The Premium Paving Aggregate

by Bill Martin, P.E. and John Ries, P.E.

This document was prompted by the August 2004 issue of *Better Roads* which featured an article on premium paving aggregates. The article did not include one of the finest paving aggregates being used today: Expanded Shale, Clay and Slate (ESCS) Structural Lightweight Aggregate. ESCS is available throughout much of the United States. Approximately 600,000 cubic yards of ESCS are used annually in the asphalt surface treatment (chip seal) market alone. To a lesser extent structural lightweight aggregate is also used in hot mix asphalt (HMA) pavement and concrete road surfaces including bridge decks. Expanded Shale, Clay and Slate Structural Lightweight Aggregate has many desirable properties that account for its long service record. Some of theses properties are covered below.

PHYSICAL PROPERTIES

All premium aggregates have some properties in common such as good particle shape, polish and abrasion resistance, and durability. Structural lightweight aggregate includes all of these as well as several additional unique factors, such as enhanced hydration of portland cement through internal curing, improved thermal resistance and superior bonding to both asphalt and cement mortar.

Particle Shape

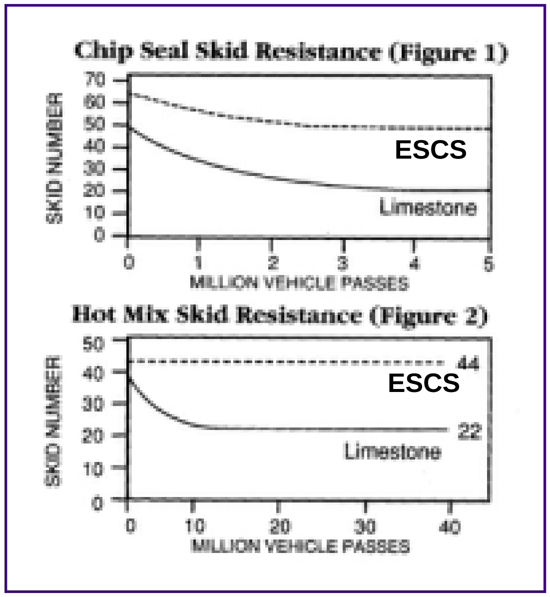
A survey of Department of Transportation (DOT) specifications shows that the preferred premium aggregates have a cubical shape that exhibits multiple fractured faces and minimum elongated or flat pieces. This is often a concern since most of the quarried coarse aggregate must be reduced in size several times to achieve the proper paving grading. However, this ideal particle shape is automatically available with ESCS because it is manufactured in a rotary kiln and the coarse particles (5/8 in-#10) used in paving applications usually only require screening. Generally, crushing ESCS does not create flat particles. The fines are normally less than 2%, with the unusual characteristic that they do not bond to the coarse particles when wet.

Low density

With a density of about 1/2 of natural aggregates, two unique premium characteristics emerge. Travel distance may double, or twice the volume of ESCS may be hauled for the same price as with natural aggregates. Additionally, due to the low density, chipping windshields or paint (a major complaint that often restricts the use of economical chip-seal paving maintenance programs) is avoided.

Polish and Abrasion Resistance

When ESCS aggregate is used in a surface course, the pavement maintains its high initial friction resistance (wet or dry) throughout its service life. The aggregate does not polish as it wears because the rough ceramic micro surface texture is constantly renewed as fresh interior cells with tough edges are continually exposed. Hot mix asphalt overlays with as little as 50% by volume of ESCS aggregates will have a wet coefficient of about 0.5. Wet coefficient values of 0.5 to 0.6 at 50 mph are maintained throughout the life of ESCS chip-seal projects. See Fig. 1 & Fig. 2.



Hundreds of tests made by the TxDot, Fort Worth Division have shown the superiority of ESCS skid resistance compared to limestone, dolomite, sandstone, and traprock. In 1992 The Center for Transportation Research reported on the accelerated polish test using Test Method Tex-438-A for PV (Polish Value). The report states [ref 1] "The PV ranged from a lowest value of 25 for a crushed siliceous gravel aggregate to a high of 51 for ESCS aggregate. The PV range was 36 to 41 for the crushed sandstone and rhyolite aggregates and 34 to 40 for the limestone. The traprock source had a PV of 34."

There are 1 million wet-weather traffic accidents per year in the U. S according to the Federal Highway Administration. To help ensure safety, U.S. roads are periodically tested to verify skid resistance as the road ages. Also, tires must be certified and graded by the US Department of Transportation for frictional performance at the Goodfellow Air Force Base in San Angelo, Texas [ref 2]. These tires are certified on hot-mix asphalt made with ESCS Lightweight Aggregate that has provided a constant Skid Number (SN) of 50 plus at 40 mph for more than 15 years. This test track does not polish with time after a huge number of certification tests.

Durability

Aggregate freezing and thawing durability is important because de-icing salts are used extensively in cold climates and result in degradation of some natural aggregates used in asphalt applications. Deicing salts also are detrimental to the durability of concrete. An example is limestone with as little as 1% natural shale. Even this tiny amount of shale is enough to start surface scaling of concrete, regardless of good air-entrainment content, according to the Oklahoma DOT.

