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ENGINEERING PROPERTIES OF CALACA BATANGAS BOTTOM ASH

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ABSTRACT

The coal-fired power plant of the National Power Corporation (NAPOCOR) in Calaca, Batangas emits an estimated 62.62 tons of coal combustion products (CCPs) per hour on a 24-hour daily basis. Like other coal power plants, the continuous disposal of coal combustions products such as fly ash, bottom ash and boiler slag in landfills or surface impounds creates environmental problems to people living in the neighboring areas. The accumulation of these by products poses a significant environmental risk at the rate these byproducts are being generated. The objective of this study is to determine the engineering properties of Calaca, Batangas bottom ash. These engineering properties can be used to find and assess the possible ways of utilizing and maximizing the potential of such byproduct in a manner that is both environmentally friendly as well as economically viable. Apart from solving the environmental problems related to its disposal, the use of coal combustion byproduct also saves natural resources and energy because it makes waste materials useful through recycling. This study focuses on the determination of the chemical composition, as well as physical and mechanical properties of bottom ash.
Keywords: *Coal Combustion Byproducts, Bottom ash*.

1. INTRODUCTION

The coal-fired power plant of the National Power Corporation (NAPOCOR) in Calaca, Batangas started operating with its 300-Megawatt generator No.1 in 1984. In 1995, another 300-Megawatt generator (generator No.2) was put into operation in order to meet the power shortage in Luzon during that time. The plant uses coal from Semirara and imported coal from Australia and Indonesia. According to the Department of Energy (DOE) Circular No. 95-05-004 (1995), 10% of NPC's coal consumption should be domestic. Approximately 80% (in the first quarter of 1998) of domestic coal was from the coal reserve of Semirara island near Calaca (JBIC, 1999).

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The combustion of coal generates enormous quantity of solid byproducts such as fly ash, bottom ash, and boiler slag. These byproducts are commonly known as Coal Combustion Byproducts or CCBs. The Calaca, Batangas Coal Power Plant emits an estimated 62.62 tons of ash per hour on a 24-hour daily basis (Greenpeace Press Release, 2001). Like other coal power plants, CCBs are being disposed in landfills, collecting ponds or in surface impounds thus creating environmental issues such as: 1) fugitive dust from coal and ash handling and storage is one of the primary sources of the plant emissions; 2) one of the primary potential sources of wastewater and surface water impact are discharges from the ash lagoons/ponds; 3) the ash lagoons, coal stock pile area, and sedimentation ponds are unlined, thus, may affect the surrounding marine ecology and water quality as well as the groundwater quality; and 4) marine impact may arise from surface-water runoff contaminated with ash and coal dust, coal and oil spill, cooling water intake and discharge. Moreover, if these combustion byproducts are not utilized, time will come when there will be no enough space for the CCBs, and the disposal of these byproducts will be a problem. Therefore, studies must be done to look for ways to utilize and maximize the potential of these materials so that their disposal without adverse environmental effects becomes possible.

The recycling of coal combustion byproducts as raw materials in applications that are environmentally sound, technically safe and commercially competitive should lead to a reduction in the practice of land filling these materials. The utilization of large quantity of bottom ash can mitigate or solve the disposal and environmental problems associated to it. Apart from solving the problems at its cause, a coal combustion byproduct is made valuable and is also a way to save natural resources as well as energy.

The advantages of utilizing coal combustion byproducts include a decrease in the need for landfill spaces, a reduction in the cost of producing electricity, lowering electricity cost for consumers, conservation of natural resources, and substantial savings for end users of coal combustion byproducts.

In connection with the anticipated problem in the disposal of coal combustion byproducts (CCBs), particularly the bottom ash, the objective of this study is to determine the engineering properties of Calaca, Batangas Bottom. These engineering properties can be used to find and assess the possible ways of utilizing and maximizing the potential of such byproduct in a manner that is both environmentally friendly as well as economically viable.

2. REVIEW OF LITERATURE

Coal-fired power plants produce a variety of solid byproducts when pulverized coal is fed into the boilers and burnt at high temperatures and pressures. These byproducts are referred to as Coal Combustion Byproducts (CCBs), such as fly ash, bottom ash, and boiler slag. Once combustion of pulverized coal has taken place, some of the unburned materials or ash is entrained in the flue gas and is captured and recovered in the precipitators as *fly ash*. The remaining fraction of the ash consists of coarse, granular, incombustible byproducts that are collected at the bottom of furnaces. Currently, two types of pulverized coal burning furnaces are in use. They include wet and dry bottom furnaces. Each produces a distinctively different coarse byproduct. In the slag or wet bottom boilers, ash collected at the bottom of the furnace is kept in liquid condition by maintaining the slag well above its fusion temperature. The boilers have a solid base with an orifice that can be opened to permit the molten ash to flow into the ash hopper below. The ash hopper contains quenching water. When the molten slag comes in contact with the quenching water, it fractures instantly, crystallizes, and forms pellets known as *boiler slag*. The resulting boiler slag, often referred as "black beauty," is a coarse, hard, black, angular, glassy material. Most modern pulverizing coal boilers, like the one installed at Calaca, Batangas, have dry bottom furnaces; that is, the ash is intended to be removed as a dry solid before complete melting occurs. This byproduct is referred to as *bottom ash*. In dry bottom boilers the ash temperature is below its fusion point and, therefore, molten slag will not be produced (EPA, 1988). In addition, furnace walls have sufficient surface areas to cool the ash and allow it to fall as a solid particle through a grate and into a collection hopper or water-filled ash pit. When a sufficient amount of bottom ash drops into the hopper, it is removed by means of high-pressure water jets and conveyed by sluiceways either to a disposal pond or to a decant basin for dewatering, crushing, and stockpiling for disposal (Hecht and Duvall, 1975). The bottom ash has significantly different characteristics than the boiler slag. The dry collection procedure yields ash having the appearance of natural fine aggregate. Bottom ash is grey to black in color, granular, has a porous surface texture, and predominantly sand size minus 12.7 mm (1/2 in) material (EPA, 1988). The bottom ash is also lighter in weight than boiler slag , thus generating a lighter product (Ghafoori, 1992).

