EVALUATION OF THE ENGINEERING PROPERTIES OF CEMENT-TREATED BASE WITH THE APPLICATION OF CRUSHED MANGIMA AGGREGATE AS ROAD BASE MATERIAL

Jonathan B. Calibara[1], Sarah O. Namoco[1], Mohd Rosli Mohd Hasan[2]
[1]University of Science and Technology of Southern Philippines, Cagayan de Oro City, Philippines
[2]Sustainable Asphalt Research Group (SARG), School of Civil Engineering, Universiti Sains Malaysia
(Engineering Campus), 14300 Nibong Tebal, Penang.
Corresponding author’s email: jonathan.calibara@ustp.edu.ph

ABSTRACT. *The construction industry's demand for aggregates is rapidly increasing resulting in a higher depletion of basalt aggregate resources. To address this growing need, it is imperative to explore alternative materials. This study investigates and assesses the viability of using cement-treated Mangima aggregate as a material for road bases. Laboratory tests conducted were the Sieve Analysis Test, Liquid Limit and Plastic Limit Test, Abrasion Test, Modified Proctor Test, CBR Test, and UCS Test. The results obtained showed that the untreated aggregate (control mix) was classified as Grading A as per item 204 of the DPWH bluebook specification of the Philippines. The soil was classified as A-2-4(0) and GM-GW according to the American Association of State Highway and Transport Officials (AASHTO) and the Unified Soil Classification System (USCS) Classifications, respectively. The results revealed that by adding Portland cement (6%, 8% & 10%), the dry density, CBR and UCS of the mixture has improved. The highest MDD, CBR, and UCS were found to be at 10% cement addition. Using SPSS, the result revealed that there was a statistically significant difference between the strength of each design mixture with a value of (H(4) = 10.828, p = 0.029); (H(4) = 12.933, p = 0.012) & (H(4) = 12.982, p = 0.011) for Compaction, CBR and UCS, respectively. The p-value for each test falls below the 0.05 significance level. The result suggests the potential of employing a Cement-Treated Base with Crushed Mangima Aggregate as a road base material. The study recommends optimizing the replacement of crushed Mangima coarse aggregate for road-based applications, particularly when considering cement stabilizers.*

Key Words: *Construction Material, Cement-Treated Base, Mangima Aggregate, Road Base Material, Stabilization*

1. INTRODUCTION

In several regions in the Philippines, the traditional materials used for road construction are becoming increasingly scarce. Simultaneously, the demand for high-strength aggregates is surging across various industries [1]. Annually, the construction industry consumes substantial amounts of natural aggregates, resulting in the depletion of raw materials and environmental ecosystem degradation [2]. Additionally, the sources of natural aggregates in proximity to Metro Manila are nearly depleted, necessitating the transportation of aggregates from distant quarries. The recycling of concrete debris presents a viable avenue to mitigate the overall environmental impact associated with the construction sector. Thus, the reclamation of aggregates from concrete debris offers both environmental and economic advantages [3].

Given the overexploitation of natural aggregate resources, it becomes imperative to prevent the depletion of these valuable natural resources. This underscores the practicality of employing recycled aggregates as a sustainable solution [4]. Current road and pavement engineering practices have turned to the utilization of reclaimed and recycled materials from old structures as a viable source of construction materials. This shift is primarily driven by the scarcity of readily available natural aggregates (granular materials) and the escalating manufacturing expenses [5].

In light of this situation, the researcher found it necessary to explore alternative options for the application of a road-based layer. One promising aggregate material is the Mangima stone, which is abundant in the local area and can be readily sourced in Bukidnon, Philippines [6].

1.1 Mangima Stone as an Aggregate

Mangima stones are used as decorative tiles for wall finishing in the building construction industry due to their rock accent effect which also improves the aesthetic appearance due to natural rock colors. When cut into tiles, these Mangima stones entail considerable waste, which is mostly overlooked as waste materials. This potential aggregate for construction purposes has been recognized in previous studies [7]. Another study suggests that when combined with eggshell powder (ESP), Mangima fine aggregate becomes a highly suitable material for the production of innovative concrete paver blocks [8].

The use of Mangima aggregate in concrete mixtures comprising 25% Mangima aggregate and 75% Basalt aggregate provides significant findings and achieves the highest compressive strength [6]. Notably, this concrete mixture exhibited a 26% higher strength compared to conventional basalt concrete. However, despite its availability, Mangima stone has not yet been employed as a road-based material due to concerns regarding its durability because the aggregate absorbs more water [7]. The objective of this research is to explore the utilization of Mangima stone as a component within the road base mixture.

According to item 203.2 of the DPWH specification, a soil aggregate, whether crushed or in its natural granular form, must comprise strong and long-lasting stones and rocks of approved quality, devoid of excessive flat, elongated, soft, or deteriorated pieces, or any undesirable elements. Meanwhile, the crushed Mangima aggregate material demonstrates certain inherent weaknesses concerning its characteristics. To address these issues, the researcher proposes the introduction of stabilization techniques for crushed Mangima aggregate.

1.2 Stabilization and Stabilizers

Stabilization represents a procedure that entails blending and integrating substances into the soil to augment particular soil qualities [9]. Its primary objective is the enhancement of the soil engineering qualities before the onset of construction operations. The introduction of cementitious agents like lime, cement, and industrial byproducts such as fly ash and slag into the soil can lead to enhancements in geotechnical properties. Among the array of stabilizing agents at any disposal, the utilization of cement-based stabilizers stands out for its capacity to enhance durability, fortify strength, and ensure the creation of a robust, crack-resistant foundational layer [10].

