Two New Methods to Measure Aggregate Embedment on Chip Seals During Construction

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Chip seals may be the most cost effective preventive maintenance tool available for asphalt pavements. However, they are also problematic. Chip seals, if not designed and constructed properly, offer significant risk to owners in the form of vehicular damage and customer dissatisfaction. This damage is often caused because of insufficient embedment of the aggregate chips into the asphalt binder. If the chips are embedded to the proper depth, the adhesive ability of the asphalt binder is greatly improved, and the potential for aggregate loss, and hence vehicle damage is reduced. Unfortunately, measuring embedment depth has been difficult in the past. In fact, the only quantitative method involves selecting some stones within the chip seal at random, removing them from the seal, and estimating the embedment percentage visually. This leads to much variability and is subject to significant judgment. This judgment has a steep learning curve as vehicle damage results if the embedment is not adequate. This research was conducted to develop a quantitative means for measuring aggregate embedment in chip seals. The result is two methods that can be used in the field to determine the depth of aggregate embedment. One method is simple to use, inexpensive, fast and relatively accurate. The other method is more difficult to use, inexpensive, somewhat fast, but very accurate.

Keywords: Asphalt pavement maintenance, chip seals, pavement preservation, aggregate embedment

Literature Review

There is a significant amount of information available on chip seal design, construction and performance. From two design methods (Hanson 1934-35; Kearby 1953) most designs used today can be traced (Epps, 1981; Marais, 1981; McLeod, 1960; Potter and Church, 1976). These methods are essentially based on the concept that aggregate in a chip seal should be a single size and that embedment of the aggregate in the asphalt binder should occupy a specific percentage of the aggregate dimension. How the aggregate dimension is determined and how the volume of asphalt binder is calculated vary between methods but usually require measuring the gradation of the aggregate in order to obtain the average least dimension (ALD) in the case of the Hanson method or the unit weight, specific gravity and spread quantity in the case of Kearby (Kearby, 1953). The shape of the aggregate is considered important and is measured using the Flakiness Index in the case of the Hanson method and the percent embedment is varied as a function of traffic for both methods.

Once the chip seal has been designed, how it performs during construction and in early life under traffic is the greatest concern. Loss of chips during construction leads to construction delays and loss of chips during early trafficking may lead to vehicular damage. Therefore, reducing this potential has been a focus of research. Benson (Benson and Gallaway, 1953) evaluated the effects of various factors on the retention of cover stone on chip seals.

Among other factors this study evaluated the effects of cover stone and asphalt quantity, aggregate gradation, time between asphalt and aggregate application, and dust and moisture content of chips on retention of cover stone.

Rollers embed the aggregate into the asphalt binder and orient the chips on their flat side. It is important to have enough rollers to complete the rolling quickly. The chips need to be embedded into the emulsion before it 'breaks' or sets. Normally, a minimum of three rollers will be required. The first two, drive side-by-side rolling the outer edges. The third roller then follows closely behind, rolling the center of the lane. It is very important for the rollers to travel slowly, no more than 5 miles per hour (8 km/hr), so the chips are correctly embedded into the binder (Janisch and Gaillard, 1998). Rolling can be standardized on the basis of certain number of roller passes, or a rolling time in hours, for each 250 gallons of binder sprayed (Potter and Church, 1976). Pneumatic rollers are preferred for rolling chip seals because they tend not to fracture the rock and will roll into depressions or wheel ruts. Rolling of a seal coat is done to orient the rock so the flattest side is parallel with the pavement surface. It takes two to four passes of the roller to set the rock. These rollers should have tire pressures of 45 psi or more. (WDOT, 2003)

Background

Embedment depth is usually determined during construction by pulling several chips out of the binder and visually estimating the amount of embedment. This is problematic even if chips have a very low flakiness index because it is difficult to assess quantitatively with any precision. Therefore, a new method based on the sand patch test was developed in this research to estimate embedment depth in the field.