Bottom ash is composed principally of silica, alumina, and iron, with smaller percentages of calcium, magnesium, sulfates, and other compounds. The composition of bottom ash is primarily affected by the source of the coal and not by the type of furnace. Bottom ash derived from lignite or sub-bituminous coals which have a higher percentage of calcium as compared to bottom ash derived from anthracite or bituminous coals.

The identification of cost effective, technically sound, and environmentally responsible programs for the beneficial use, rather than disposal, of CCP has been the goal of many research and demonstration projects over the past several years. Ghafoori (1992) made a study on the utilization of bottom ash in cement-based concrete mixtures. Ghafoori and Bucholc (1997) studied the performance characteristics of dry bottom ash, as partial or full replacement of natural fine aggregate, in structural concretes. Ghafoori and Cai (1997) used coal combustion byproducts in roller compacted concrete. Coal combustion byproducts in roadways and parking lots were investigated by Ghafoori (2000). Kumar (2000) studied the use of CCPs in construction of deep foundations. Butalia and Wolfe conducted research on the utilization of the Ohio coal combustion products (CCPs). Dr. Diola and Dr. Pulmano (2004) of University of the Philippines studied the use of Calaca, Batangas bottom ash for cement-based civil engineering applications. The study investigated the use of bottom ash as partial sand replacement for concrete mixes and for controlled low strength material (CLSM). Also, bottom ash was used, together with some other admixtures, to develop suitable mix proportions for flowable concrete.

The leading applications of bottom ash are snow and ice control (for cold countries), as aggregate in light weight concrete masonry units, and raw feed material for production of Portland cement. Bottom ash has also been used as road base and subbase aggregate, structural fill material, as fine aggregate in asphalt paving and flowable fill, granular base embankment, backfill material, and for pipe-bedding material because of its low density and good drainage characteristics.

3. METHODOLOGY

The dry bottom ash samples used in this research were taken from different locations of the collecting ponds (or surface impounds) of the Calaca, Batangas Coal Power Plant and then mixed thoroughly and stored at the University of the Philippines Construction Materials and Structures Laboratory (UP CMSL). The determination of engineering properties of Calaca, Batangas Bottom Ash was divided into three categories: 1) Chemical Analysis – to know its chemical composition and its pH; 2) Physical Properties –includes the determination of the following properties: specific gravity and absorption, unit weight and voids, grain size distribution, Atterberg Limits, and soil classification; and 3) Mechanical Properties –includes the determination of the following properties: compaction characteristics, consolidation characteristics, shear and bearing strength parameters, durability and permeability. In this study it is assumed that the properties of bottom ash were constant during the period this study was conducted.

The engineering properties of Calaca, Batangas bottom ash were determined by conducting laboratory tests similar to test procedures for natural soils. The following laboratory tests were conducted on samples of the Calaca bottom ash.

Determination of Chemical Composition

The test method for chemical analysis covers the determination of chemical composition of Calaca, Batangas bottom ash. The UP Building Research Service (UP BRS), headed by Dr. Nathaniel Diola, requested the Industrial Technology Development Institute (ITDI) to conduct the chemical analysis. The percentages of oxides and loss on ignition (LOI) were determined. The oxides include Silicon Dioxide, Aluminum Oxide, Iron Oxide, Calcium Oxide, Magnesium Oxide, and Sulfur Trioxide.

Determination of pH

Standard test method for pH of soils provided in ASTM D 4972 – 95a was used. This test method covers the measurement of the pH of soils for uses other than for corrosion testing. This measurement determines the degree of acidity or alkalinity in soil materials suspended in water and a 0.01 *M* calcium chloride solution. Measurements in both liquids are necessary to fully define the soil's pH. This variable is useful in determining the solubility of soil materials and the mobility of ions in the soil and assessing the viability of the soil-plant environment.

Measurement of the pH of soils in both suspensions of water and calcium chloride solution were made with a potentiometer using a pH sensitive electrode system. The potentiometer was calibrated with buffer solutions of known pH.

Determination of Specific Gravity of Soils

Standard test method for specific gravity of soils provided in ASTM D 854 – 92 was used. This test method covers the determination of the specific gravity of soils that pass the 4.75-mm (No. 4) sieve, by means of pycnometer. When the soil contains particles larger than the 4.75-mm sieve, Test Method C 127 shall be used for the material retained on the 4.75-mm sieve.

Determination of Specific Gravity and Absorption of Fine Aggregate

Standard test method for Specific Gravity and Absorption of Fine Aggregate provided in ASTM C 128 – 93 was used. This test method covers the determination of bulk and apparent specific gravity, and absorption of fine aggregate.

The Bulk Specific Gravity is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate including Portland cement concrete, bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis. Bulk specific gravity determined on the saturated surface-dry basis is used if the aggregate is wet. Conversely, the bulk specific gravity determined on the oven-dry basis is used for computations when the aggregate is dry or assumed to be dry. The Apparent Specific Gravity pertains to the relative density of the solid material making up the constituent particles not including the pore space within the particles that is accessible to water. The Absorption values are used to calculate the change in the weight of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate has been in contact with water long enough to satisfy most of the absorption potential.

Determination of Unit Weight and Voids

Standard test method for unit weight and voids provided in ASTM C 29/C 29M – 91a was used. This test method covers the determination of unit weight in a compacted or loose condition and calculated voids in fine, coarse, or mixed aggregates based on the same determination. This test method is often used to determine unit weight values that are necessary for use for many methods of selecting proportions for concrete mixtures. It may also be used for determining mass/volume relationships for conversions.