1.3 Cement as Stabilizer

Cement is used for cementing properties and pozzolanic activity in most soil improvement applications [11]. To unlock the potential of crushed Mangima aggregate for use as a road-based material, the researcher intends to explore a solution involving the incorporation of cement into the material. The researcher introduces the use of cement as a stabilizer. One specific form of stabilized foundation layer is known as a cement-treated base (CTB). Road bases or sub-base pavements often incorporate cement-treated materials, which are combinations of compacted granular aggregates, Portland cement, and water [12]. The use of Portland cement type-I as a stabilizing agent offers several advantages, which include: (a.) enhanced strength and stiffness (b.) improved volume stability, and (c.) enhanced durability [13].

1.4 Cement-Treated Base

Cement-treated base (CTB) has become the most popular cement-modified road-base material [14]. *In-situ* cement stabilization is the most cost-effective and environmentally friendly method [15]. The results revealed that by adding Portland cement, the mechanical properties of the mixture have improved [16]. Cement Treated Base (CTB) becomes more important to modern road pavement under a better performance perspective. Furthermore, another study revealed that a more compacted cement paste structure is beneficial to improve the mechanical properties of CTB [17]. However, CTB has the inherent characteristic of fatigue deterioration corresponding to damage evaluations under repeated loading [18].

To harness the potential of crushed Mangima aggregate as a road construction material, the researcher plans to investigate a potential remedy by introducing cement into the mix. Specifically, this study intends to seek answers to the following questions:

1. What is the physical property of the untreated and treated mixtures in terms of sieve analysis, liquid limit plastic limit, and abrasion?
2. What is the mechanical property of the untreated and treated mixtures in terms of Modified Proctor, California Bearing Ratio, and Unconfined Compressive Strength?
3. What is the significant difference between the means of the strength of different mixtures?

H_0 = There is no significant difference between the means strength of the treated mix to the control mix.

H_1 = There is a significant difference between the means strength of the treated mix to the control mix.

2. Methodology

2.1 Specimen Preparation

The study began by collecting the necessary materials for the experimentation. These materials include Mangima stone, conventional basalt and soil, Portland cement, and water. It was emphasized that all collected materials were clean and free from any deleterious substances or contaminants. This ensures that the materials used in the experiments meet the required quality standards of DPWH. The collected Mangima stone was crushed into the desired aggregate shape. This step is crucial for preparing the crushed Mangima aggregate, which is a key component of the road base material. The researcher followed and adhered to the minimum requirements and standards set by relevant organizations, including the American Society for Testing and Materials (ASTM) and the Department of Public Works and Highways (DPWH). Compliance with these standards is essential for ensuring the validity and reliability of the experiments. The materials, once prepared, were subjected to sampling, preparation, and testing. These tests and procedures are conducted by established standards to assess the properties and performance of the proposed road mix base material. All samples were prepared by the researchers and tested in an independent testing laboratory. The physical and mechanical testing results were gathered through official reports from the accredited laboratory of the DPWH. The results were subject to data analysis.

By the DPWH bluebook specification, the modified base course typically comprises a soil-aggregate mixture, with 55% consisting of coarse aggregate and 45% fine aggregate. This traditional mixture served as the basis for modifying the coarse aggregate combination. The current study, however, employed a mixture proportioning approach [6]. This approach entails using a blend of 25% crushed Mangima aggregate and 75% Basalt aggregate. The design mixtures for this study are detailed in Table 1.

Table 1 Design Mix for the Road Base Material

	Coarse Aggregate		Fine Aggregate	Stabilizer
Design Mix	Basalt Aggregate (%)	Crushed Mangima Aggregate (%)	Conventional Fine Materials	Cement (%)
Conventional Mix	55%	0%	45%	0%
Control Mix	41.25%	13.75%	45%	0%
Cement-Treated-1 (CT-1)	41.25%	13.75%	45%	6%
Cement-Treated-2 (CT-2)	41.25%	13.75%	45%	8%
Cement-Treated-3 (CT-3)	41.25%	13.75%	45%	10%

Source: DPWH Bluebook Specification(Item 204)

2.2 Laboratory Testing and Specifications

The Mangima aggregate underwent a series of quality tests mandated by the DPWH. These tests include sieve analysis, plastic limit and liquid limit test, LA Abrasion test, Modified Proctor test, CBR test, and UCS test. To obtain a specimen, three different methods (moist, air-dry, and oven-dry) were outlined for processing the sample. For mechanical testing, each design mixture has three (3) samples indicated in Table 1 that were subject to testing of Modified Proctor, CBR, and UCS.

2.2.1 Sieve Analysis (ASTM D6913)

This test was conducted to evaluate the distribution of various grain sizes within a soil sample, utilizing a mechanical or sieve analysis method [19]. In this study, the untreated mixtures, including both conventional and control samples, were used for the sieve analysis testing. The procedure employed square opening sieves with standard sizes ranging from 3 inches (75 millimeters) down to No. 200 (75 micrometers) sieves. To set up the stack of sieves, the researcher began by placing the largest sieve at the top and continued adding the remaining sieves in descending order of sieve size. The pan was placed at the bottom, and the lid at the top of the sieve stack. The dried soil sample was transferred from its container onto the top sieve in the stack. Then, the researcher started sieving the soil and weighed the retained soil in each sieve. The percent passing was calculated.

2.2.2 Liquid Limit and Plastic Limit (ASTM D4318)

The Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) of soils were frequently used, either separately or in combination with other soil characteristics, to establish correlations with engineering properties [20]. These limits were essential in defining the various consistency states of plastic soils. In this study, the soil material from the proposed mixtures was employed to determine and assess the plasticity index of the material. To conduct the liquid limit and plastic limit tests, the researcher selected the soil specimen material that had passed through the 425-μm (No. 40) sieve. The collected soil specimen for LL and PL testing weighed approximately 150 to 200 grams.

