Technical note

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Characterization of Unbound Aggregates Revealed Through Laboratory Tests

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Abstract: Unbound aggregates are often used in pavement base layers, whose properties play an important role in pavement performance. Gradation of unbound aggregate is one of the key factors directly affecting grain-to-grain contacts, which in turn have significant influence on properties of unbound aggregates, such as strength, stiffness, and permanent deformation. It is possible, therefore, to optimize properties of unbound aggregates by optimizing their gradations. To this end, a limestone aggregate used in Louisiana highways was investigated by conducting Dynamic Cone Penetrometer (DCP), California Bearing Ratio (CBR), and Repeated Load Triaxial (RLT) tests. DCP and CBR tests will yield indirect shear strength under static loading while RLT tests will provide performance–related information such as resilient modulus and permanent deformation under repeated loading. Different gradations were obtained by first sorting the limestone into several groups of different particle diameters and then remixing them together at desired proportions. This paper will present details of these laboratory testing programs. The results from these tests will be discussed, with emphasis on how different gradations affect different properties and which testing procedure will be more appropriate in characterizing unbound pavement base materials.

***Key words**: Dynamic modulus; Dynamic shear modulus; Master curve; Simple performance test; Superpave; Synthetic zeolite; Viscosity; Warm mix asphalt.*

Introduction

As benefits from the inclusion of a subsurface drainage system in pavement construction are receiving increasing recognition among pavement practitioners, more and more highway agencies are willing to adopt such a technology in their pavement design and rehabilitation practice. Although a complete subsurface drainage system is made of several components, including permeable base layer, longitudinal drains, and transverse outlet systems daylighted to surface drainage channels, the properties of permeable base layer are crucial to the desired performance of the whole drainage system [1]. Three types of permeable base layers (asphalt-treated, portland cement-treated, and unbound aggregate permeable bases) are often used in subsurface drainage systems. Compared to asphalt- and cement-treated permeable bases, unbound aggregate may provide a more cost-effective alternative to low- to medium-volume roadways when graded properly. Such an unbound aggregate should have adequate permeability while remaining structurally stable during the construction and throughout pavement service life. In general, a trade-off between structural stability and permeability of unbound aggregates exists: Increase in permeability is often at the cost of structural stability or a vice-versa. The permeability of granular soils is usually determined by conducting constant-head hydraulic conductivity test. However, the permeability is not the focus of this paper and will not be discussed further. The structural stability of an unbound aggregate was investigated through a series of laboratory tests, including dynamic cone penetrometer (DCP), California bearing ratio (CBR), and repeated load triaxial (RLT) tests. The results from the above testing procedures were examined with an emphasis on the appropriateness of testing procedures in characterizing structural stability of the aggregate.

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Laboratory Testing Program

Testing material, Mexican limestone, is a brown crushed aggregate, which is often used as base material in Louisiana highways. Its specific gravity and water absorption are 2.54 and 5.71, respectively. The fine portion (passing through No. 40 sieve) is found to be nonplastic. Since the process of determining an optimum gradation that meets both permeability and structural stability is somewhat trial-and-error in nature, Mexican limestone specimens in different gradations were studied. These gradations were obtained by first sorting original unbound aggregate into different particle size groups and then remixing them in a desired proportion. This sorting and remixing process is illustrated by a schematic diagram in Fig. 1. In this study, five different gradations were evaluated. One of these gradations is Louisiana class II gradation (designated as LA II in this paper) specified by Louisiana Department of Transportation and Development (LA DOTD), which was first evaluated to provide a benchmark for other gradations [2]. LA II gradation consists of coarse and fine branches, as shown in Fig. 2. Since the range bounded by LA II coarse and fine branches is relatively wide, the properties of each branch were evaluated individually. New Jersey permeable unbound aggregate gradation, which is recommend by Federal Highway Administration (FHWA), is also included in Fig. 2. New Jersey gradation is a well-known gradation that provides adequate permeability, but the performance of its structural stability is less documented. Only the medium gradation within the New Jersey gradation range was studied for providing some reference