Particle-Size Analysis

Standard test method for sieve analysis and hydrometer analysis of soils provided in ASTM D 422 – 63 was used. This test method covers the quantitative determination of the distribution of particle sizes larger than 75 μm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 μm is determined by sedimentation process, using a hydrometer to secure the necessary data. A knowledge of the sizes of solid particles comprising a certain soil type and their relative proportion in the soil mass is often useful. Particle-size distribution is used in soil classification, soil filter design, and used to predict in a general way how a soil may behave with respect to shear strength, settlement, and permeability.

Determination of Atterberg Limits

Standard test method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils provided in ASTM D 4318 – 84 was used. This test method covers the determination of the liquid limit, plastic limit, and plasticity index of soils. These limits distinguish the boundaries of several consistency states of plastic soils. This test method is used as an integral part of several engineering classification systems to characterize the fine-grained fractions of soils and to specify the fine-grained fraction of construction materials. The liquid limit, plastic limit, and plasticity index of soils are also used extensively, either individually or together with other soil properties to correlate with engineering behavior such as compressibility, permeability, compactibility, shrink-swell, and shear strength.

Soil Classification

Standard classification of soils for engineering purposes provided in ASTM D 248 – 92 was used. This standard describes a system for classifying mineral and organo-mineral soils for engineering purposes based on laboratory determination of particle-size characteristics, liquid limit, and plasticity index and shall be used when precise classification is required. The group symbol portion of this system is based on laboratory tests performed on the portion of a soil sample passing the 3-in. (75-mm) sieve. As a classification system, this standard is limited to naturally occurring soils. This standard is the ASTM version of the Unified Soil Classification System (USCS).

Compaction Test

Test method for laboratory compaction characteristics of soil using Modified Effort (Modified Proctor Test) provided in ASTM D 1557 – 91 was used. This test method covers laboratory compaction procedures used to determine the relationship between water content and the dry unit weight of soils (compaction curve). Compacted in a 4- or 6-in (101.6 or 152.4 mm) diameter mold with a 10-lbf (44.5-N) rammer dropped from a height of 18 in. (457 mm) producing a compactive effort of 56,000 ft-lbf/ft^3 (2,700 kN-m/m^3).

Soundness Test

Standard test method for soundness of aggregates provided in ASTM C 88 – 90 was used. This test method covers the testing of aggregates to estimate their soundness when subjected to weathering action in concrete or in other applications. This is accomplished by repeated immersion in saturated solutions of sodium or magnesium sulfate followed by oven drying to partially or completely dehydrate the salt precipitated in permeable pore spaces. The internal expansive force, derived from the rehydration of the salt upon re-immersion, simulates the expansion of water on freezing. This test method furnishes information helpful in judging the soundness of aggregates when adequate information is not available from service records of the material exposed to actual weathering conditions. The loss, difference between the original weight and the final weight of the test sample, is expressed as a percentage of the original weight of the test sample. This value is defined as the *Percent Loss*.

Los Angeles Abrasion Test

Standard test method for resistance to degradation of small-size coarse aggregate provided in ASTM C 131 – 89 was used. This test method covers a procedure for testing sizes of coarse aggregate smaller than 1½ in. (37.5 mm) for resistance to degradation by abrasion and impact in the Los Angeles Machine. The Los Angeles test has been widely used as an indicator of the relative quality or competence of various sources of aggregates having similar mineral compositions. The results do not automatically permit valid comparisons to be made between sources distinctly different in origin, composition, or structure. Specification limits based on this test should be assigned with extreme care in consideration of available aggregate types and their performance history in specific uses. The loss, difference between the original weight and the final weight of the test sample, is expressed as a percentage of the original weight of the test sample. This value is defined as the *Percent Loss*.

Consolidation Test

Standard test for one-dimensional consolidation properties of soil provided in ASTM D 2435 – 90 was used. This test method covers procedures for determining the magnitude and rate of consolidation of soil when it is constrained laterally and drained axially while subjected to incrementally applied controlled-stress loading. The data from the consolidation test are used to estimate the magnitude and rate of both differential and total settlement of a structure or earthfill. Estimates of this type are key importance in the design of engineered structures and the evaluation of their performance.

California Bearing Ratio Test

Standard test method for California Bearing Test Ratio (CBR) of laboratory-compacted soils provided in ASTM D 1883 – 92 was used. This test method covers the determination of the CBR of pavement subgrades, subbase, and base/coarse materials from laboratory compacted specimens. The test method is primarily intended for but not limited to, evaluating the strength of cohesive materials having maximum particle sizes less than ¾ in. (19 mm). This test method is used to evaluate the potential strength of subgrade, subbase, and base course materials including recycled materials for use in road and airfield pavements. The CBR value obtained in this test forms an integral part of several flexible pavement design methods.

Direct Shear Test

Standard test method for Direct Shear Test of Soils Under Consolidated Drained Conditions provided in ASTM D 3080 – 90 was used. This test method covers the determination of the consolidated drained shear strength of a soil material in direct shear. The test is performed by deforming a specimen in a controlled strain rate on or near a single shear plane determined by the configuration of the apparatus. Generally, three or more specimens are tested, each under a different normal load, to determine the effects upon shear resistance and displacement, and strength properties such as Mohr strength envelopes.

Permeability Test

The permeability test covers the determination of coefficient of permeability of soils. The permeability of a soil is a measure of the ease with which a particular fluid (especially water) flows through its voids and has the same unit as velocity. The Falling–Head method provided in EM-1110-2-1906 was used to determine the coefficient of permeability of compacted Calaca, Batangas bottom ash and it was conducted by Philippine Geoanalytics, Inc. (PGA). In this test method, the bottom ash sample was compacted inside the permeameter and then saturated with water. The water was allowed to move through the specimen under falling head condition, while the time required for a certain quantity of water to pass through the specimen was measured and recorded.