Liquid Limit Test

The researcher started the test by thoroughly mixing the soil specimen in its mixing cup. As needed, the water content was adjusted until the consistency required approximately 25 to 35 blows from the liquid limit device to close the groove. The prepared material was placed in the mixing/storage dish, its consistency was checked and covered to prevent moisture loss. The material was allowed to stand (cure) for a minimum of 16 hours, typically overnight. Using a spatula, a portion or portions of the prepared soil were transferred into the cup of the liquid limit device. The cup rested on the base, was pressed down, and spread evenly within the cup. The depth was approximately 10 mm at its deepest point, gradually tapering to create a roughly horizontal surface. Any soil not used was stored in the mixing/storage dish. The mixing/storage dish containing the unused soil had to be covered with a damp towel or other methods to prevent moisture from escaping. After each trial, the water content (Wn) of the soil specimen was determined following Test Method D 2216. An oven capable of maintaining a consistent temperature of 110 ± 5 °C was used for the water content determination.

Plastic Limit Test

For the PL test, the researcher began by selecting a portion of the plastic-limit specimen that weighed between 1.5 to 2.0 grams. The chosen portion was shaped into an ellipsoidal mass. The soil mass was rolled using one of the following methods: the hand method or a rolling device. The soil mass was rolled between the hand (palm or fingers) and a ground-glass plate. Just enough pressure was applied to shape the mass into a thread of uniform diameter throughout its length. The thread was deformed on each stroke until its diameter reached 3.2 mm (1/8 inch). After each trial, the water content (Wn) of the soil specimen was determined following Test Method D 2216. The water content determination was conducted inside an oven utilizing a consistent temperature of 110 ± 5 °C. Once the values for the liquid limit and plastic limit had been obtained, the plasticity index was calculated by subtracting PL from LL.

2.2.3 Los Angeles Abrasion Testing (ASTM C131)

The Los Angeles Abrasion Test principle involved assessing the percentage of wear caused by the interaction between the aggregate sample and steel balls acting as an abrasive charge [21]. In this study, the crushed Mangima aggregate was used as the sample to evaluate the hardness and durability of the materials. The researcher started the test by placing the sample, along with the charge (steel balls), into the Los Angeles testing machine. The drum of the L.A. abrasion machine started rotating, and during this rotation, a shelf plate collected the aggregate sample along with the steel balls. The machine was rotated at a speed ranging from 30 to 33 revolutions per minute (r/min) for a total of 500 revolutions. This replicated the abrasive wear that the material might undergo in real-world applications. The drum rotated for a predetermined number of rotations or revolutions, subjecting the aggregate to repeated abrasive action. After completing the specified number of revolutions, the material was discharged from the machine. An initial separation of the sample was conducted using a sieve that was coarser than the 1.70-mm (No. 12) sieve. The aggregate portion of the sample was then sieved to determine the percentage loss of particles.

2.2.4 Modified Proctor Test (ASTM D1557)

Laboratory compaction tests were crucial for determining vital parameters such as percent compaction and the molding water content required to achieve specific engineering properties [22]. These tests played a critical role in quality control during construction, ensuring that the desired compaction levels and water contents were achieved. In the case of base course materials, like those utilized in this study, the modified Proctor test was employed. These test methods were applicable to soil samples containing 30% or less, by mass, of particles that were retained on the 3/4-inch (19.0-mm) sieve. The researcher prepared a specimen that should not have been previously compacted in a laboratory setting, meaning that previously compacted soil should not have been reused in these tests. The compaction procedure involved moist soil being compacted into the mold in five layers, with each layer having approximately equal mass and/or thickness. Each layer underwent 56 blows, ensuring that the blows were evenly distributed over the surface of the material. This modified compaction process was used to determine key parameters such as the maximum dry density and optimum moisture content, which were crucial for assessing the soil's compaction characteristics.

After the compaction process, the researcher carefully trimmed the compacted specimen so that it was level with the top of the mold. A straightedge was used to scrape across the top of the mold and remove any excess soil. The trimmed specimen, along with the mold, was weighed, and the mass was recorded accurately. The compacted soil was removed from the mold, and a specimen or a representative portion was obtained from the compacted soil. This sample was used to determine the moisture content of the soil. To establish the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC), an increased amount of water was added to the specimen. This additional water helped achieve the desired compaction characteristics. To establish the compaction curve, the dry density values obtained at various moisture contents were plotted. This curve provided a graphical representation of how the soil's density changed with varying moisture content.

2.2.5 California Bearing Ratio Test (ASTM D1883)

The CBR (California Bearing Ratio) test method was employed to assess the potential strength of various materials, including subgrade, subbase, and base course materials, as well as recycled materials, for their suitability in road and airfield pavement construction [23]. This laboratory test was an empirical method that compared the resistance to penetration of the test specimen to that of a "standard" sample of well-graded crushed stone material, using a piston of standardized size. The primary purpose of the CBR test was to determine how well a given material could support load-bearing applications in pavement construction. In this study, the researcher employed a standard piston with a diameter of 50 mm (1.969 inches) to penetrate the soil specimen at a uniform rate of 1.25 mm (0.049 inches) per minute. During the test, the piston was slowly driven into the soil specimen, and the resistance to penetration was measured. The CBR test was standardized to ensure consistency in testing procedures and results, making it a valuable tool for pavement design and quality control.

2.2.6 Unconfined Compression Strength Test (ASTM D1632 & ASTM D1633)

This practice outlined the procedure for creating and curing compression and flexure test specimens of soil cement in a laboratory setting. It involved precise control over material quantities and testing conditions [24]. However, in this specific study, only compression testing was conducted. The Unconfined Compressive Strength (UCS) was measured as the maximum axial compressive stress that a specimen could withstand when subjected to zero confining stress. This property was significant for assessing the strength and load-bearing capacity of soil-cement mixtures. Compression testing helped determine how well the soil-cement material could withstand compressive forces, making it an essential parameter for various engineering applications, particularly in the construction of soil-cement structures and foundations.