ESCS aggregate was first introduced in the asphalt market in the mid 1950's and continues to prove its durability by providing safe, long-lasting road surfaces that maintain high skid resistant surfaces. These commercial roads are cost effective and use standard construction methods. ESCS lightweight aggregate was first introduced in concrete in 1918 and has proven its freezing and thawing durability due in part to its superior bonding capability to the cement matrix and its contribution to enhanced cement hydration. There are over 600 major structural lightweight concrete bridge decks in the United States alone. Many of these are salted regularly during the winter season. To some degree ice crystals are accommodated within the pores of ESCS unlike the layers and cracks of natural aggregates. The Durability Index (AASHTO T 210) generally ranges in the 80s. For other characteristics, see [ref 3].

Nothing proves durability better than proven performance at actual installations. For example Tarrant County Texas, used ESCS coarse aggregate in the following hot mix designs. The information and photos were provided by TxDOT Fort Worth District Pavement Engineer, Andrew Wimsatt, P.E.:

State Highway 183, N. W. Fort Worth, Tx, 19 year old ESCS overlay, since 1985 over jointed concrete.

- Tarrant County, TxDOT, SH 183 from Azle Blvd. to SH 199, still in service after 19 years beginning in 1985. ADT is 16,000 both directions with 11% trucks. (Photos)

- Tarrant County, TxDOT, SH 183 from Spur 580 to I 30, still in service after 18 years beginning in 1986. ADT was 19,000 both directions with 10% trucks.

- Tarrant County, TxDOT, SH 121(Airport Freeway), 12 years of service from 1985 to 1997. The current ADT is 94,000 both directions with 9% trucks.

Tarrant County also had multiple installations of ESCS HMA overlays installed around 1975 [ref 2], which lasted into the 1990s.

ESCS HMA surface courses have been used in Texas, Tennessee, Wyoming, Mississippi, and Alabama [ref 2]. ESCS HMA has a high degree of internal friction and high shear strength because the aggregate angles of internal friction generally exceed 40 degrees when tested in the direct shear box in accordance with ASTM D 3080 *Standard Test Method for Direct Shear Test of Soil Under Consolidated Drained Conditions*. This high angle of internal friction is a major reason for the pavement longevity and resistance to rutting. The aggregate's consistently high angle of internal friction is also a key reason lightweight aggregate is used extensively for geotechnical applications.

Bonding to Asphalt (anti-stripping)

Various State DOT's have aggregate stripping tests that show the aggregate-asphalt bonding characteristics. These tests are all variations of the aggressive boiling test. MODOT Test Method T 12 and California Film Stripping Test CT 302 are examples of these "boil" tests. More than 15 states use the "10 minute" boil test. The results of testing the bond between asphalts and ESCS show a high affinity for resisting stripping. The best natural aggregates may lose only 10% of their oil during the test. In contrast, the loss of oil for ESCS, depending on the test type, is generally less than 5%.

Texas uses a much more rigorous test method called the modified Lottman or TX-531-C. This is where samples are conditioned by vacuum saturating the samples, freezing, then thawing them. The tensile strength ratio (TSR) is then measured as a comparison of tensile strength between the unconditioned and conditioned samples. Eighty percent (80%) is the required TSR on most mixtures. In a recent test program completed by Texas Industries, Inc, that utilized ESCS in a typical surface paving mixture, the sample recorded a TSR of 93%. ESCS has a strong affinity for asphalt, which results in part from its surface charge and its rough ceramic micro-surface texture. This naturally rough surface forms an excellent bond with polymer modified and rubber modified liquid asphalt, as it has been demonstrated with portland cement mortar, creating a longer-service life.

Insulating qualities

The insulating qualities of lightweight aggregate is considerably greater than that of natural aggregate. This is very beneficial in thermally sensitive areas like fill around water lines or as road base over areas that are very susceptible to frost heave. The University of New Brunswick (UNB) has reported tests where the regular density aggregates were replaced with structural lightweight aggregate in hot mix asphaltic concrete mixtures in order to provide an effective method of reducing frost penetration to the underlying layers by providing a less conductive asphalt concrete surface layer.

To evaluate the effectiveness of lightweight aggregate hot mix asphalt a 2.5 km. long two lane highway between Minto and Chipman in New Brunswick, Canada was laid in 1971. The work was done by the New Brunswick Department of Highways with the aggregates supplied by Avon Aggregates and the instrumentation by the Department of Civil Engineering of the University of New Brunswick [ref 6].

Prior to placing the asphalt, a series of thermocouple probes were placed vertically under the roadway at one foot spacings to a depth of 8 ft. Two probes were placed in the lightweight asphalt and two were placed in the normal weight asphalt with half of the probes under the road center line and the rest in the outer wheel lane. The road had initially a four inch layer of asphalt. Half of the test section was retopped with four inches of lightweight asphalt, the other half by a four inch lift of regular asphalt. Thermocouple readings were taken at regular intervals over the winter and indicated that the lightweight asphalt had a significant effect on the depth of frost penetration. This is to be expected because vesicular aggregates have a thermal conductivity of about one twelfth that of regular aggregates.

