Structural Characteristics of Stabilized Base Materials

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ABSTRACT: As a type of traditional materials, stabilized materials or semi-rigid base materials are widely used in all grades of pavement in China. As well as other materials, performance of stabilized base materials are not only related with its composition but also controlled by its structure. Performance of stabilized base composed by same materials is different in practice. According to the distribution of coarse and fine aggregates stabilized base can be divided into four structure types. They are skeleton-dense structure, skeleton-porous structure, suspension-dense structure and uniformity-dense structure. Types of base material have specific physical concepts. It can be made sure by the ratio between residual void of compacted coarse aggregate and the volume of compacted fine aggregate and binder material. It also can be checked by indoor tests. Structure type of stabilized base material is controllable and realizable in mix proportion design. Systemic tests indicate that performance of stabilized material with different structural type is featured and skeleton-dense structure is better than suspension-dense structure in performance of cracking and erosion resistance. The testing results, for three structural types of cement stabilized crushed stone including suspension-dense, skeleton-dense and skeleton-porous structures, for two structural types of lime fly-ash stabilized crushed stone including suspension-dense and skeleton-dense structures, were presented in this paper.

KEY WORDS: Stabilized base material, structural, performance.

1 INTRODUCTION

Semi-rigid materials are usually mixed with cement, lime and other inorganic binder and mineral materials in appropriate proportions, then the compaction and curing could make the mixture have certain strength. As semi-rigid materials can utilize local raw materials conveniently, apply cold mixing and cold compacting techniques, also have high strength, they are widely used as pavement base in China, and for a long period semi-rigid base have been being a main type of expressway bases [1-3].

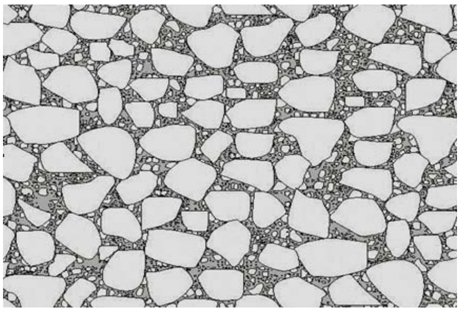
Experts and scholars in many countries, including China, US, South Africa and Denmark, are constantly studying on semi-rigid materials to further recognize, improve and utilize their features, thus fully exert the excellent properties [4-7]. The research and application of semi-rigid base materials in China lasts more than half a century, and have obtained remarkable achievement. But the early damage phenomenon of asphalt pavement with semi-rigid base shows that the understanding about this kind of materials is still incomplete, and there are even some misunderstandings [8]. Semi-rigid base materials with same composition have obvious difference of performance in some cases. In addition, distribution state of fine and course aggregates is the main cause of the performance differences. So the performance of semi-rigid materials is not only relevant to its component, but also decided by the mixture structure.

At present, the most common semi-rigid base materials are cement stabilized material (CTM) and lime fly-ash stabilized material (LFTM). Based on clearly defining the four structure types of semi-rigid base materials, different structure types and verification methods are proposed. The strengths, modulus, shrinkage performances and anti-eroding performances of different structure types of CTM and LFTM are studied.

