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STRENGTH PROPERTIES OF ROAD BASE MATERIALS BLENDED WITH WASTE LIMESTONES

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ABSTRACT: Most areas in the Philippines experience high road construction cost due to the limited supply of suitable materials for road embankment within economic haul distances. Considering that the country is currently having extensive infrastructure development, potential use of naturally-occuring materials such as limestones was tested resulting not only as an economic alternative to the conventional materials, but leading to an improved strength of roads. Geotechnical and morphological properties of pure and blended materials were determined characterizing the behavior of the strength of the materials as limestone blend varies. A 50% blend of limestone to conventional road base materials provided optimum strength increasing the values up to 30%, 100% and 40% for unsoaked CBR, soaked CBR and UCS, respectively.

Keywords: Limestone, Road Embankment, CBR, Road Base Material

1. INTRODUCTION

In the Philippines, road construction is one of the prevailing infrastructure developments by the government because of the many inland transport systems used to deliver goods in different regions of the country. High haulage cost due to inflation is one of the constraints in the availability of providing high quality underlying soil layers in most areas of the country. These underlying soil layers known as subgrade, subbase and base act as the foundation of the pavement and its performance [1] is strongly influenced by its stability, bearing strength, consolidation over time and moisture susceptibility. Hence, taking into account the materials and strength requirements of these layers are important in achieving the expected performance of the roads. The possibility of using naturally-occuring materials for road embankments was given emphasis in this study to provide economic solution to this problem.

An abundant resource recognized in this study is limestone. Limestone is a calcium carbonate type of rock that is widely available all over the world, as it constitutes more than 4% of the Earth's crust. In the Philippines, the Mines and Geosciences Bureau (MGB) projected an estimate of 4 billion metric tons of limestone deposit in 1992. Limestones are potentially known to exhibit characteristics needed for road embankments. There are several reactions occurring when soil is mixed with lime [2], many studies were also done to study the properties of lime [3].

The objective of the study is to determine the suitability of blending waste limestones to conventional materials as a road embankment material and to establish strength properties of different limestone blends. Strength properties considered are the California bearing ratio (CBR), unconfined compressive strength (UCS) and undrained shear strength. Regression analysis was also performed correlating the values of different strength tests with different blend proportions of limestone. Soil stabilization was achieved since soil properties were altered [4]. Soil stabilization is important in the safety of life, property and effort [5].

Other than geotechnical properties, physical properties were also considered since the strength is found to be greatly influenced by its mineralogical composition. The mineralogy of the materials was defined through analyzing the mineral peaks from the X-ray Diffraction (XRD) graphs. Furthermore, Scanning Electron Microscope (SEM) was also conducted to determine some of the morphological characteristics of the materials.

2. MATERIAL SOURCES

2.1 Limestone

Limestones coming from Guimaras Island are accredited by the Department of Public Works and Highways (DPWH) of the Philippines for use as material for road construction. Specifically, limestones tested were from Sta. Fe Lime Enterprises, located in Buenavista, Guimaras Island, Philippines. The quarry covers a total area of 350m^2 with an annual extraction rate of 70,000 mertric tons of limestone. Currently, Sta Fe. Limestone quarry have already extracted more than 60% of the area. The company is planning to expand, having an additional four (4) hectares of land to be extracted. The company is in partnership with Dorilag Cement Corp. where they supply lime as the main ingredient for cement.

2.2 Conventional Materials

In characterizing the commonly used aggregates in the Philippines, conventional materials for road bases from Batong Angono Aggregates Corporation (BAAC) were examined. Aggregates from BAAC were good representatives of the aggregates in the Philippines considering that BAAC supplied most of the DPWH road projects.

3. METHODOLOGY

3.1 Soil Specimen Preparation

The materials used in the study were oven dried to make sure that materials acquire 0% water content as required for testing. In addition, sieving was done for both conventional materials and limestones to meet the grading requirements provided in the study.

3.2 Index Properties

The index properties (i.e. specific gravity, Atterberg limits, particle size distribution and relative density) of both the control mix and limestone-blended conventional road base materials were identified following the ASTM procedures [6]. Index properties defined the material's basic properties providing basis for further strength behavior analyses.

3.3 Blending of Materials

The blending of materials was arithmetically computed following a specific gradation. Specific weights of materials for each range of size were identified and measured satisfying the material requirements for subgrade, subbase and base courses as stipulated in the DPWH standards and specifications for Highways, Bridges and Airports [7]. The study required blending of limestone having different gradation to suitable aggregates to come up with a blend that will meet the gradation specifications. The materials passing No. 4 sieve (4.75mm opening) were mixed at blend proportions of 0, 20, 40, 60, 80 and 100% of limestone by weight, equivalent to 0, 7, 14, 21, 28 and 35% of limestone by total weight, respectively.