In this study, the researcher utilized a mold with a diameter of 4.0 inches and a height of 4.6 inches, resulting in a height-to-diameter ratio of approximately 1.15. The prepared soil-cement mixture was compacted in the mold in three equal layers, resulting in a total compacted depth of approximately 5 inches (130 mm). Each layer was compacted using 25 blows from a rammer. The rammer was dropped from a height of 12 inches (304.8 mm) above the elevation of the soil-cement. If a sleeve-type rammer was used, it was ensured that the blows were uniformly distributed over the surface of the layer being compacted. The compacted material was then removed from the mold and sliced vertically through the center of the compacted specimen. A representative sample of the material was taken from the full height of one of the cut faces, ensuring that the sample weighed not less than 100 grams. The collected sample was weighed immediately. The load was continuously applied at a rate of 0.5 MPa/s to 1.0 MPa/s (in the case of a stress-controlled load device) [25].

2.3 Data Analysis

This section presents the test on the analysis of the physical properties of the untreated mixture, the mechanical properties of the untreated and treated mixtures, and the statistical analysis of the significant difference in the strength of different mixtures. Table 2 below presents the criteria for acceptability of the test results based on the DPWH specifications.

The Kruskal-Wallis Test, a nonparametric statistical test, was employed in this study. Nonparametric tests are utilized when dealing with data that are measurable on a nominal scale or an ordinal scale. These tests do not rely on assumptions about the data's distribution, making them suitable for a wide range of experimental designs and data types. The mean score for the control group was compared to that experimental group.

Table 2 Criteria of Acceptable Range of Values

Criteria	Acceptable Range of Values	Description
Physical Property		
Sieve Analysis	See Table-3	The grading requirements must passed either Grading A or Grading B.
Plasticity Index	$4 \leq PI \leq 10$	The Plasticity Index shall not be less than 4 nor more than 10.
Abrasion	≤ 50%	The aggregate shall have a mass percent of wear not exceeding 50.
Mechanical Property		
Soaked-CBR	≤ 100%	The mixture passing the 19mm (3/4 in.) sieve shall have a minimum soaked CBR value of 100%.
UCS	≤ 2.1 MPa(300 psi)	The 7-day compressive strength shall not be less than 2.1 MPa (300 psi).

Source: DPWH Bluebook Specification

3. RESULTS AND DISCUSSION

Based on the criteria and requirements established by the DPWH Bluebook and the American Society for Testing and Materials (ASTM), the physical and mechanical parameters were determined, through laboratory testing that included sieve analysis, plastic and liquid limit tests, and abrasion tests, Modified Proctor Test. CBR Test and UCS Test.

3.1 Physical Property

3.1.1 Sieve Analysis Test Results

Table 3 presents the percent passing of the untreated mixtures. The laboratory results, demonstrate that both the conventional and control mixtures satisfy the grading criteria outlined in item 204 of the DPWH Bluebook for the modified base course. Consequently, the outcome designates it as meeting Grading A.

Table 3 Test Result on Sieve Analysis (Gradation Test) of the Conventional and Control Mix

Sieve Size		Percent Passing %		
Standard (mm)	US Standard (inch)	Conventional Mixture (%)	Control Mixture (%)	Govt. Specs Grading A (%)
5.00	2	100	100	100
4.75	No.4	48	45	45 – 100
2.00	No. 10	40	37	37 – 80
0.425	No. 40	20	20	15 – 20
0.075	No. 200	8	8	0 – 25

3.1.2 Liquid Limit and Plastic Limit Test Results

As shown in Table 4, the initial blend without any treatment demonstrates a plasticity index of 7%. When different proportions of cement (6%, 8%, and 10%) were introduced to the soil, the plasticity index decreased to 6.5%, 5.5%, and 4%, respectively. The specimen shows a low level of plasticity, as shown by the plasticity index value [26]. A low-plasticity soil typically refers to a type of soil that exhibits low plasticity characteristics, meaning it has a relatively low capacity to deform and change its shape when subjected to moisture content variations. These soils tend to have lower clay content and are less prone to shrink and swell significantly with changes in water content. They are often more stable and less susceptible to volume changes compared to highly plastic soils. However, it is essential to note that the specific classification of soils into low, medium, or high plasticity categories can vary depending on the classification system used. The most commonly referenced classification system is the Unified Soil Classification System (USCS), which categorizes soils into several groups based on their particle size distribution and plasticity characteristics..

Table 4 Test Result of Plastic and Liquid Limit Test

Sample	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
Untreated Control Mix	38.0	31.0	7.0
Cement-Treated Mix-1	36.5	30.0	6.5
Cement-Treated Mix-2	36.0	30.5	5.5
Cement-Treated Mix-3	35.0	31.0	4.0

According to both the American Association of State Highway and Transport Officials (AASHTO) and the Unified Soil Classification System (USCS), the soil falls into the classifications of A-2-4(0) and GM-GW, respectively

3.1.3 Los Angeles Abrasion Test Results

The aggregate toughness and abrasion resistance, such as crushing, degradation, and disintegration, are measured by the abrasion test. Table 5 presents the percentage loss of 100% crushed Mangima aggregate which is 27.5% while the combination of 25% crushed Mangima aggregate and 75% basalt is 22%. The material being tested has exhibited a relatively higher resistance to abrasion or wear. In the context of an abrasion test, lower test results indicate that the material has experienced a lower degree of wear or deterioration when subjected to abrasive forces, compared to materials with higher test results. In practical terms, high test results in an abrasion test suggest that the material may be less durable or less able to withstand abrasive conditions in real-world applications. When choosing materials like aggregate for construction or engineering endeavors, especially when the ability to withstand wear and abrasion is of paramount importance.