4. RESULTS AND DISCUSSION

Chemical Analysis

Bottom ash is composed principally of silica, alumina, and iron, with smaller percentages of calcium, magnesium, and other compounds. The bottom ash from Calaca, Batangas is made up of eight compounds where in the silicon dioxide is the most abundant and followed by aluminum oxide (Table 1). The loss on ignition is relatively high which means that the bottom ash still contains unburned carbon or other organic matters before the chemical analysis was performed. It should be noted that the loss on ignition is the fraction of the original material that has been lost after igniting the material to constant weight in an uncovered porcelain crucible at 1382 ± 122°F (750 ± 50°C). This ignition is only done after the material has been oven-dried at 221 to 230°F (105 to 110°C). A pie graph for the chemical composition of the bottom ash is shown in of Fig.1.

Table 1 – Chemical Composition of Bottom Ash

Compound	Symbol	Percentage
Silicon Dioxide	S_iO_2	49.11
Aluminum Oxide	Al_2O_3	21.81
Iron Oxide	Fe_2O_3	5.89
Titanium Dioxide	TiO_2	0.42
Calcium Oxide	CaO	6.64
Magnesium Oxide	MgO	3.24
Potassium Oxide	K_2O	0.91
Sodium Oxide	Na_2O	0.72
Sulfur Trioxide	SO_3	0.00
Loss on Ignition	LOI	11.29

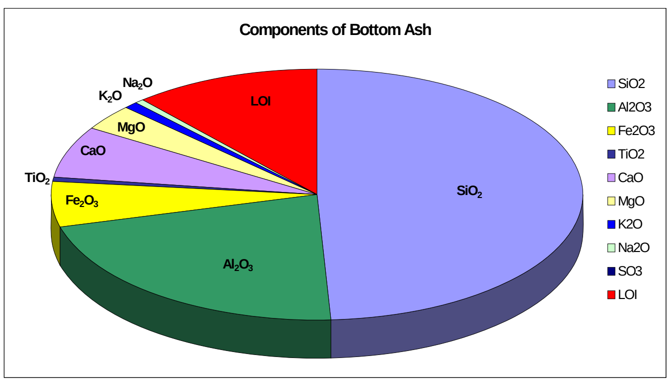

Fig. 1 – Pie Chart for the chemical Composition of Bottom Ash

pH Measurement

The measurement of pH for the bottom ash samples in both suspensions of water and calcium chloride were done using an electronic (digital) pH meter. Test results showed that the bottom ash in water suspension gave an average pH of 6.16 while the bottom ash in suspension of calcium chloride solution gave an average pH of 5.62. pH values obtained in the suspension of calcium chloride solution were slightly lower due to the release of more alumina ions which then hydrolyses. Calaca, Batangas bottom ash is relatively acidic but plants can still thrive on it.

Specific Gravity

The specific gravity and absorption of dry bottom ash is a function of chemical composition, with higher carbon content resulting in lower specific gravity and higher absorption. Also, bottom ash with a low specific gravity and high absorption has a porous or vesicular texture, a characteristic of popcorn-like particle that readily degrade under loading or compaction.

Using the standard test method for determining the specific gravity of soils (ASTM D 854 – 92), the specific gravity of the bottom ash fraction passing U.S. Sieve No. 4 was observed to range from 1.899 to 1.903. The average specific gravity for the three samples was 1.9.

Using the standard test method for determining the specific gravity and absorption of fine aggregates (ASTM C 128 – 93) for the bottom ash fraction passing U.S. Sieve No. 4 were the following: the average bulk specific gravity (dry) was observed to be 1.85, the average bulk specific gravity (saturated surface dry) was observed to be 1.94, and the average apparent specific gravity was observed to be 2.03. The absorption of the bottom ash was observed to range from 4.07% to 5.66%, and the average was 4.81%.

Based on the results of the determination of specific gravity and absorption, it shows that Calaca, Batangas bottom ash is much lighter than ordinary sand, which has a specific gravity of 2.65, and has a relatively high absorption. This is caused by the presence of unburned carbon and very porous or vesicular textured particles. On the other hand, low specific gravity means that it has more volume per unit-weight.

Unit Weight and Voids

The unit weight and voids of the bottom ash using ASTM C 29/C 29M – 91a were the following: for Roding Method, the average unit weight and average void ratio were observed to be 10.277 kN/m^3 and 76.31%, respectively; and for the Shoveling Method, the average unit weight and average void ratio were observed to be 9.275 kN/m^3 and 95.22%, respectively.

Particle-size Analysis

The grain or particle-size distributions obtained from the three samples were relatively close to each other. As shown in Fig. 2 (a), bottom ash can be considered fairly well graded. The fine fraction passing U.S. Sieve No. 200 was in the range of 1.03% to 2.28%. The Uniformity Coefficient, $\mathbf{C_u}$ ranged from 9.73 to 10.313 and the Coefficient of Gradation, $\mathbf{C_c}$ ranged from 0.732 to 0.751.

The lower and upper limits of fine aggregate gradation based on the Standard Specifications for Concrete Aggregate ASTM C 33 – 92a are also shown in Fig. 2 (a). It can be observed that the gradation of the bottom ash does not fit the acceptable range for concrete fine aggregates. Thus, the Calaca, Batangas bottom ash should be mixed with other graded aggregates if it is intended to be used as concrete fine aggregate. Moreover, Fig. 2 (b) shows the gradation of four different types of construction materials namely: Boulder Dam concrete aggregate, Fort Peck sand, Well-graded rolled-fill dam material, and Boston blue clay.

