman and with the full support of university officials, administration, faculty, staffs and students, both Civil and Sanitary Engineering programs have been accredited by both national and international accrediting bodies such as Philippine Technological Council (PTC), Accrediting Agency of Chartered Colleges and Universities in the Philippines (AACCUP) and Accreditation Board for Engineering and Technology (ABET). Engr. Dimailig also served as PASUC QA Engineer on Road Projects. Moreover, he is as an ISO Internal Auditor of Batangas State University for ISO 9001:2008 and ISO 9001:2015. Currently, Engr. Dimailig serves as Director for Academe Sector of PICE-Batangas Chapter. He has been serving the professional organization as an active officer for almost 10 years. In addition, Engr. Dimailig acts as a Program Evaluator for Civil Engineering for PTC Accreditation where he already evaluated two (2) universities in the Philippines. Engr. Dimailig is currently pursuing graduate studies taking up Doctor of Philosophy major in Material Science and Engineering in Mapua University, Intramuros, Manila.