3.4 Compaction Characteristics

Following the ASTM procedure for Moisture-Density Relationship, compaction characteristics of the materials were determined. Standard Proctor Tests were obtained for each blend wherein nine (9) points were identified in order to acquire precise values of maximum dry densities and optimum moisture contents. Such property enabled the determination of the water content at which the compaction is best.

3.5 Strength Tests

One way of determining the strength of thesubgrade, subbase and base materials for use in road pavements is the CBR test [8]. CBR strength test (ASTM D1883) was performed under soaked and unsoaked conditions. Under each result, corrections were made due to surface irregularities, depicted by a concave upward behavior at the start of the Stress vs Penetration curve. The strength property is the basis for determination of the materials applicability as road embankment.

The ASTM D2166 was referenced for procedure for the determination of the unconfined compressive strength, a height-to-diameter ratio of 1.65 was considered and was remoulded following the required specimen conditions. The test was also able to estimate the undrained shear strength of the specimens in the wet state.

4. TEST RESULTS

4.1 Geotechnical Properties of Conventional Materials Blended with Different Percentages of Limestone

Specific Gravity

The control and blended specimens showed a decreasing trend of specific gravity as the percentage blend of limestone is increased due to the difference of the weights of minerals in material and the presence of depressed structure within particle surfaces. The behavior of values resulted to an empirical formula showed in Eq. (1).

$$Gs = 2.7775\exp^{0.0009L} \qquad (1)$$

Where:
Gs = specific gravity;
L = limestone content in percent.

Atterberg Limits - Liquid Limit

The results of soil-limestone mixture at different percentages are shown in Fig. 1. Plotting the values provided an empirical formula shown in Eq. (2).

$$LL = 15.33\exp^{0.0031L} \qquad (2)$$

Where:

LL = Liquid Limit.

Evidently, increasing limestone content increases the liquid limit of the blend since limestones have greater tendency to attract water to its particle surfaces. Changes in engineering properties of the aggregates blended with limestone may be due to the cationic exchange, flocculation of the clay, agglomeration and pozzolanic reactions as explained by Thompson [9] and Bell [10].

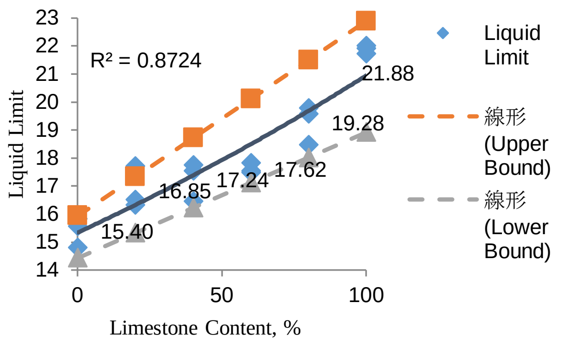

Fig. 1. Liquid Limit vs Limestone Content

Atterberg Limits -Plastic Limit

Soil-limestone mixture makes variations of plastic limit at different percentages as shown in Fig. 2. Similar to the liquid limit, changes in the engineering properties may be due to the reactions mentioned as limestone is blended to crushed aggregates. In addition, the values of plastic limit followed similar behavior as the liquid limit wherein values behaved exponentially generating a correlation shown in Eq. (3).

$$PL = 12.876exp^{0.0025L} \quad (3)$$

Where :
PL = Plastic Limit.

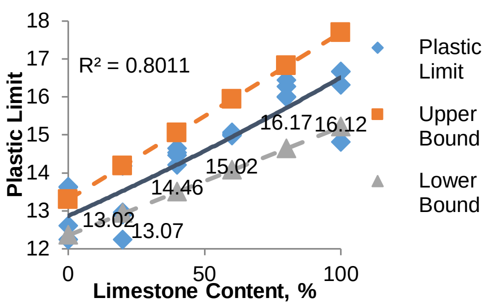

Fig. 2. Plastic Limit vs Limestone Content

Atterberg Limits –Plasticity Index

At different percentages of limestone, deviation in values of plasticity indices is measured as shown in Fig. 3. Similarly, values also formed a correlation wherein values of plasticity indices can be estimated at any limestone content as shown in Eq. (4).

$$PI = 1.8771exp^{0.0088L} \quad (4)$$

Where:
PI = Plasticity Index.

The results confirmed that the plasticity index increases with increasing limestone content at all percentages. Because both materials exhibit low plasticity characteristics, the combination of the two materials still satisfies the general specification for road embankment which requires that plasticity index not to exceed a value of six (6).