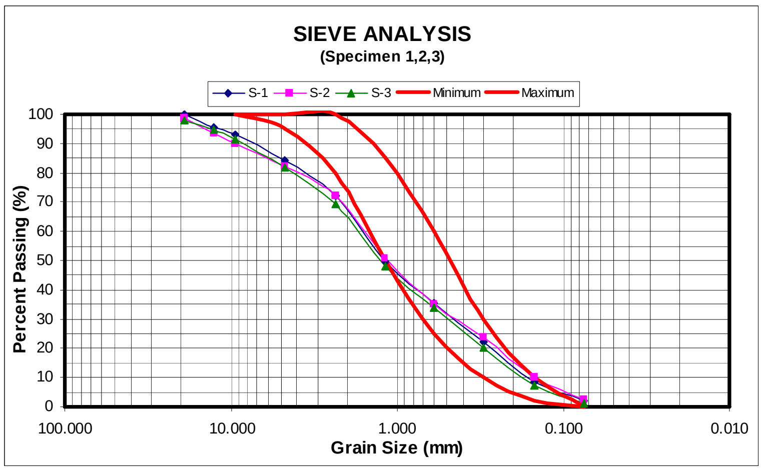

Fig. 2(a) – Bottom Ash

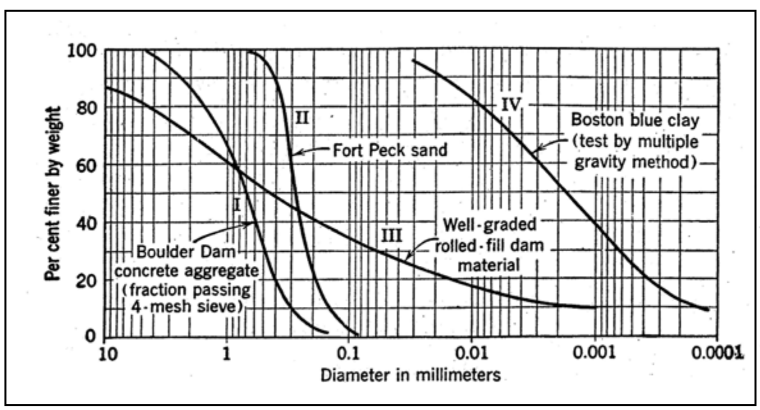

Fig. 2(b) – Other Construction Materials (Taylor, 1967)

Fig. 2 – Particle-Size Distribution of Bottom Ash and Other Construction Materials

Atterberg Limits

As expected, bottom ash has no Atterberg Limits. Even if the tests were done with extreme care, the bottom ash pat keeps on sliding relative to the surface of the liquid limit device when making the groove. As a result, only one blow was required to close the groove. Therefore the bottom ash is conclusively a cohesionless coarse granular material.

Soil Classification

Using the results of the Particle-Size analysis for the three specimen samples, the following were observed: 1) more than 50% were retained on the U.S. No. 200 sieve; 2) more than 50% of the coarse fraction passed thru the U.S. No. 4 sieve; 3) the fine fraction is more than 12%; and 4) contains less than 15% gravel. Based on the Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System) describe in ASTM D 2487 – 92, the Calaca, Batangas bottom ash falls under the Silty Sand (SM) classification.

Compaction Test

Three sets of compaction test, using the standard method provided in ASTM D 1557 – 91 for Modified Effort (Modified Proctor Test), were done to determine the compaction behavior of the bottom ash. The compaction curve for Trial 2 gave the highest maximum dry unit weight of 11.983 kN/m^3 (maximum dry density, MDD = 1221.88 kg/m^3) with optimum moisture content (OMC) of 25.124%, as shown in Fig. 3. The bottom ash gave maximum dry unit weights ranging from 11.675 kN/m^3 to 11.983 kN/m^3 at optimum moisture contents ranging from 17.1% to 25.124%. The average values for the maximum dry unit weight and optimum moisture content were 11.779 kN/m^3 (MDD = 1201.11 kg/m^3) and 22.24% respectively.

The shape and size distribution of bottom ash particles and their relative positions influence the denseness of packing. Void ratios ranging from 0.555 to 1.081 were computed from the three samples. It should be noted that the compaction curves for bottom ash samples have no pronounced peaks.

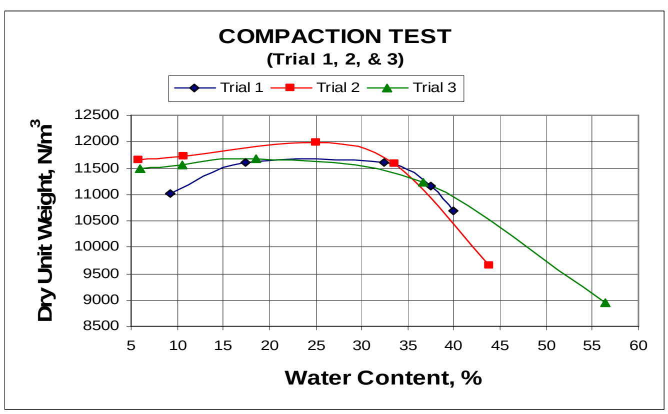

Fig. 3 – Compaction Curves for Bottom Ash

Degradation

Soundness Test

Using the test method provided in ASTM C 88 – 90, three sets of soundness tests were conducted. Each bottom ash specimen were repeatedly immersed in saturated solution of sodium sulfate followed by oven drying to partially or completely dehydrate the salt precipitated in permeable pore spaces. After five (5) cycles of immersion and drying, the measured losses were 20.6%, 22.7%, and 18.6% (average loss = 20.6%). This percent loss is relatively high compared to the 15% weight loss specification provided in ASTM D 1073 (Standard Specifications for Fine Aggregate in Bituminous Paving Mixtures).