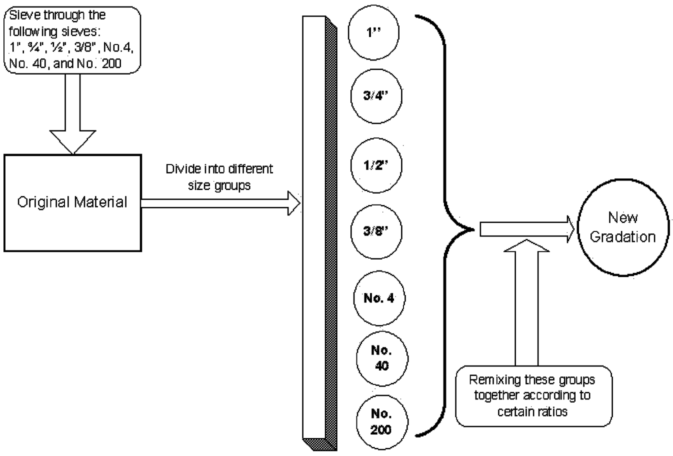

Fig. 1. Schematic Diagram for Testing Procedure to Obtain Different Particle Size Gradations.

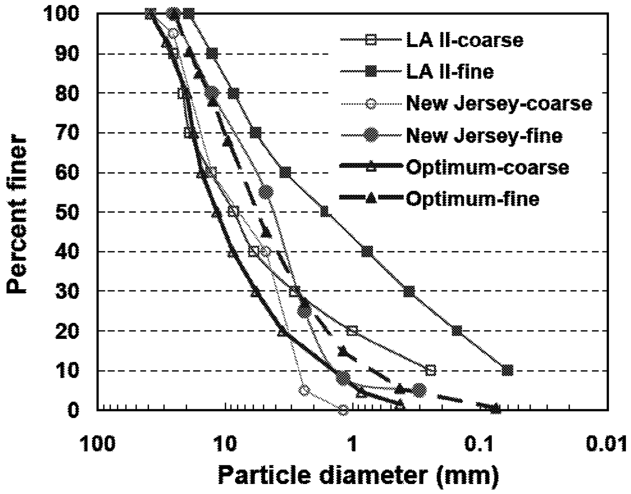

Fig. 2. Particle Size Distributions for Tested Mexican Limestone Specimens.

information in the process of gradation optimization. After a series of trial-and-error tests, with the help of the reported results in the literature, an optimum gradation was identified, which is also included in Fig. 2 [3]. The criteria in optimizing gradation are from two standpoints: one is the permeability quantified by saturation hydraulic conductivity that should be equal to or larger than 0.35cm/sec. (1,000ft/day); and the other is the relative structural stability compared with that of LA II gradation.

Basic physical properties of the aggregate, including specific gravity, gradation analysis, plasticity index (PI), and moisture-density

Table 1. Parameters Related to Particle Size for Different Gradations.

Gradation	C_u	C_c	ρ_{200} (%)	USCS/AASHTO
LA II-coarse	53.09	2.59	5.0	GW/A-1-a
LA II-fine	55.61	0.64	12.0	GW-GM/A-1-b
New Jersey medium	4.86	0.71	3.0	GP/A-1-a
Optimum-coarse	17.86	2.50	<1.5	GW/A-1-a
Optimum-fine	37.46	4.29	3.0	GW/A-1-a

Note: C_u = coefficient of uniformity; C_c = coefficient of curvature; ρ_{200} = percent of fines (passing through No. 200 sieve).