Testing revealed that the regular asphalt had a thermal conductivity of 4.0 whereas the lightweight asphalt had a thermal conductivity of only 2.8 BTU/ft^2/in/hr/°f. The frost depth under the lightweight asphalt section (4” of lightweight and 4” of regular asphalt) was found to be only 16 inches whereas under the eight inches of regular asphalt it was 32 inches. On projects where the frost penetration must be limited to 16 inches it was found that the reduction in the depth of granular fill more than offset the additional cost of the lightweight aggregate. Perhaps more important was the fact that thawing occurred from the bottom up rather from both the top and bottom of the frost layer as is the case for regular asphalt. Consequently the road was able to retain its load carrying capacity much longer during the spring.

No particular problem was experienced with the design of the asphalt mixture nor with the placing and rolling the lightweight asphalt. Both types of asphalt served for several years before they had to be given a 2-inch topping layer to counteract sub-base settlement [ref 6]. UNB developed a finite element model to provide information on the results. Laboratory and full scale field tests are planned to confirm these results [ref 5].

Internally-cured Concrete Pavement

ESCS aggregate containing high internal moisture content may be substituted for natural aggregates to prolong and increase cement hydration (commonly called internal curing), by the slow release of moisture into the hardening cement matrix. This is particularly beneficial for high performance concrete mixtures with low water cementitious ratios. The internal pores in the aggregate act as reservoirs, storing water that is separate from the mixing water. Paving concrete is always subject to rapidly changing weather conditions. Efforts for applying surface curing methods are often overcome by high temperatures, low humidity, and wind. Internal release of moisture will increase cement hydration, flexural strength and compressive strength as well as reducing early age shrinkage cracking.

Alkali-Silica Reactivity (ASR)

Though ACI 201.1 reports no documented instance of in-service distress with lightweight concrete, all standard practices must be utilized in mitigating ASR whether the aggregate is normalweight or lightweight. Extensive studies have shown that ESCS tends to mitigate the ASR of the other ingredients in the concrete mixture. This result was reported in the publication by Boyd, et. al. [ref 4] 2003 where tests were conducted on lightweight ESCS concrete mixtures that included reactive natural sand known to cause ASR expansion. Test results indicate minimal difference in performance between concrete mixtures with lightweight coarse aggregate combined with either reactive, non reactive, or lightweight fine aggregate. The properties measured included expansion, indirect tensile strength, and compressive strength.

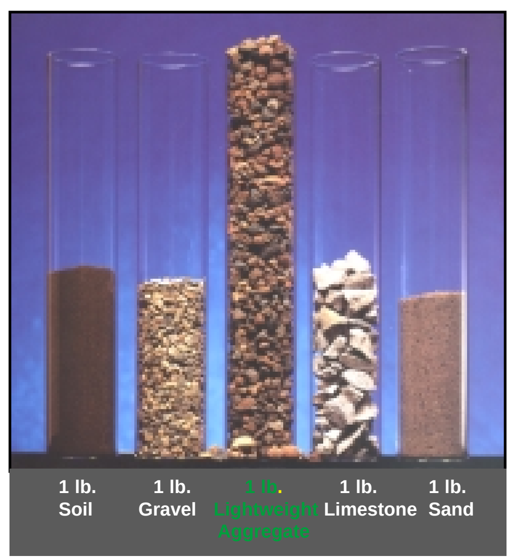
AVAILABILITY

ESCS structural lightweight aggregates are readily available throughout the USA and much of the world. Because of its low density it is often shipped very long distances to provide economic solutions in asphalt and concrete applications, as well as geotechnical and horticulture green roof applications.

When it comes to availability Bill Martin, PE with Chandler Material Company reports “Even though our manufacturing plant is the smallest in the U. S., we can provide the coarse aggregate for a two-inch overlay, 22 feet wide, and 70 miles long per year. Alternatively, this small plant can provide the chip-seal aggregate for a 22 foot wide road, 250 miles per year, and that’s sufficient to satisfy the local market.”

SPECIFICATIONS

When structural lightweight aggregate is used, DOT specifications often need to be modified so a realistic comparison can be made between the lightweight aggregate and natural aggregates. One of the obvious changes that need to be made is in the bid forms to allow for the large difference in density. Structural lightweight aggregate is typically one-half the bulk density of natural aggregate, resulting in one ton of ESCS yielding twice the volume of natural material.



In HMA mixtures revisions to design procedures need to be made, since the ESCS is normally mixed with natural sand-sized aggregates, two materials of significantly different densities.

The following table shows some of the differences for one location. Oklahoma DOT Lab test comparing Tulsa County Limestone with ESCS, both routinely used in paving in Tulsa County:

	Tulsa County Limestone	Tulsa County #3 ESCS Chip
Dry, Rodded density, AASHTO T 19 (pcf)	94.1	50.6
LA Abrasion, AASHTO T 96 (%)	33.3	23.2
Durability Index, AASHTO T 210	56	84
% Insoluble Residue, OHD L 25 (HCL)	1.3	97.9

For additional information and manufacturing plant locations go to www.escsi.org

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REFERENCES

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