Table 5 Test Result on Los Angeles Abrasion

Design Mixture	Percent Loss
100% Crushed Mangima Aggregate	27.5%
25% Crushed Mangima Aggregate and 75% Basalt	22.0%

3.2 Mechanical Property

3.2.1 Modified Proctor Test Results

In this study, the CT-3 has the highest MDD at 2104 kg/m³, indicating it can achieve the highest density when compacted under specific conditions. CT-2 follows closely with 2058 kg/m³. The Conventional Mix has an MDD of 2046 kg/m³, while the Control Mix has a slightly lower MDD of 2026 kg/m³. CT-1, Control Mix, and CT-2 all must have very similar OMC values, ranging from 7.9% to 8.0%. This suggests that they require approximately the same moisture content for optimal compaction. CT-3 also has an OMC of 8.0% as shown in Table 6.

Table 6 Average Maximum Dry Density & Optimum Moisture Content

Mixture	Conventional Mix	Control Mix	CT-1	CT-2	CT-3
Maximum Dry Density, kg/m^3	2046	2026	2044	2058	2104
Optimum Moisture Content, %	8.0	7.9	7.9	8.0	8.0

The results indicate variations in the compaction characteristics of the different mixtures and control tests. CT-3 shows the highest maximum dry density, while the Conventional Mix and Control Mix exhibit lower values. The Optimum Moisture Content for CT-1, Control Mix, CT-2, and CT-3(10 % cement) is relatively close, suggesting they require similar moisture content for optimal compaction. The addition of different percentages of cement improves the Maximum Dry Density as shown in Figure 1.

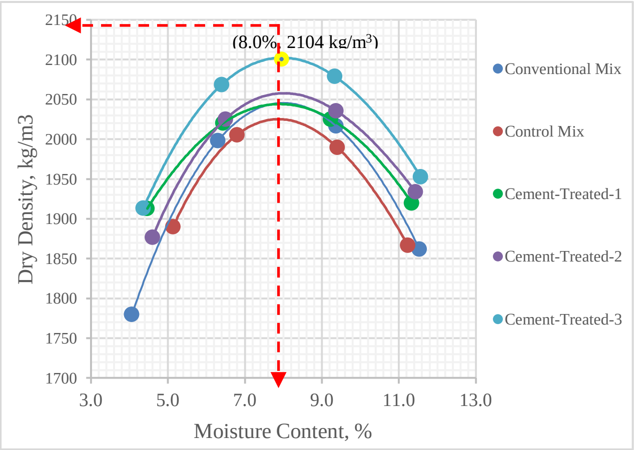

Figure 1 Dry Density-Moisture Content Relationship

The relationship between the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) is a fundamental concept in soil engineering. Achieving MDD at OMC is important because it represents the highest density that a particular soil can achieve with the least amount of moisture. This condition ensures that the soil is compacted to its maximum potential and is crucial for pavement design and construction.

3.2.2 California Bearing Ratio Test Results

In the context of the California Bearing Ratio (CBR) test, conducting the test at the OMC and determining the percent CBR value at MDD is a common practice. Table 7 shows the average value of the relationship between CBR and Maximum Dry Density. From the table, at 100% maximum dry density, the conventional mix showed a lower CBR value of 31.1% when compared to the control mix which has 36.3%. Meanwhile, the addition of cement to the control mix showed an increased CBR value of 94.6%(CT-1), 96.9%(CT-2) and 101%(CT-3). These results suggest that the cement-treated mixes have significantly improved strength properties compared to the non-treated mixes. The higher CBR values indicate that the cement-treated mixes are better suited for use in road construction and can withstand heavier loads. In practical terms, these findings imply that the addition of cement to the control mix has a positive impact on the strength and load-bearing capacity of the soil mixture. This information is valuable for designing road bases and pavements, where the soil's mechanical properties are critical for long-term performance and durability. The higher CBR values for cement-treated mixes indicate their suitability for use in road construction projects where higher strength requirements are essential.

Table 7 Average Percent CBR at Maximum Dry Density

Mixture	Conventional Mix	Control Mix	CT-1	CT-2	CT-3
Maximum Dry Density, kg/m^3	2046	2026	2044	2058	2104
CBR, %	31.1	36.3	94.6	96.9	101.0

Figure 2 illustrates the relationship between California Bearing Ratio (% CBR) and Maximum Dry Density (MDD) for the proposed mixtures, including the control, conventional, and cement-treated mixtures. The % CBR values for the control mixture are generally higher compared to the conventional mixture. This indicates that the control mixture has better load-bearing capacity. The % CBR values seem to increase with higher MDD, suggesting that increasing compaction results in improved strength. The conventional mixture shows lower % CBR values compared to the control mixture across the range of MDD values. This implies that the conventional mixture is less capable of supporting heavy loads than the control mixture. The cement-treated mixtures (CT-1, CT-2, and CT-3) exhibit significantly higher % CBR values compared to both the control and conventional mixtures. Among the cement-treated mixtures, CT-3 stands out with the highest % CBR values, reaching 101% at the highest MDD. CT-1 and CT-2 also show substantial improvements in % CBR compared to the control and conventional mixtures. These results confirm that the addition of cement to the mixtures has a substantial positive effect on their strength properties, as indicated by the % CBR values. Higher % CBR values signify increased load-bearing capacity and better resistance to deformation. The relationship observed between MDD and % CBR suggests that proper compaction plays a crucial role in achieving the desired strength characteristics. Additionally, the increase in % CBR with the addition of cement is consistent with previous studies [27] indicating that cement improves the strength of soil mixtures and enhances their load-bearing capacity.