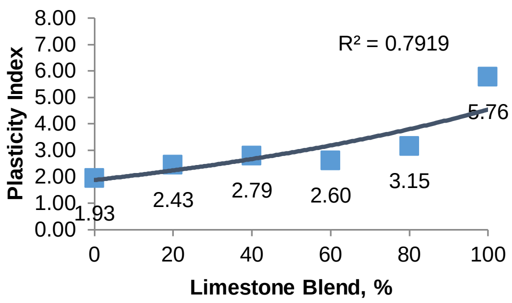

Fig. 3. Plasticity Index vs Limestone Content

Maximum and Minimum Index Densities

In performing tests for identification of maximum and minimum index densities, it was found that in both loosest and densest condition of the materials, values of index densities are decreasing as limestone content is increased. Even though the range of particle size is standardized for this test, it can still vary by volume considering that limestone is larger in volume due to its light weight. As limestone content is increased, more conventional materials are substituted by lighter particle providing drop in unit weight of the limestone- blended materials. Empirical relationships developed are as follows:

$$\text{Max. Index Density} = 22.562\ exp^{0.002L} \quad (5)$$
$$\text{Min. Index Density} = 18.101\ exp^{0.002L} \quad (6)$$

The exponential behavior of the data provided correlation of values wherein index densities can be obtained at any given limestone blend.

Compaction Characteristics

The Standard Proctor Test was performed following the ASTM D698 procedures in order to obtain the exact amount of moisture needed in sample preparation for strength tests. The results in the determination of optimum moisture content (OMC) and maximum dry density (MDD) are summarized in Table 1:

Table 1 Summary of OMC and MDD Values for Each Blend

Limestone Content, %	OMC, %	MDD, kN/m^3
0	5.00	24.23
20	5.56	23.05
40	5.98	22.18
60	6.63	22.09
80	7.98	21.68
100	9.54	21.08

As shown in Table 1, the MDD decreases while the OMC increases with increasing percentage of limestone. Considerable agglomerations of smaller particles of limestone occur resulted to larger ones, which prohibit the specimens to be properly compacted. This happens when there is cationic exchange wherein higher valence cations replace those with lower valence and larger cations replace those that are smaller having same valence. With the voids not filled up as much, the MDD then decreases. It can easily be seen that the limestone has lighter weight as compared to the conventional materials because of its mineralogical composition. On the other hand, the OMC increases mainly due to the additional water held within the flocculated soil structure. The increase in fines content as well as the high affinity of limestone to water caused the increase in OMC as percentage blend of it is increased. According to Akoto and Singh [11], increase in water is needed for providing more Ca^{2+} ions for the cation exchange reaction. As observed, large drop of MDD is experienced with increasing limestone content up to 40%. Okagbue and Yakubu [12] explained that the initial drop is due to the flocculation and agglomeration of the clay particles due to the cation exchange reaction. Smaller decrease in MDD as more limestone is added is due to the replacement of particles of limestone, which have comparatively low specific gravity with that of the conventional road base materials.

Plotting the behavior of MDD and OMC at different limestone content gave an empirical formulas shown in Eq. (7) and (8), respectively.

$$MDD, kN/m^3 = 23.881\exp^{0.001L} \quad (7)$$

$$OMC, \% = 4.9213\exp^{0.0061L} \quad (8)$$

Where:
MDD = maximum dry density;
OMC =optimum moisture content.

The empirical formulas obtained provided exponential behavior for both property in which values of MDD and OMC can be determined at any limestone blend.

4.2 Strength Characteristics of Conventional Materials Blended with Different Percentages of Limestone

California Bearing Ratio- Unsoaked condition

Remarkable values of CBR under unsoaked condition were obtained providing good performance for road subgrade, sub-base and base. On the average, different CBR values were obtained for each blend providing an empirical relationship shown in Eq. (9).

$$\boldsymbol{CBR_{Unsoaked}}, \% = -\mathbf{0.0107}\boldsymbol{L^2} + \mathbf{0.9194}\boldsymbol{L} + \mathbf{50.351} \quad (9)$$

Where:
$CBR_{unsoaked}$ = unsoaked CBR of the specimen.

Given this model that will produce the maximum CBR value, it can be computed that the blend accounts to blend L42.96-C57.04. This is likely to give an approximate CBR value of 70%. Comparing the unsoaked CBR strength value of 53.75% provided by the controlled specimens to the optimum blend with unsoaked CBR value of 70%, it can be concluded that optimum blend can increase the strength by 30%. The behavior of the CBR value is increasing until it reached the 42.96% blend of limestone and eventually decreases as it approaches 100%. The increase of strength of the blended materials with increasing limestone content is mainly due to the considerable plasticity of limestone. This provides binding property among particles that allows the material to gain strength. The cohesive strength limestone provided increased the over-all strength of the specimen. Other authors working on the soil-limestone mixture noted similar behavior. Newbauer and Thompson [13] explained that the increase in strength may be due to the immediate reaction endowed by the cation exchange and the flocculation and agglomeration reactions, while Van Ganse [14] postulated that this is due to the formation of crumbs of soils maintaining their individuality when the mixture is compacted.