Experimental Method

Constant Volume Spreading Experiment

A laboratory experiment was designed using limestone (LSTN) and granite (GRNT) aggregates. These aggregates represent a range of flakiness (Arizona DOT, Texas DOT) from a high of approximately 34 percent for the limestone to a very low 6 percent for the granite. The particles were oriented on their widest faces so that the average particle heights were their average least dimensions. Void ratio and embedment percentage were determined for each specimen based on the aggregate average least dimension. The known void ratio and average chip seal height, along with proposed diameters and proposed volumes of glass beads were used to calculate theoretical textures and embedment percentages using equations 2 and 3 below:

The texture height (T) is the average height of aggregate that is exposed above the surface of the asphalt or (ALD – the embedment depth) as shown in Figure 1.

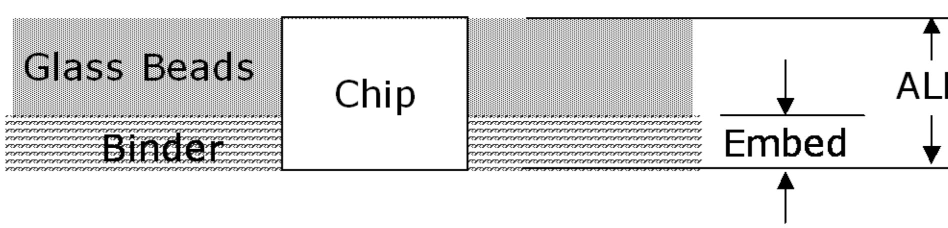

Figure 1. Embedment Depth Experiment Model

The theoretical texture height can be calculated as follows:

$$T = \frac{\text{volume of beads and aggregate above the asphalt surface and below the average particle height}}{\text{plan area of beads and aggregate}} \qquad (1)$$

The above statement may be re-written as:

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$$T = \frac{B + (T*A*S)}{A} = \frac{B}{A} + T*S\ ; \qquad \therefore\ T - T*S = \frac{B}{A}\ \text{, and} \quad T = \frac{B}{A*(1-S)} = \frac{B}{A*V} \qquad (2)$$

And embedment may then be determined using:

$$\text{embedment (\%)} = \frac{H - T}{H} \qquad (3)$$

Where:

T = texture height, in (mm),
B = volume of glass beads, in^3 (mm^3) below the average particle height,
A = plan area of chip seal, in^2 (mm^2),
S = the solid ratio (1-void ratio),
V = the known void ratio, and
H = average particle height, in (mm).

Equation 2 assumes that the volume of glass beads is spread over the chip seal up to the peak of each particle. That is, the glass beads must follow the profile of the particle peaks. In this way, the average height of the glass beads on the actual chip seal is equivalent to the void height that would be seen between equal-height particles of a chip seal that is built with exactly one-sized aggregate.

According to equations 2 and 3, for a chip seal of known void ratio and average particle height, it is theoretically possible to calculate the texture depth (T) and the percent embedment by spreading a fixed volume of glass beads in a circle and measuring the resulting area.

Results of Constant Volume Spreading Experiment

Figure 2 is a comparison of the theoretical glass bead diameters and the actual measured diameters for the limestone and granite aggregates embedded to 20 and 80 percent. The difference between the texture depth obtained by this procedure and the ALD was considered the embedment depth. Two pans of embedded chips were prepared for each aggregate for a total of four experimental runs. A description of the experiment is presented in the Appendix to this report.