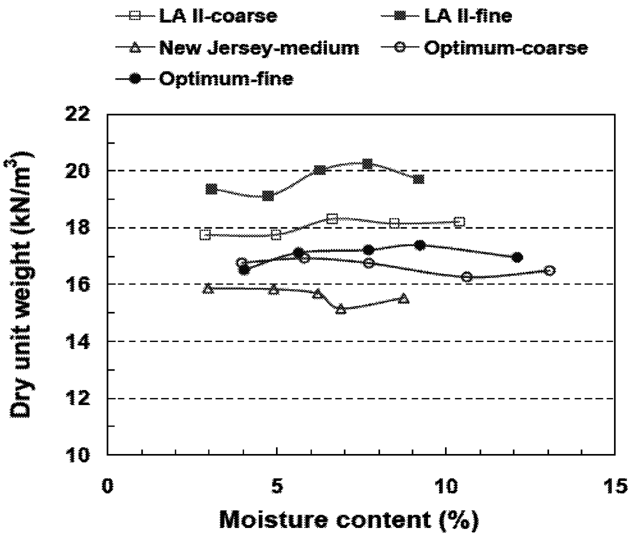

Fig. 3. Moisture-Density Relationships for Mexican Limestone with Different Gradations.

relationship, were determined in accordance with respective ASTM specifications (ASTM D854, D422, D4318, and D698). These physical properties were used to provide preliminary characterization and classification for the tested unbound aggregate, with the results listed in Table 1. Also, the moisture-density relationship for specimens with different gradations provides the information of optimum moisture content and maximum dry density that were used in preparing samples for other tests. Fig. 3 shows these relationships for these different gradations.

CBR

The CBR test, a relatively simple testing procedure, is commonly used to characterize shear strength of pavement base, subbase, and subgrade soils. Mexican limestone specimens in various gradations were prepared for the CBR test, at their respective optimum moisture content and maximum dry density. For each gradation under investigation, both unsoaked and soaked CBR tests were performed. The former is penetrated after the specimen is prepared and the latter is tested after the specimen has soaked in water for 96 hours to evaluate the influence of saturation on the CBR value. All the CBR tests were performed in compliance with ASTM D1883.

DCP

The DCP is a simple and effective tool for evaluating in-situ strength of pavement layers [4]. The DCP tests were conducted on compacted aggregate in a 305 × 305 × 305mm (12 × 12 × 12inches) pit dug at the center of a steel-framed box with dimensions of 1500 × 900 × 900mm (5 × 3 × 3ft). Adjacent soil that provides lateral confinement for the DCP specimens is compacted silty clay left from a previous research project. Mexican limestone specimens in various gradations were compacted into the pit at their respective optimum moisture content and maximum dry density. All the DCP tests were performed in accordance with ASTM D6951.

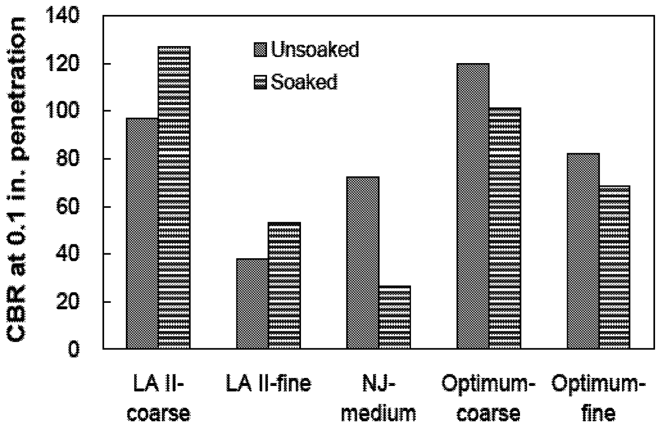

Fig. 4. CBRs at 0.1in. Penetration for Mexican Limestone with Different Gradations.

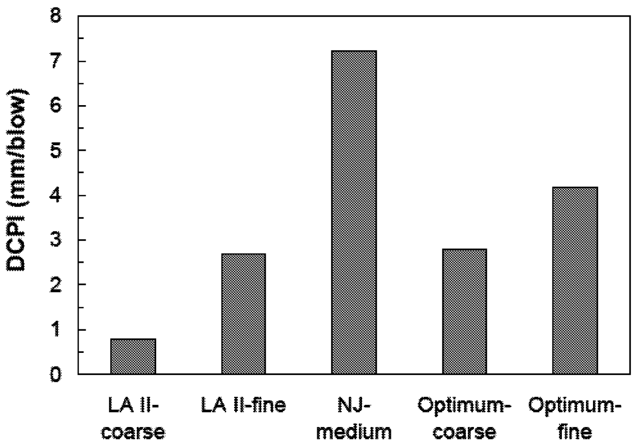

Fig. 5. DCP Result Summary for Mexican Limestone with Different Gradations.