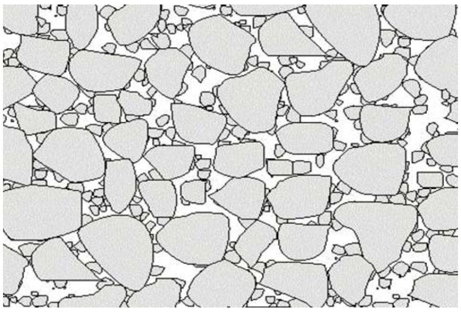
2 CLASSIFICATION AND VERIFICATION OF BASE MATERIAL STRUCTURE TYPES

2.1Classification of Base Material Structure Types

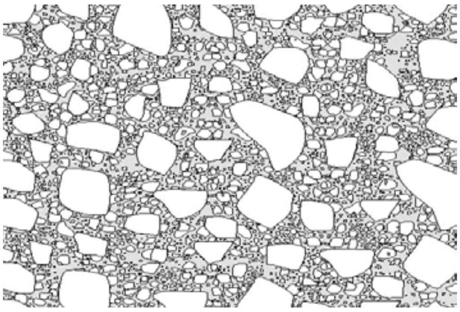
In the process of compacting formation, there are known binders and aggregates included in the semi-rigid materials. Based on the relative size of particle, binders and aggregates could be divided into coarse and fine parts. In accordance with usual practice, aggregate size above 4.75mm is considered as the coarse material part, the rest aggregate and binder less than 4.75mm are regarded as the fine material part. Therefore, the semi-rigid materials can be divided into four structure types according to the proportion and distribution of coarse and fine materials:(1) skeleton-dense structure: coarse material part forms the mutual embedded extruded skeleton, fine material part fills the residual void between skeleton in fully dense state(Fig.1 a); (2) skeleton-porous structure: coarse material part forms the mutual embedded extruded skeleton, part of the residual void between skeleton is filled by fully dense fine material, and some void remains (Fig.1 b); (3) suspension-dense structure: coarse material part does not form the mutual embedded extruded skeleton, just dispersedly distributes in the fully dense fine material (Fig.1 c); (4) uniformity-dense structure: no coarse material, fine aggregate or fine grained soil with similar grain size are in full dense state (Fig.1 d).



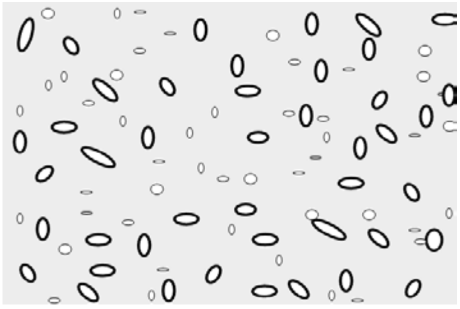
a) Skeleton-dense structure



b) Skeleton-porous structure



c) Suspension-dense structure



d) Uniformity-dense structure

Figure1: Base material structure types.

According to physical concept, structure formation depends on the relationship between void in coarse aggregate and compacted volume of fine aggregate. When the void in is same to the volume, the structure formation is skeleton-dense; when the void is much larger than the compacted volume, the residual void in coarse aggregate cannot be fully filled by fine aggregate, the structure formation is skeleton-porous; when the void is less than the compaction volume, the coarse aggregate cannot form the mutual embedded extruded skeleton, but distributes or suspends in the compacted fine aggregate and binder, the structure formation is suspension-dense.

2.2 Verification of Base Material Structure Type

Structure type of base material can be verified by means of indoor test. Whether the base mixture is composed of coarse aggregate or fine aggregate should be identified at first. If the mixture is all fine aggregate or stabilized soils, the base material structure type can be assigned to uniformity-dense; if there are both coarse material and fine material in the mixture, coarse material and fine material should be tested respectively to ascertain the structure in the rest of three types.

Separating out the coarse aggregate above 4.75mm, and compacting the aggregate to a certain volume, the residual void V_1 in the mixture after compaction is calculated by Eq.1:

$$V_1 = V_C - \frac{m_C}{\rho_{C1}} \quad \text{or} \quad V_1 = \left(1 - \frac{\rho_C}{\rho_{C1}}\right) \times V_C \qquad (1)$$

In Eq.1: V_1–void volume of coarse aggregate; V_c–compacted volume of coarse aggregate; m_C–quality of coarse aggregate; ρ_{c1}–apparent density of coarse aggregate, ρ_C–compacted density of coarse aggregate.

Then after fine aggregate less than 4.75mm is separated out and mixed with binder in scheduled proportion, the density test of mixture should be taken under standard compaction power to determine its maximum dry density and the optimum moisture content. Finally the compacted volume V_2 of fine aggregate and binder is calculated by Eq.2:

$$V_2 = \frac{m_F (1 + \omega_F)}{\rho_F} \qquad (2)$$

In Eq.2: V_2–volume of compacted mixture of fine aggregate and binder; m_F–quality of fine aggregate and binder; ρ_F and ω_F–maximum dry density and the optimum moisture content of mixture of fine aggregate and binder.

The void volume V_1 and compacted volume V_2 should be compared to determine the material structure type. When $V_1=V_2$, the structure type is skeleton-dense; when $V_1>V_2$, it is skeleton-porous; when $V_1<V_2$, it is suspension-dense.

As the base material structure has received little attention in the past, most of the semi-rigid base materials in service belong to suspension-dense structure type.