On the other hand, increasing the limestone blend to more than 42.96% decreased the over-all strength of the specimen. Although the cohesive strength of the blend increases, there is a point in which the frictional strength is affected by the reduction of conventional materials due to the increase in volume of the limestone. Frictional strength is contributed by large particles and high cohesive strength would mean lesser contact of larger particles with each other thus, a drop of frictional strength.

California Bearing Ratio- Soaked condition

To test the strength of the limestone-blended materials at its worst condition, CBR values for soaked condition were also identified. The values demonstrated good performance resulting to CBR values greater than 20. The blend that is anticipated to attain the peak strength is L50-C50, which will give a CBR value of 60% based on the empirical relationship as shown in Eq. (10).

$$\boldsymbol{CBR_{Soaked}}, \% = -\mathbf{0.0102}\boldsymbol{L}^{\mathbf{2}} + \mathbf{0.9976}\,\boldsymbol{L} + \mathbf{50.35} \quad (10)$$

Where:
CBR_{soaked} = the soaked CBR of the specimen.

Being able to determine the optimum strength enabled the estimation of percentage increase in strength of the optimum blend with respect to the controlled specimen. With a soaked CBR value of 30% and 60% for controlled and optimum blend respectively, a 100% increase in strength is realized.

It can be observed that CBR values from soaked condition is lesser compared to that of the CBR values under unsoaked condition. This is due to the permeation of water in soaked condition decreasing its strength. The behavior of CBR values under soaked condition is similar to that of the unsoaked condition. Reporting the swell of the materials after four (4) days of soaking period, it was observed that on the average, swell of materials on all blends have no significant value accumulating less than 1% swell.

Unconfined Compressive Strength

To further verify the results provided by CBR tests, the Unconfined Compressive Strength (UCS) test was conducted. This quickly estimates the undrained shear strength of the material. The empirical relationship was determined to describe the strength behavior as limestone content varies forming an empirical formula shown in Eq. (11).

$$\boldsymbol{UCS}, \boldsymbol{kPa} = -\mathbf{0.0087}\boldsymbol{L}^{\mathbf{2}} + \mathbf{0.8254}\boldsymbol{L} + \mathbf{47.301} \quad (11)$$

Where:
UCS = unconfined compressive strength

With this equation, L50-C50 is found to generate the optimum strength value of 70kPa. Comparing the UCS of controlled specimen to that of the optimum blend, an increase of 40% in strength is observed. The behavior of the results followed a parabolic curve concaving downward which entails that a 50% limestone substitution to the fine aggregates would produce maximum strength of the specimen since it adds cohesion to the strength of material owing to its binding characteristics. Since undrained shear strength can be estimated with results obtained in the UCS, it can be concluded that this property exhibited similar behavior with that of the UCS. According to Lees et al. [15] and Bell [16], the increase in strength may be due to the formation of larger particles, making it behave as coarse-grained, strongly bonded, particulate material. Nonetheless, further increase of limestone would tend to decrease its over-all strength due to the drop of frictional strength as an effect of the domination of fine particles in volume. This permits less contact of coarse particles with one another leading to loss of friction.

5. CONCLUSION

Having analyzed the different properties and strength characteristics of road base materials blended with limestones at different percentages, the following conclusions were made:

Waste limestones from Guimaras Island, Philippines can be utilized in road construction considering that replacing 100% of the fine aggregates with limestone yielded to acceptable values of CBR for both soaked and unsoaked conditions;

From the empirical relationships given by the strength parameters considered, it can be concluded that a range of 40% to 50% blend of limestone would optimally give the most favorable strength for both unsoaked and soaked CBR and UCS. Comparing the strength values of optimum blend to purely conventional materials, a remarkable increase of up to 30% for unsoaked CBR, up to 100% for soaked CBR and upto 40% to unconfined compressive strength values were realized;

It is recommended that deleterious effects of weathering and dissolution of limestone when exposed to acid rain [17][18]. Dissolution happens when carbon dioxide and water reacts with calcium carbonate contained in limestone. The reaction will convert it into calcium hydrogen carbonate, which is soluble in water. On the other hand, weathering happens with frequent contact with water. With these causes, it is recommended to provide proper pavement drainage so that ingress of water to base course can be prevented.

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