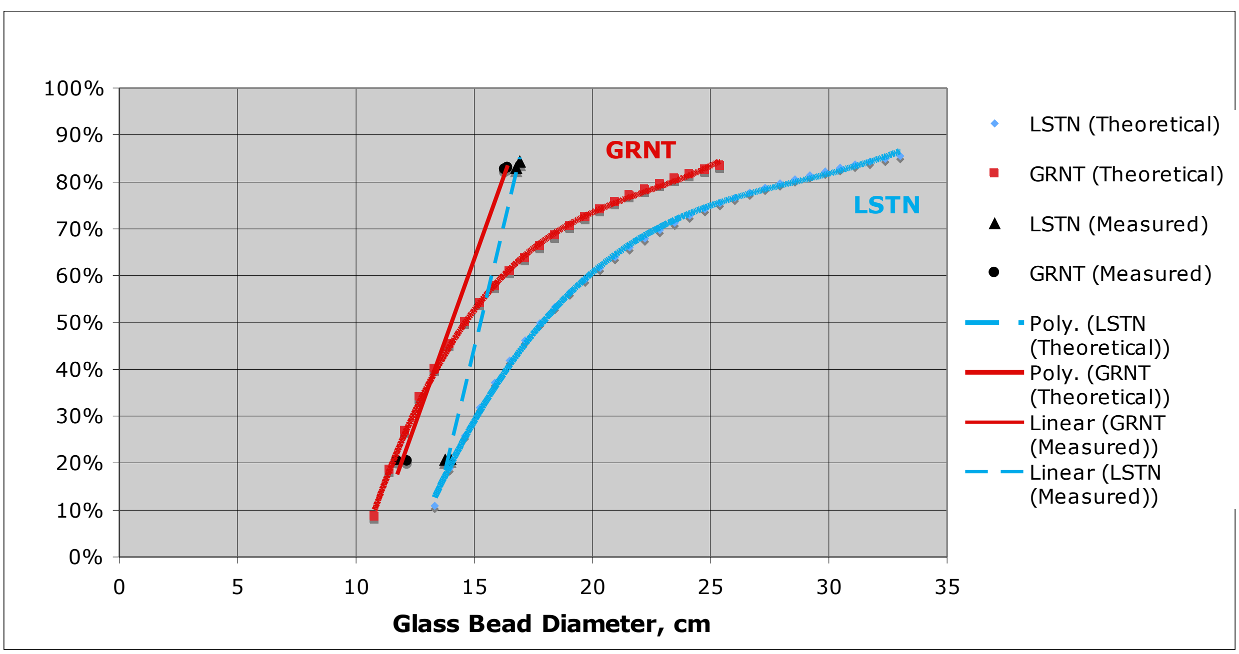

Figure 2. Comparison of Theoretical to Measured Embedment Depth

At 20 percent embedment, the measured diameters are fairly close to the theoretical diameters. At 80 percent embedment, however, the measured diameters are 53 and 65 percent for the limestone and granite, respectively.

Texture heights are plotted in Figure 3 with measured textures similar to theoretical values at 20 percent embedment but varying at 80 percent.