3 CHARACTERISTICS OF CEMENT STABILIZED SEMI-RIGID MATERIALS WITH DIFFERENT STRUCTURE TYPES

Cement stabilized material is the most common kind of semi-rigid materials. Based on the testing method, according to the relationship between the volume of coarse aggregate and fine aggregate, the aggregate gradations of three structure types of cement stabilized aggregate are designed(Table1), in which the dosage of cement are all 6%. Then the performance comparison is taken between forming density, strength, modulus, shrinkage coefficient.

For convenience, the three structure types of cement stabilized aggregate are labeled by the following code: Cement stabilized aggregate with suspension-dense structure is shown by CTM-A; Cement stabilized aggregate with skeleton-dense structure is shown by CTM-B; Cement stabilized aggregate with skeleton-porous structure is shown by CTM-C.

Table1: The aggregate gradations of different structure types.

Structure Type	Sieve Size (mm)												
	31.5	26.5	19.0	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
CTM-A	100	96.8	93.5	84.7	75.9	67.0	39.0	26.0	20.5	15.0	11.2	7.3	3.5
CTM-B	100	90.4	73.6	65.2	58.0	46.0	26.8	25.8	18.0	9.1	4.4	1.6	0.5
CTM-C	100	86.3	62.8	52.5	41.1	26.3	11.2	5.0	3.0	2.0	1.0	0.0	0.0

From Table 1, in suspension-dense structure, skeleton-dense structure and skeleton-porous structure, the proportions of coarse aggregate take in the total aggregate weight are 61.0%, 73.2% and 88.8% respectively.

3.1 Maximum Dry Density and the Optimum Moisture Content of Cement Stabilized Aggregate

Different from previous heavy compaction method, the maximum dry density and the optimum moisture content of mixture are ascertained by vibratory method in this paper. The vibration parameters in the test are: static pressure 140KPa, vibration frequency 28HZ, and vibration force 5500N. The previous studying indicates that moisture content-dry density curve of semi-rigid base mixture from vibratory compaction method is similar to the curve from heavy compaction method, they are all convex parabola.

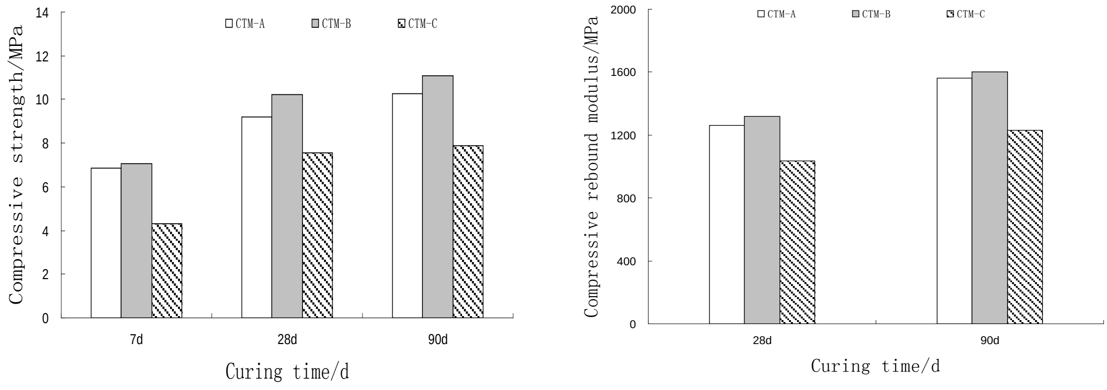
Table2: Maximum dry density and optimum moisture content of cement stabilized aggregate by vibratory compaction method.

Structure types	Optimum moisture content (%)	Maximum dry density (g/cm^3)
CTM-A	5.00	2.435
CTM-B	5.00	2.428
CTM-C	3.80	2.205

The maximum dry density and the optimum moisture content of cement stabilized aggregate with suspension-dense structure are only a little different from skeleton-dense structure. Science there is less fine aggregate, both the maximum dry density and the optimum moisture content of cement stabilized aggregate with skeleton-porous structure decrease (Table 2).

3.2 Compressive Strength and Compressive Resilient Module of Cement Stabilized Aggregate

The Φ15cm×h15 cm specimens of cement stabilized aggregate with different structure types are formed by vibratory compaction method, the vibration parameters include: Static pressure is 140KPa, vibration frequency is 28HZ, and vibration force is 5500N. After forming, the specimens are cured under standard condition. The 7 days, 28 days and 90 days compressive strength and compressive resilient modulus are tested respectively (Fig.2).



a) Compressive strength　　　b) Compressive resilient modulus

Figure2: Strength and modulus of cement stabilized aggregate with different structure types.