RLT Test

RLT is a customary procedure to determine resilient modulus of pavement materials in the laboratory. A 150 × 325mm (6 × 13inches) split mold and a vibratory compaction device were used for preparing samples. Two membranes were used to prevent any damage caused by coarse particles during specimen preparation, with the aid of vacuum to achieve a good contact with the mold. The compacted samples were 150 × 300mm (6 × 12 inches) (diameter by height) cylinders. All RLT tests were conducted on specimens at their respective optimum moisture content and maximum dry density as determined from standard Proctor testing procedure. The RLT test consisted of first conditioning the samples in the same procedure used in the AASHTO T307-99 [5] and applying 10,000 repeated load cycles. Additional details about RLT tests may be referred to Tao and Farsakh [6].

Analysis of Test Results

CBR Results

CBR results at a penetration of 0.1in. for tested specimens are plotted in Fig. 4. LA II-coarse and the optimum-coarse gradations obtained much higher CBR values, compared to the other gradations; LA II-fine had the lowest value. The influence of soaking/saturation on CBR is not consistent for tested specimens, with three gradations having smaller soaked CBR values than unsoaked ones, but two gradations have the opposite trend. This observation suggests that CBR may not be a good indicator toward indicating the influence of saturation on shear strength of coarse materials, such as those tested in this study.

DCP Results

DCP results are often represented by dynamic cone penetration index, DCPI, which is averaged penetration per blow (mm/blow) over the thickness of the tested layer. A higher DCPI value generally implies weaker shear strength for a given aggregate. DCPIs for tested gradations are shown in Fig. 5. New Jersey medium gradation had the largest DCPI, followed by optimum gradation-fine, optimum gradation-coarse, LA II-fine, and LA II-coarse.

RLT Test Results

Both resilient modulus, M_r, and permanent deformation, ε_p, can be determined from RLT tests. Resilient modulus is a parameter to characterize stiffness of pavement materials under repeated loading, with consideration of influence of stress levels (both confining pressure and deviatoric stress) and the nonlinearity induced by traffic loading. Resilient modulus has been an essential input parameter in the current AASHTO empirical pavement design guide in selecting pavement layer thickness and even receives more attention in the forthcoming AASHTO new mechanistic-empirical pavement design guide. The resilient moduli for these gradations under investigation are summarized in Fig. 6, with similar magnitudes for all gradations except for New Jersey-medium. Resilient moduli ranged from 260 to 290MPa for optimum gradation-fine, optimum gradation-coarse, LA II-fine, and LA II-coarse while it is only 191MPa for New Jersey-medium gradation.

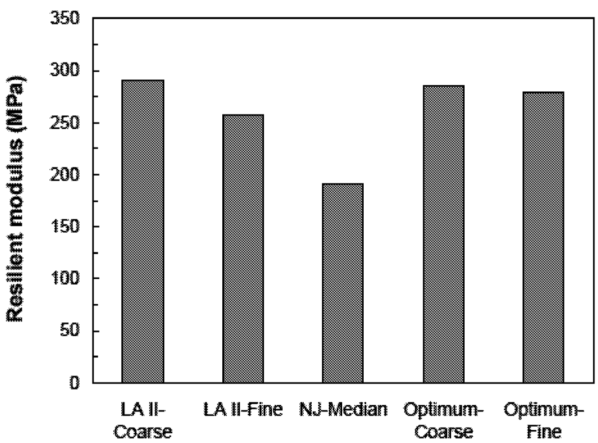

Fig. 6. Summary of Resilient Modulus for Mexican Limestone with Different Gradations.