Los Angeles Abrasion Test

The Los Angeles Abrasion test was conducted to measure the degradation of bottom ash, falling under Grading D and with a total mass of 5 kg, resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum which contained six steel spheres with a total charge weight of 2512.2 g. As the drum rotates, a shelf plate picks up the sample and steel spheres, carrying them around until they are dropped to the opposite side of the drum, creating an impact-crushing effect. The contents then roll within the drum with an abrading and grinding action until the shelf plate impacts and the cycle is repeated. After 500 revolutions at a speed of 33 revolutions per minute (rpm), the bottom ash was removed from the drum and sieved using U.S. Sieve No. 12.

Two specimen samples were used to determine the general degradation characteristic of bottom ash for the Los Angeles Abrasion Test. The test results showed that for the first sample the percent loss was 51.34% while for the second sample the percent loss was 56.4%. These values exceed the ASTM D 1241 – 68 requirement for soil aggregate base and subbase materials (less than 50%). Thus, Calaca, Batangas bottom ash cannot be used as base or subbase material.

Compaction Test

The results of the sieve analysis after the compaction test on the three bottom ash samples showed significant degradation of bottom ash particles. The samples were compacted at optimum moisture content (OMC = 22.24%) using the Modified Effort (2,700 kN-m/m_3). The changes in the percent retained on the sieves used in the particle-size analysis are shown in Table 2. A negative percent change means loss of retained particles while a positive percent change means gain of retained particles. It can be observed that the average change in percent retained for the U.S. Sieve Nos. 8, 16, 30, and 50 were all negative while for U.S. Sieve Nos. 100 and 200 were positive. This means that the bottom ash particles with sizes ranging from 0.30 mm to 2.36 mm were the ones that generally degrade during the compaction. These particles can be associated to the agglomerated or popcorn-like particles. Also, it should be noted that the particles retained in U.S. Sieve No. 6 (1.18mm) had the maximum recorded change in percent retained (-32.49%).

Table 2 – Degradation of Bottom Ash after Compaction Using Modified Effort

Sieve No.	Sieve Size	Percent Change in % Retained			
	(mm)	Specimen 1	Specimen 2	Specimen 3	Average
No. 8	2.360	-19.42	-22.67	-27.91	-23.34
No. 16	1.180	-26.55	-25.76	-32.49	-28.27
No. 30	0.600	-19.55	-20.12	-21.78	-20.48
No. 50	0.300	0.75	-7.81	1.18	-1.96
No. 100	0.150	15.41	15.10	15.13	15.21
No. 200	0.075	26.03	19.72	21.87	22.54
PAN		62.03	85.92	35.89	61.28

The fraction of the bottom ash samples for Specimens 1, 2, and 3 that generally degrade were 9.91%, 11.36% and 9.60%, respectively. The following figures show the particle-size distribution for the three bottom ash samples before and after laboratory compaction using the Modified Effort (2,700 kN-m/m^3).

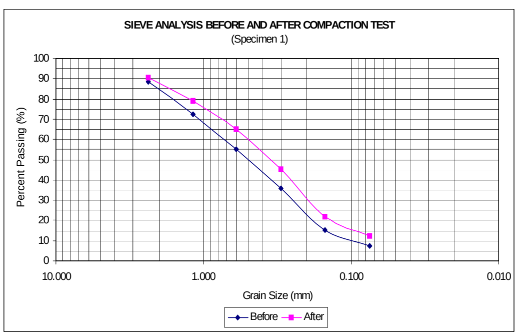

Fig. 4(a) – Specimen 1

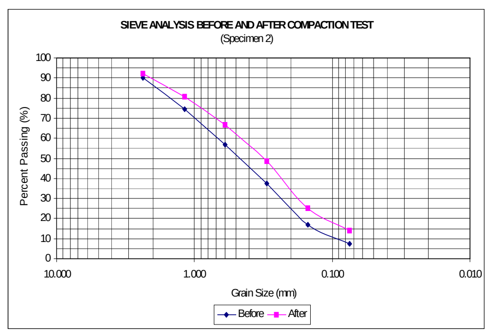

Fig. 4(a) – Specimen 2

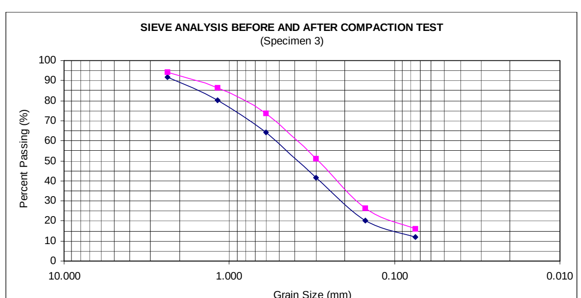

Fig. 4(a) – Specimen 3

Fig. 4 - Particle-Size Distribution Before and After Laboratory Compaction Using Modified Effort

Consolidation Test

Only one bottom ash sample was tested for consolidation. The bottom ash specimen was prepared in a loose condition with moisture content of 22.24% (OMC) on the consolidation ring. The initial void ration was computed equal to 1.57. The specimen was inundated immediately after the application of the seating load and subjected to increments of constant load: 1, 2, 4, 8, and 16 kg. The duration of each load increment was one day (24 hours), conforming to ASTM guidelines. For each load increment, the deformation reading at the elapsed times were recorded and plotted using Logarithm of Time Fitting Method.

For each load increment, the final void ratio, $\boldsymbol{e}$, and coefficient of consolidation, $\boldsymbol{C_V}$, were computed. The values of the coefficient of consolidation ranged from 10.872 to 65.403 mm^2/min while the compression index, $\boldsymbol{C_{Cc}}$, was observed to be equal to 0.138 as shown in the void ratio versus vertical pressure graph in Fig. 5.