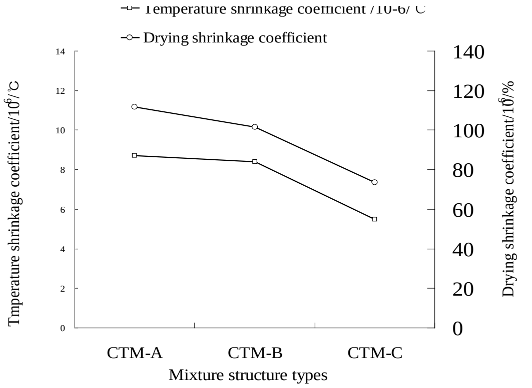
From the test results, in the same cement dosage and curing time, the compressive strength and compressive resilient modulus of cement stabilized aggregate with different structure types are different from each other. The compressive strength of cement stabilized aggregate with skeleton-dense structure is the highest in each curing period, suspension-dense structure is middle, and skeleton-porous structure is lowest. As cement stabilized aggregate with dense structure, coarse aggregate skeleton could improve the strength significantly. Much void of skeleton-porous structure is the main reason causing the lowest strength. The variation trend of compressive resilient modulus of cement stabilized aggregate with three different structure types is similar to that of the compressive strength.

3.3 Shrinkage Coefficient of Cement Stabilized Aggregate

Shrinkage coefficient is tested with 10cm×10 cm×45cm beam specimen that is shaped by vibratory compaction method. Specimens for temperature shrinkage test are cured under standard condition for 28 days and then dried. The average shrinkage coefficient is tested at 55℃~ -15℃. Specimens for drying shrinkage test are cured under standard condition for 7 days and then the average shrinkage coefficient is tested at 40℃. The average temperature shrinkage and drying shrinkage coefficient test results of cement stabilized aggregates with three structure types are shown in Figure 3.

The test results show that the average temperature shrinkage coefficient of all types of cement stabilized aggregates decreases as the coarse aggregate increases. Cement stabilized aggregate with skeleton-dense structure has lower average temperature shrinkage coefficient than that of suspension-dense structure, and cement stabilized aggregate with skeleton-porous structure has lowest shrinkage coefficient. The main reason is that coarse aggregate has small volume change with temperature changes and fine aggregate and binder play opposite role which could constrain the shrinkage of mixture with skeleton-porous structure to the lowest.

Average drying shrinkage coefficient of the cement stabilized aggregate has the same rule as the average temperature shrinkage coefficient. Namely, average drying shrinkage coefficient of cement stabilized aggregate with suspension-dense structure is the largest, skeleton-dense structure is the medium, and skeleton-porous structure is the smallest. But the reasons are different, drying shrinkage deformation is mainly caused by water losing amount. Along with the coarse aggregate increasing and fine aggregate and binder decreasing, the water content of mixture decreases, which leads to lower drying shrinkage coefficient.



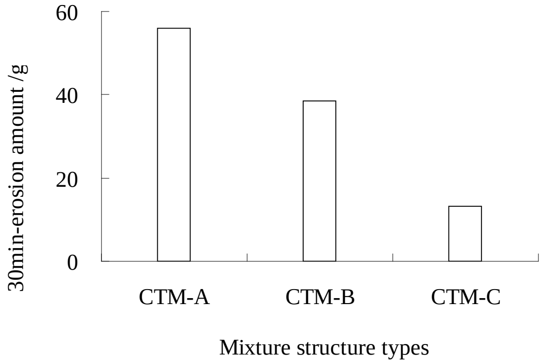


Figure3: Shrinkage coefficient test results structure of different cement stabilized aggregate.

Figure4: Anti-erosion test results of different types of cement stabilized aggregate.

3.4 Anti-erosion Performance of Cement Stabilized Aggregate

The forming method of anti-erosion test specimen is same to that of the compressive strength. Test specimens are cured under standard condition for 28 days and then tested. Specimens were tested for 30 minutes by the special designed erosion machine, and anti-erosion performance could be evaluated by the erosion weight dropped from original specimen. Figure 4 shows anti-erosion test results of cement stabilized aggregates with three structure types.

It is shown that the order of erosion resistance of cement stabilized aggregate with different structure is: suspension-dense structure ＞ skeleton-dense structure ＞ skeleton-porous structure. Coarse aggregate has significant contribution to the anti-erosion performance of dense structure. Skeleton-porous structure has the best performance as it has larger void ratio which can dissipate dynamic water pressure.