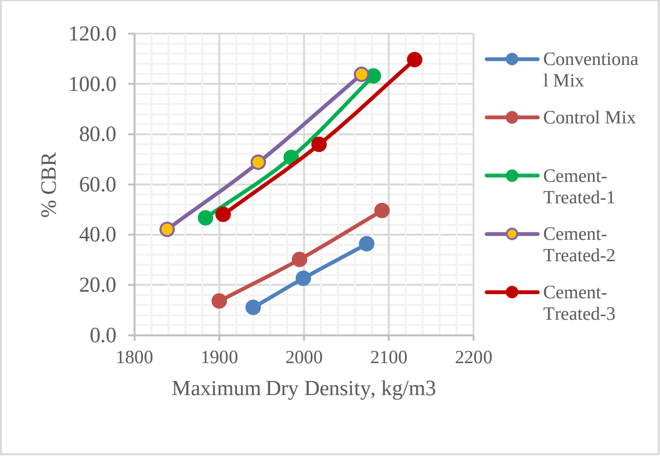

Figure 2 Combined Graph of CBR – Dry Density Relation

3.2.3 Unconfined CompressionStrength Test Results

The UCS value of the road mix base course using 25% crushed Mangima aggregate (Control Mix + 0% cement) passed the minimum UCS value in item 204 of the DPWH Bluebook. Table 8 shows the average value of the Unconfined Compression Strength of the soil specimen. From the table, the conventional mix showed a higher UCS value of 86.1 psi when compared to the control mix which has 69.5 psi. Meanwhile, the addition of cement to the control mix showed an increased UCS value of 89.4 psi (CT-1), 216.8 psi (CT-2), and 334.4 psi (CT-3).

These results indicate a clear correlation between cement content and UCS. As the cement content increased in the mixtures, the UCS values also increased significantly. This demonstrates the cement's role as a stabilizing agent, enhancing the compressive strength of the road mix base course. The UCS values are essential for evaluating the suitability of road mix base courses for their intended applications. Higher UCS values typically indicate that the material is better equipped to withstand compressive loads and stresses, making it a more robust choice for road construction. It was worth noting that the specific proportions of crushed Mangima aggregate, cement, and other components in each mixture can have a considerable impact on the final UCS values. Engineers and researchers can use this information to fine-tune the mixture ratios to meet the desired strength and performance criteria for road-based construction projects.

Table 8 Average Unconfined Compression Strength

Mixture	Conventional Mix	Control Mix	CT-1	CT-2	CT-3
Unconfined Compressive Strength, psi	86.1	69.5	89.4	216.8	334.4

It was observed that the UCS value of the conventional mixture was higher than that of the control mixture. Meanwhile, the CT-3 provides the highest value of UCS compared to the other treated mixtures and untreated mixtures. It was observed in the results that more cement added to the control mixture provided an increase in the UCS. The observed increase in Unconfined Compression Strength (UCS) with higher cement content in the mixtures aligns with well-established principles of soil stabilization and cementitious materials. Cement contains active compounds that undergo hydration when mixed with water. This hydration process forms crystalline structures that interlock and bond with soil particles and aggregates. As the cement content increases, there are more cement particles available for hydration, leading to the formation of a larger number of rigid bonds within the soil matrix. These bonds enhance the rigidity and strength of the mixture by filling in the pore spaces and creating a stronger interlocking structure. Hydration is a time-dependent process, meaning that it continues to progress over time after mixing. As hydration progresses, the strength of the bonds between soil particles and cementitious materials increases. This progressive strengthening effect leads to an improvement in unconfined strength, as observed in your results. The direct relationship between cement content and UCS is well-documented. Higher cement content provides more bonding material, resulting in stronger bonds between the soil components. This strengthening effect is one of the primary reasons why adding cement to soil, as in cement-treated base courses (CTB), is an effective method for enhancing the mechanical properties of the mixture. The UCS values obtained in this study, ranging from 69.5 psi for the control mix to 334.4 psi for CT-3 (with the highest cement content, presumably 10%), fall within the typical range for CTB compressive strength, which typically ranges from 300 to 800 psi. These values indicate that the mixtures, especially those with higher cement content, possess the necessary strength for various road construction applications. The increase in UCS with higher cement content is a well-understood phenomenon in soil stabilization. The formation of strong bonds between soil particles and cementitious materials plays a pivotal role in enhancing the mechanical properties of the mixture.

The result of the analysis shows a reciprocal relationship where the increase of the cement content increases the strength of the mixture due to the hydration products of the cement which fill in the pores of the matrix thus enhancing the rigidity of its structure by forming a large number of rigid bonds in the soil [28]. The hydration process was found to progress with time, creating a stronger bond between the aggregates, which leads to improvement in unconfined strength. It should also be noted that higher cement content will increase the strength of the bond between materials and will lead to higher UCS value [29], [1]. The results revealed that by adding Portland cement, the mechanical properties of the mixture have improved and the UCS is found to be an important quality indicator. CTB compressive strength (psi) ranges from 300 to 800 psi [16]. The application of this stabilizer with cement not only enhances durability but also improves strength, ensuring a robust base layer that resists cracking [10].

3.6 Significant Difference in the Strength

In this study, the Kruskal-Wallis test, which is a nonparametric statistical test, was utilized to examine three mechanical strength test. Chi-square test was used to determine the significant difference in the strength of the untreated and treated mixtures. Table 9 presents the results of the data analysis. Using SPSS, the result revealed that there was a statistically significant difference between the strength of each design mixture with a value of ($H(4) = 10.828$, $p = 0.029$); ($H(4) = 12.933$, $p = 0.012$) and ($H(4) = 12.982$, $p = 0.011$) for Compaction, CBR, and UCS, respectively. The p-value for each test falls below the 0.05 significance level. A post hoc test is performed to precisely identify which groups exhibit differences from one another, and in this case, the Bonferroni was utilized for this purpose.

Table 9 Test Statistics Kruskal Wallis Test

	MDD	**CBR**	**UCS**
Chi-Square	10.828	12.933	12.982
df	4	4	4
Asymp. Sig.	0.029	0.012	0.011

3.7 Post Hoc Analysis

The Bonferroni test is a multiple comparison test commonly employed in statistical analysis to control errors when conducting multiple comparisons. In the context of non-parametric statistics, the Bonferroni test can be a useful tool [30]. In analysis using SPSS, it was determined which groups were statistically significant compared to others.