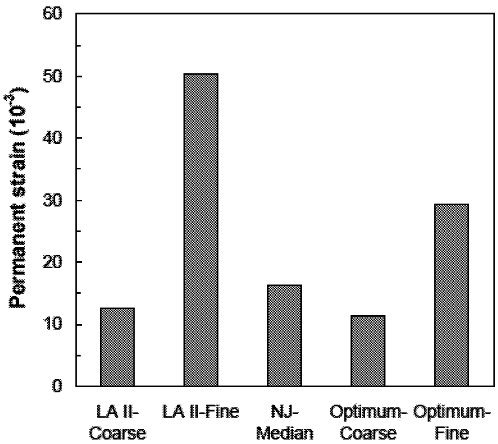

Fig. 7. Summary of Permanent Deformation for Mexican Limestone with Different Gradations.

Table 2. Ranking of Different Gradations on the Basis of Shear Strength and Stiffness

Gradation	CBR-unsoaked	CBR-soaked	DCP	M_r	ε_p
LA II-coarse	B	A	A	A	B
LA II-fine	E	D	B	D	E
NJ-medium	D	E	E	E	C
Optimum-coarse	A	B	C	B	A
Optimum-fine	C	C	D	C	D

Permanent deformation is a parameter reflecting rutting potential and structural stability of individual pavement layers. The permanent deformations are plotted in Fig. 7 for these gradations, with a larger permanent deformation associated with relatively finer gradations (e.g., LA II-fine and optimum gradation-fine).

Possible correlations between DCP values and other tested properties are examined in Fig. 8, by plotting DCPI against unsoaked CBR at 0.1in., soaked CBR at 0.1in., resilient modulus, and permanent deformation strain. Among relations shown in Fig. 8, only DCPI vs soaked CBR at 0.1in. and DCPI vs resilient modulus had significant correlation, with their coefficients of determination R^2 larger than 0.7. There was no strong correlation between DCPI and unsoaked CBR or permanent deformation strain.

Testing results in Table 2 elucidate the influence of particle size gradation on shear strength and stiffness of the aggregate. Different gradations are ranked in terms of their corresponding CBR, DCP, resilient modulus, and permanent deformation magnitudes, with "A" representing the best performance and "E" representing the worst performance.

Conclusions

The above result analyses indicate that particle size gradation affects shear strength and stiffness of the aggregate by changing packing configurations that is reflected by different maximum dry densities among these gradations.

Overall LA II-coarse and optimum-coarse gradations achieved higher shear strength and stiffness while NJ-medium and LA II-fine had lower strength and stiffness. Optimum-fine gradation had intermediate values in terms of shear strength and stiffness. This finding suggests that neither a very uniform gradation nor the one with excessive fines content will perform well.

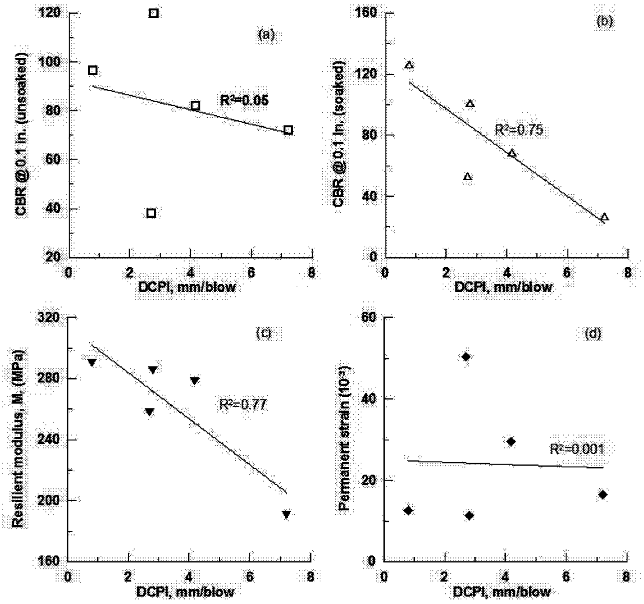

Fig. 8. Correlations between DCPI and Properties Including CBR, Resilient Modulus, and Permanent Deformation Strain.

For the influence of water content/saturation on shear strength of the aggregate, it seems that CBR procedure is not effective. Further studies are ongoing to investigate the effectiveness of DCP and RLT tests for identifying this effect.

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