4 CHARACTERISTICS OF DIFFERENT STRUCTURE TYPES OF LIME AND FLY-ASH STABILIZED MATERIALS

Lime and fly-ash stabilized material is another kind of widely used semi-rigid material. And the main difference between this material and cement stabilized material is that it contains a large amount of fly-ash. Because the early strength of lime and fly-ash stabilized mixture is lower, it is not suitable to be used as skeleton-porous structure. The skeleton-dense and suspension-dense structure lime and fly-ash stabilized aggregate are designed according to the relation between the residual void volume of coarse aggregate and the filling volume of fine aggregate. The proportion of lime, fly-ash and aggregate is 4:11:85. And the mixture density, strength, modulus, shrinkage coefficient and anti-erosion performance are compared. The two types of aggregate gradations of the mixture used in formed specimens are shown in Table 3, and the two gradations are named for short as below:

Suspension-dense structure lime fly-ash stabilized aggregate is shown by LFTM-A;

Skeleton-dense structure lime fly-ash stabilized aggregate is shown by LFTM- B;

Table3: Different structure lime and fly ash stabilized aggregate (4:11:85) gradations.

Structure Type	Sieve Size (mm)												
	31.5	26.5	19.0	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
LFTM-A	100	94.8	89.5	80.0	70.5	61.0	40.0	28.0	18.5	13.0	9.8	6.7	3.5
LFTM-B	100	95.4	86.3	58.9	45.2	17.7	8.6	7.3	5.6	2.9	1.5	0.9	0.4

Table 3 shows that in order to form the skeleton-dense structure of lime and fly-ash stabilized aggregate, the proportion of the fly-ash, lime and aggregate is 4:11:85, and the content of coarse aggregate above 4.75 mm should be around 90%. While in the suspension-dense structure, the content of coarse aggregate above 4.75 mm is much less, about 60%.

4.1 Maximum Dry Density and the Optimum Moisture Content of Lime and Fly-Ash Stabilized Aggregate

The test method of maximum dry density and the optimum moisture content of lime and fly-ash stabilized aggregate mixture is same to that of cement stabilized aggregate. Table 4 is the test result of the maximum dry density and optimum moisture content under vibratory compaction condition.

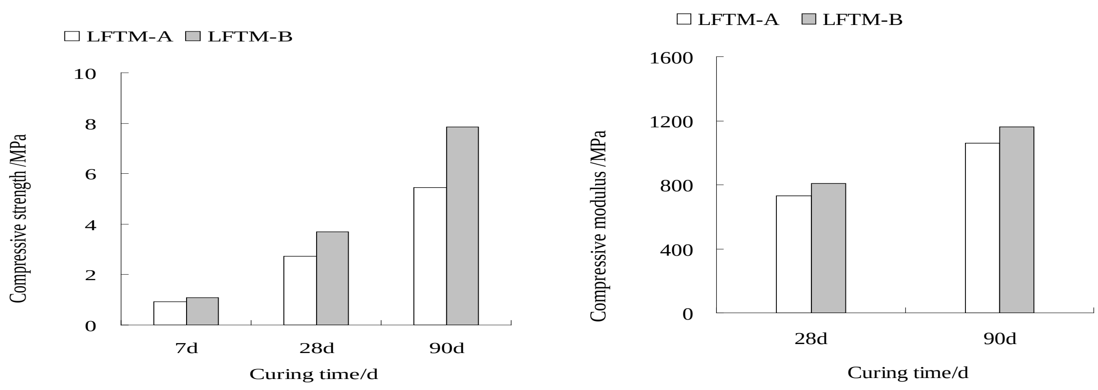
Table4: Maximum dry density, the optimum moisture content under vibratory compaction condition.

Structure types	Optimum moisture content (%)	Maximum dry density (g/cm^3)
LFTM-A	8.5	2.215
LFTM-B	8.0	2.239

Table 4 shows that the maximum dry density of suspension-dense lime and fly-ash stabilized aggregate is less than that of skeleton-dense structure, while the optimum moisture content has opposite role.