In the Maximum Dry Density (MDD) testing, the results indicate that Group 5 (Cement-Treated-3) exhibits statistical significance in comparison to Group 1 ($p = 0.004$), Group 2 ($p < 0.001$), Group 3 ($p = 0.003$), and Group 4 ($p = 0.018$). This suggests that the utilization of Cement-Treated-3 results in a notable elevation in Maximum Dry Density when contrasted with the other groups, as detailed in Table 10.

Table 10 MDD Testing Multiple Comparison using Bonferroni

Group Number	(J) Groups				
	1	2	3	4	5
1	-	20.667 (0.868)	2.667 (1.000)	11.333 (1.000)	57.333 (0.004*)
2	20.667 (0.868)	-	18.000 (1.000)	32.000 (0.148)	78.000 (0.000*)
3	2.667 (1.000)	18.000 (1.000)	-	14.000 (1.000)	60.000 (0.003*)
4	11.333 (1.000)	32.000 (0.148)	14.000 (1.000)	-	46.000 (0.018*)
5	57.333 (0.004*)	78.000 (0.000*)	60.000 (0.003*)	46.000 (0.018*)	-

**The mean difference is significant at the 0.05 level.*

Group 1: Conventional Mix
Group 2: Control Mix
Group 3: Cement-Treated-1
Group-4: Cement Treated-2
Group-5: Cement Treated-3

In the California Bearing Ratio (CBR) testing, the results reveal that Group 3, Group 4, and Group 5 exhibit statistical significance in comparison to Group 1 and Group 2, with all of them showing a p-value of less than 0.001 ($p < 0.001$). This suggests that Cement-Treated-1, Cement-Treated-2, and Cement-Treated-3 all yield significantly higher values in CBR testing when compared to Group 1 and Group 2, as illustrated in Table 11.

Table 11 CBR Testing Multiple Comparison using Bonferroni

Group Number	(J) Group				
	1	2	3	4	5
1	-	5.267 (0.249)	63.500 (0.000*)	65.800 (0.000*)	70.400 (0.000*)
2	5.267 (0.249)	-	58.233 (0.000*)	60.533 (0.000*)	65.133 (0.000*)
3	63.500 (0.000*)	58.233 (0.000*)	-	2.300 (1.000)	6.900 (0.062)
4	65.800 (0.000*)	60.533 (0.000*)	2.300 (1.000)	-	4.600 (0.441)
5	70.400 (0.000*)	65.133 (0.000*)	6.900 (0.062)	4.600 (0.441)	-

**The mean difference is significant at the 0.05 level*

In the Unconfined Compression Strength (UCS) testing, the results suggest that Group 3 is statistically significant in comparison to Group 2, with a p-value of less than 0.001 ($p < 0.001$). Group 4 demonstrates statistical significance when compared to both Group 1 and Group 2, with p-values less than 0.001 ($p < 0.001$). Group 5 exhibits statistical significance when contrasted with Group 1, Group 2, Group 3, and Group 4, all with p-values less than 0.001 ($p < 0.001$). These findings indicate that, in the context of UCS testing, Cement-Treated-1, Cement-Treated-2, and Cement-Treated-3 yield significant values when compared to the other groups, as displayed in Table 12.

Table 12 UCS Testing Multiple Comparison using Bonferroni

Group Number	(J) Group				
	1	2	3	4	5
1	-	16.733 (0.123)	-3.167 (1.000)	130.567 (0.000*)	245.300 (0.000*)
2	16.733 (0.123)	-	19.900 (0.046*)	147.300 (0.000*)	262.033 (0.000*)
3	3.167 (1.000)	19.900 (0.046*)	-	127.400 (0.000*)	242.133 (0.000*)
4	130.567 (0.000*)	147.300 (0.000*)	127.400 (0.000*)	-	114.733 (0.000*)
5	245.300 (0.000*)	262.033 (0.000*)	242.133 (0.000*)	114.733 (0.000*)	-

** The mean difference is significant at the 0.05 level.*

4. CONCLUSION

The study aligns with sustainable practices in the construction industry by exploring alternatives to traditional aggregates, which can contribute to a reduction in environmental impact and the depletion of resources. The untreated soil-aggregate was initially categorized as Grading A following the criteria of item 204 in the DPWH Bluebook specifications. According to the AASHTO classification system, the mixture was classified as A-2-4(0), and under the USCS classification system, it was identified as GW-GM, which corresponds to well-graded gravel with silt. The modified Proctor Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the conventional mixture were found to be higher than those of the control mix. The inclusion of varying percentages of cement resulted in an improvement in the Maximum Dry Density. Notably, the CT-3 (with 10% cement) exhibited the highest MDD. The soaked California Bearing Ratio (CBR) value increased with the addition of cement. Furthermore, the optimal percentage of cement as a stabilizer for the base course, as determined by the results, was found to be 10%. This percentage yielded a CBR value that met the standard specifications outlined in item 204 of the DPWH Bluebook. Additionally, the Unconfined Compressive Strength (UCS) value was determined, and it was the CT-3 (with 10% cement addition) that yielded the highest UCS value.

REFERENCES

[1] A. Mohammadinia, A. Arulrajah, J. Sanjayan, M. Disfani, M. Bo and S. Darmawan, "Laboratory evaluation of the use of cement-treated construction and demolition materials in pavement base and subbase applications.," *Journal of Materials in Civil Engineering*, 2015.

[2] N. Mohanta and M. Murmu, "Alternative coarse aggregate for sustainable and eco-friendly concrete-A review," *Journal of Building Engineering*, 2022.

[3] T. Ganiron Jr, "Recycling concrete debris from

construction and demolition waste.," *International Journal of Advanced Science and Technology,* pp. 7-24, 2015.