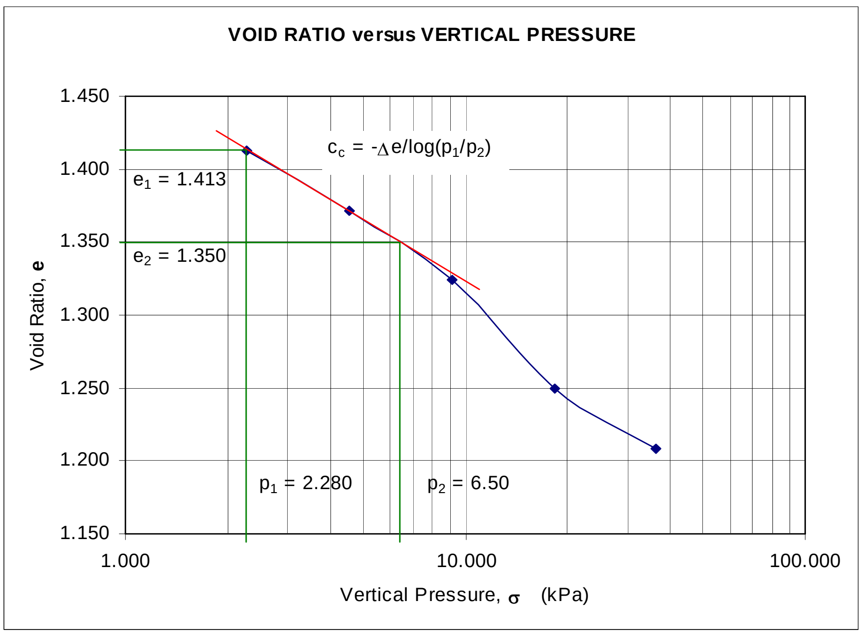

Fig. 5 – Determination of Compression Index, $\mathbf{C_c}$

Since bottom ash falls under the SM (Silty Sand) classification, it is considered as a free-draining material that can be compacted into relatively dense incompressible mass. Also, there will be no (if not little) problems in development of excess pore water pressure. For these reasons, structural fills constructed from bottom ash will exhibit small amounts of time-dependent, post construction consolidation or deformation. Most deformation due to the mass of the fill or structure will occur during construction.

California Bearing Ratio (CBR) Test

Three specimens of bottom ash samples were compacted at optimum moisture content (OMC = 22.24%) using the modified effort compaction procedure (ASTM D 1557). The number of blows used per layer for each compacted specimen were 10, 30, and 65 in order to determine the CBR at maximum dry unit weight. The measured CBR values for each bottom ash specimens were 1.3%, 15.1%, and 38.1%, respectively. Using these data, the CBR versus the molded dry unit weight were plotted as shown in Fig. 6. From the graph, the Design CBR for at the maximum dry unit weight was identified to be equal to 36.33%, which is within the range of the CBR values for "Good" materials that can be used as Base or Subbase (refer to Table 3).

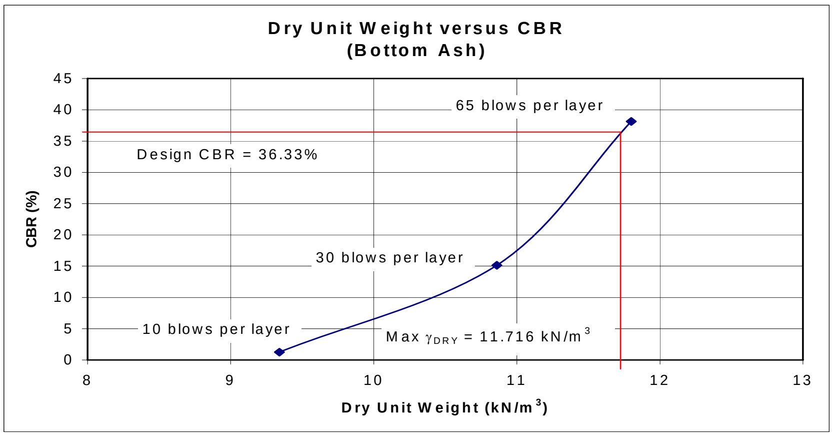

Fig. 6 – Design California Bearing Ratio (CBR)

Table 3 – CBR Rating (Bowles, 1986)

CBR No.	General Rating	Uses	Classification System: Unified	Classification System: AASHTO
0 - 3	Very poor	Subgrade	OH, CH, MH, OL	A5, A6, A7
3 - 7	Poor to fair	Subgrade	OH, CH, MH, OL	A4, A5, A6, A7
7 - 20	Fair	Subbase	OL, CL, ML, SC, SM, SP	A2, A4, A6, A7
20 - 50	Good	Base, subbase	GM, GC, SW, SM, SP, GP	A1b, A2-5, A3, A2-6
> 50	Excellent	Base	GW, GM	A1a, A2-4, A3

Direct Shear Test

Three specimen samples were prepared for the direct shear test of the compacted bottom ash. Initially, the bottom ash was intended to be compacted to its maximum dry unit weight of 11.779 kN/m^3. However, difficulty was encountered in compacting the specimens in the direct shear test apparatus. Compaction of the three specimen samples could only be achieved up to 11.219 kN/m^3, which is still above 95% of the maximum dry unit weight (11.190 kN/m^3). The tests were conducted under consolidated drained condition with a shearing rate of 0.12 mm/min.

The normal stresses used to determine the maximum shear stresses for each of the three specimen samples were 0.278, 4.0, and 8.0 kg/cm^2, respectively. The maximum shear stress is taken to be either the peak shear stress on the Shear Stress (kPa) versus Horizontal Shear Displacement (mm) graph or the shear stress at horizontal shear displacement of 10% of the original dimension, whichever is obtained first during the test. Table 4 shows the normal stresses and the corresponding maximum shear stresses, both in kilo Pascals (kPa), for the three specimen samples.