4.2 Compressive Strength and Compressive Modulus of Lime and Fly-Ash Stabilized Aggregate

The lime and fly-ash stabilized aggregate specimens are also shaped by vibratory compaction method, as same as cement stabilized aggregate. The specimens are cured under standard condition for scheduled days and then the 7, 28, 90 days unconfined compressive strength and 28 days, 90 days compressive modulus is tested. The test results are shown in Figure 5.



a) Compressive strength b) Compressive rebound modulus

Figure5: Compressive strength and modulus of lime and fly-ash stabilized aggregate.

The results suggest that the compressive strength and compressive modulus of mixture are mainly affected by structure types when the lime and fly-ash stabilized aggregate has same composition proportion. At each curing period, skeleton-dense structure has higher compressive strength than the suspension-dense structure, so the coarse aggregate skeleton could improve both the strength and modulus of lime and fly-ash stabilized aggregate too.

4.3 Shrinkage Coefficient of Lime and Fly-Ash Stabilized Aggregate

The forming and curing method of shrinkage coefficient specimen of lime and fly-ash stabilized aggregate is same to the cement stabilized aggregate. Figure 6 shows shrinkage coefficient results of different lime and fly-ash stabilized aggregate structure types.

The results indicate that the average temperature shrinkage coefficient and the average drying shrinkage coefficient decrease as the coarse aggregate increases, meanwhile the average temperature shrinkage and drying shrinkage deformation also reduce.

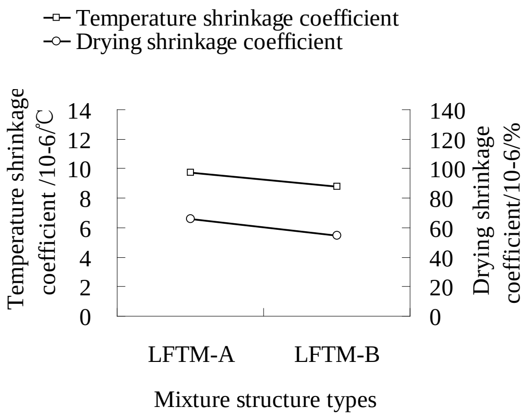


Figure6: Shrinkage coefficient results of lime fly-ash stabilized aggregate.

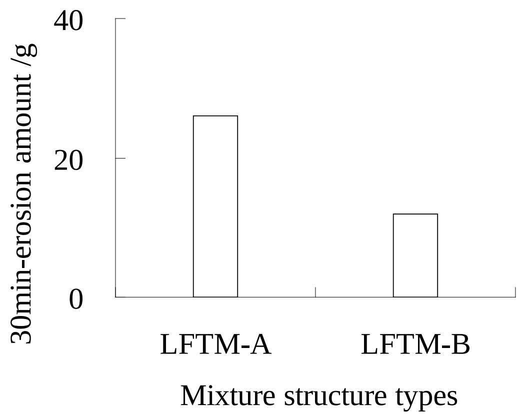


Figure7: Anti-erosion test results of lime fly-ash stabilized aggregate.

4.4 Anti-erosion Performance of Lime and Fly-Ash Stabilized Aggregate

The testing specimen and method of anti-eroding test of lime and fly-ash stabilized aggregate is same to that of cement stabilized aggregate. But the curing period is 90 days, or the specimen may damage during test due to the low strength.

Figure 7 shows the anti-erosion test results of suspension-dense and skeleton-dense lime and fly-ash stabilized aggregates. The results show the 30 minutes erosion weight of skeleton-dense is obviously less than that of suspension-dense. Coarse aggregate skeleton can protect the inner fine aggregate and keep the erosion weight steady. While the lime and fly-ash stabilized aggregate with less coarse aggregate may continuously lose the fine particle until damage under the dynamic water pressure.

5. CONCLUSIONS

According to the distribution of coarse and fine aggregates, the stabilized materials can be divided into four structure types: skeleton-dense structure, skeleton-porous structure, suspension-dense structure and uniformity-dense structure. The structure types can be designed base on the ratio between residual void volume of compacted coarse aggregate and the volume of compacted fine aggregate and binder material, also can be verified by tests.

The impact of mixture structure types on its performance is obvious. For either cement stabilized aggregate or lime and fly-ash stabilized aggregate, with the same material composition, skeleton-dense structure has larger strength, modulus and lower temperature shrinkage, drying shrinkage coefficient. Skeleton-porous structure could be used as permeable base, considering the coarse aggregate skeleton effect is obvious and the strength is low in this structure, the shrinkage coefficient and anti-eroding performance is the best. Suspension-dense structure could be applied in low traffic volume pavement.

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