[4] G. Del Angel, A. Aghajanian, P. Tamayo and C. Thomas, "Siderurgical Aggregate Cement-Treated Bases and Concrete Using Foundry Sand," *Applied Sciences,* 2021.

[5] M. Arshad and M. Ahmed, "Potential use of reclaimed asphalt pavement and recycled concrete aggregate in base/subbase layers of flexible pavements.," *Construction and Building Materials*, pp. 83-97, 2017.

[6] R. Cabahug, R. G. Cabahug , J. Lamberte and A. Neri, "Mangima Stone as Alternative Coarse Aggregate in Concrete," *Mindanao Journal of Science and Technology,* 2011.

[7] J. Calibara and R. Cabahug, "Effects of Water-Reducing Admixture on the Compressive Strength of Concrete Using Crushed Mangima Stone as Fine Aggregate," *Mindanao Journal of Science and Technology,* 2020.

[8] E. Getes and V. Caingles, "Evaluation of the compressive strength of paver blocks with the inclusion of Mangima stone and Eggshell powder," *International Journal of Health Sciences*, pp. 12044-12053, 2022.

[9] S. Sebesta, J. Kim, Y. Rew, R. Taylor and P. Townsend, "Accelerating Mixture Design for Cement Treated Base Material," *Transportation Research Record*, 2022.

[10] S. Marik, R. Ransinchung, A. Singh and L. Khot, "Laboratory study and performance evaluation of cement treated base using chemical stabiliser," *Road Materials and Pavement Design,* pp. 1-20, 2022.

[11] S. Rabab'ah, A. Sharo, M. Alqudah, A. Ashteyat and H. Saleh, "Effect of using Oil Shale Ash on geotechnical properties of cement-stabilized expansive soil for pavement applications," *Case Studies in Construction Materials,* pp. 2214-5095, 2023.

[12] D. Xuan, L. Houben, A. Molenaar and Z. Shui, "Mechanical properties of cement-treated aggregate material–a review," *Materials & Design,* pp. 496-502, 2012.

[13] I. Hastuty, "Comparison of the use of cement, gypsum, and limestone on the improvement of clay through unconfined compression test," *In Journal of the Civil Engineering Forum,* pp. 131-138, 2019.

[14] P. Jitsangiam, K. Nusit, S. Likitlersuang and J. Kodikara, "Using damage evaluation to assess the fatigue behaviour of cement-treated base material from laboratory and full-scale performance tests," *Transportation Geotechnics*, 2021.

[15] A. Grilli, E. Bocci and A. Graziani, "Influence of reclaimed asphalt content on the mechanical behaviour of cement-treated mixtures," *Road Materials and Pavement Design,* pp. 666-678, 2013.

[16] A. Ismail, M. Baghini, M. Karim, F. Shokri, R. Al-Mansob and A. Firoozi, "Laboratory Investigation on the Strength Characteristics of Cement-Treated Base," *Applied Mechanics and Materials,* pp. 353-360, 2014.

[17] X. Zhao, Q. Dong, J. Yuan , X. Chen and J. Yang, "Micro-scale characterization of the heterogeneous properties of in-service cement-treated base material," *Micro-scale characterizatioConstruction and Building Materials,* 2020.

[18] K. Nusit and P. Jitsangiam, "Damage behavior of cement-treated base material," *Procedia engineering*, pp. 161-169, 2016.

[19] "ASTM D6913 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis.," in *American Society for Testing and Materials*, ASTM International, 2021.

[20] "ASTM D 4318 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils," in *American Society for Testing and Materials*, ASTM International, 2018.

[21] " ASTM C131 Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine," in *American Society for Testing and Materials*, ASTM International, 2020.

[22] "ASTM D1557-12 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft3 (2,700 kN-m/m3).," in *American Society for Testing and Materials,* ASTM International, 2021.

[23] "ASTM D1883-21 Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils," in *American Society for Testing and Materials*, ASTM International, 2021.

[24] "ASTM D1632-17e1 Standard Practice for Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory.," in *American Society for Testing and Materials*, ASTM International, 2020.

[25] "ASTM D1633-17 Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders.," in *American Society for Testing and Materials*, ASTM International, 2018.

[26] S. Roy and S. Bhalla, "Role of geotechnical properties of soil on civil engineering structures," *Resources and Environment*, pp. 103-109, 2017.

[27] A. Cabalar, M. Abdulnafaa and Z. Karabash, "Influences of various construction and demolition materials on the behavior of a clay," *Environmental Earth Sciences,* pp. 1-9, 2016.

[28] W. Mampearachchi, W. Bandara and K. Sampath, "Cement stabilized soil as a road base material for use in Sri Lankan roads.," 2017.

[29] M. Asgari, A. Baghebanzadeh Dezfuli and M. Bayat, "Experimental study on stabilization of a low plasticity clayey soil with cement/lime," *Arabian Journal of Geosciences*, pp. 1439-1452, 2015.

[30] A. Hayes, "What Is the Bonferroni Test (Correction) and How Is It Used?," Investopedia, 2021 November 2021. [Online]. Available: https://www.investopedia.com/terms/b/bonferroni-

test.asp. [Accessed 8 November 2023].

[31] Y. Cho, K. Lee and S. Ryu, "Development of cement-treated base material for reducing shrinkage cracks," *Transportation research record*, pp. 134-143, 2006.

[32] R. MacCuspie, H. Hyman, C. Yakymyshyn, S. Srinivasan, J. Dhau and C. Drake, " A framework for identifying performance targets for sustainable nanomaterials," *Sustainable materials and Technologies*, pp. 17-25, 2014.

[33] P. Nicholson, Soil improvement and ground modification methods, Butterworth-Heinemann, 2014.

[34] R. Pai, S. Patel and M. Bakare, "Applicability of Utilizing Stabilized Native Soil as a Subbase Course in Flexible Pavement," *Indian Geotech J 50*, pp. 289-299, 2020.