In order to establish the shear strength parameters (cohesion and angle of internal friction) of the compacted bottom ash, the graph of Maximum Shear stress (ordinate) versus Normal Stress (abscissa) was prepared as shown in Fig. 7. A straight line (best fit) was drawn through the plotted points and extended to intersect the ordinate. The shear stress intercept gives the cohesion, c, while the slope of the line gives the angle of internal friction, ϕ, of the sample. From the graph, it was determined that the cohesion and the angle if internal friction of the compacted bottom ash were 59.944 kPa and 42.41°, respectively.

It should be noted that in the direct shear test, the specimens are forced to fail along the horizontal plane only and not along the weakest plane. Thus, the test method gives relatively high strength parameters.

Table 4 – Maximum Shear and Normal Stresses

Maximum Shear Stress (kPa)	Normal Stress (kPa)
47.89	27.26
489.53	392.28
742.06	784.56

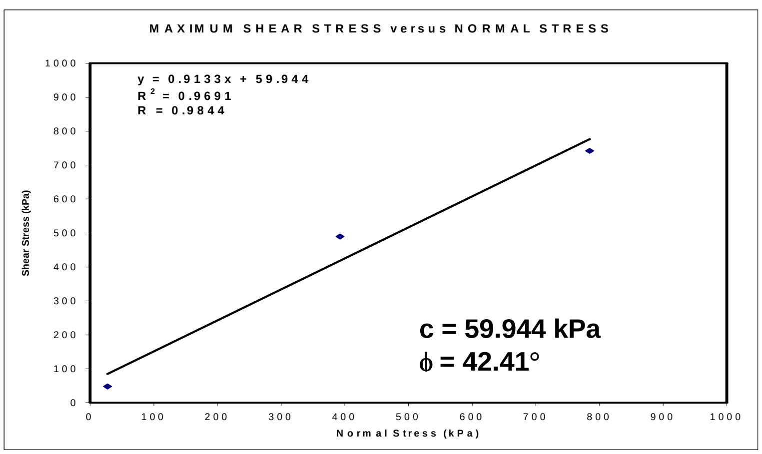

Fig. 7 – Cohesion and Angle of Internal Friction Using Direct Shear Test

Permeability Test

Two specimen samples of compacted bottom ash (100% BA) were prepared at 100% MDD for the permeability test using the falling head method. Ten permeability readings were done for each sample. The average values of coefficient of permeability for the two samples were 6.7275 x 10^{-5} and 5.6348 x 10^{-5} cm/s. With this range of coefficient of permeability values, compacted bottom ash can be compare to the permeability of silts ($10^{-3} < k < 10^{-5}$). Based on the classification of soils according to their coefficient of permeability by Terzaghi, both compacted bottom ash samples have "low" degrees of permeability.

Comparison of physical and mechanical properties of Calaca, Batangas bottom ash with USA bottom ash are shown in Table 5.

Table 5 – Comparison of Physical and Mechanical Properties of Bottom Ash

Property	Calaca, Batangas Bottom Ash	USA Bottom Ash
Specific Gravity	1.9	2.1 – 2.7
Dry Unit Weight (kN/m^3)	9.02 – 10.87	7.06 – 15.69
Absorption	4.07 – 5.66	0.8 – 2.0
Plasticity	None	None
Maximum Dry Unit Weight (kN/m^3)	11.68 – 11.98	11.87 – 15.89
Optimum Moisture Content (%)	17 - 25	12 – 24
Sodium Sulfate Soundness Loss (%)	18.6 – 22.7	1.5 – 10
Los Angeles Abrasion Loss (%)	51.34 – 56.4	30 – 50
Coefficient of Consolidation, C_v (mm^2/min)	10.87 – 65.4	
California Bearing Ratio (CBR%)	36.33	40 – 70
Internal Friction Angle, ϕ (degrees)	*42.41	32 – 45
Cohesion, c (kPa)	*59.944	
Permeability (cm/sec)	*5.63 x 10^{-5} – 6.73 x 10^{-5}	10^{-2} – 10^{-3}

*compacted

5. CONCLUSIONS

Calaca, Batangas bottom ash is composed principally of silica and alumina with smaller percentages of calcium, iron and other compounds. pH measurement of bottom ash in water suspension gave an average pH of 6.16 while the bottom ash in suspension of calcium chloride solution gave an average pH of 5.62. The bottom ash is relatively acidic but plants can still thrive on it.

The bottom ash is light-weight, non-plastic and free-draining material that falls under the Silty Sand (SM) classification. The bottom ash can be used as construction material for structural fills, back fills, embankments, dikes, and other applications requiring a compacted fill material provided that it should be properly compacted. Although the compacted bottom ash had a good result in the California Bearing Ratio Test, bottom ash might not be an effective construction material for Base or Subbase due to its degradation characteristic.

The low specific gravity (Gs = 1.9) of this material can be advantageous for some structural fill applications. Using a lighter weight material will reduce the load on weak layers or zones of soft foundation soils such as poorly consolidated or landslide-prone soils. Additionally, the low unit weight of this material will reduce the transportation costs since less tonnage of material is hauled to fill a given volume.

It should be noted that as long as the coal source and the furnace combustion efficiency are kept the same, then it can be concluded that the engineering properties of the bottom ash will most likely stay the same. Finally, the recycling of coal combustion byproducts (CCBs) as raw materials in applications that are environmentally sound, technically safe and commercially competitive should lead to a reduction in the practice of land filling these materials. The utilization of large quantity of bottom ash can mitigate or solve the disposal and environmental problems associated to it. Apart from solving the problems at its cause, a coal combustion product is made valuable and is also a way to save natural resources as well as energy.

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