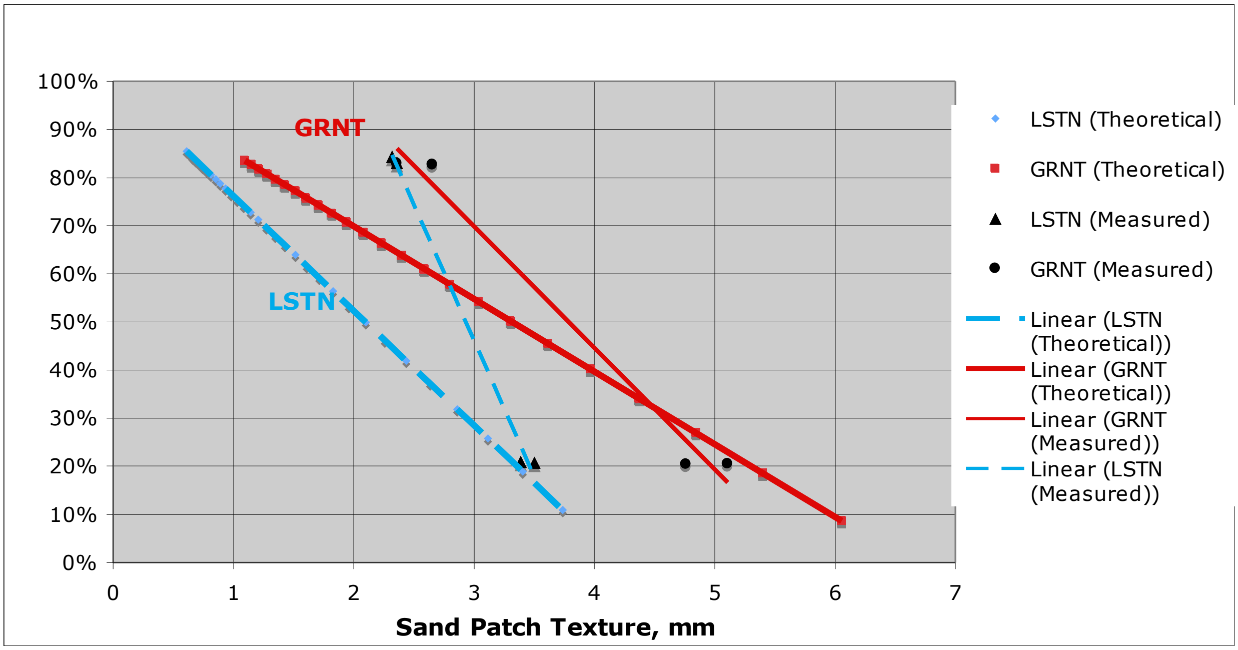

Figure 3. Estimating Embedment Depth From Texture

In practice, to spread glass beads to meet the peak of each particle is not easy to accomplish. However, when an average fill height is used, fairly good results were achieved at the lower embedment level. This might be the case because at 20 percent embedment, voids are deep, taking in much of the beads, and the procedure of leveling between the particle peaks contributes less to error than it does at higher embedment percentages.

At the higher embedment level, many particles in the chip seal specimens were fully covered by asphalt and their peaks were not discernible. In keeping with the requirement to fill the spaces between particles to the average particle height, one should shape the profile of the glass beads, above the asphalt level, the same way for all asphalt heights. While this is possible for low embedments, it becomes impossible to bridge between all the peaks with glass beads at very high embedments. In such a case, theoretically, isolated peaks should have just a small area of glass beads surrounding them. But this is difficult to accurately estimate in practice, with the result that pools of asphalt end up being covered with glass beads where there should not be any. This results in smaller diameters and thicker calculated textures.

The submerged-peak locations were even more difficult to discern with the flatter LSTN particles that may be the reason for the larger deviations seen with LSTN compared to the blockier GRNT. Additionally, aggregates with smaller textures, LSTN in this case, should be naturally more sensitive and will exhibit larger diameter changes, for a particular volume of sand, than more angular or blocky aggregates would. This condition is exacerbated at higher embedments.

By contrast, at 20 percent embedment, the lower required angle of repose to fill between the mildly undulating peaks of the flat and elongated LSTN particles, when compared to the angle required to bridge between the widely varying peak height of the less elongated GRNT particles, may be the reason why the measured LSTN diameters and textures correspond better with the theoretical values than those for GRNT.

The results indicate that this procedure may be useful where chip seal particle embedments are less than or equal to 50 percent or where average sized particles are not submerged.

Constant Diameter Submerging Experiment

Because the outcome of the constant volume experiment described above resulted in a significant difference between the theoretical and measured diameters at 80 percent embedment, a second experiment was conducted using a fixed diameter and variable quantities of glass beads.

In this experiment, chip seal specimens of 20 percent and 80 percent embedment, were covered with glass beads to full submergence in a mold. By a process of subtracting the volume of beads above the average particle height of a fixed area specimen, the volume of beads below the average particle height could be determined.

The submerging procedure requires that the void ratio as well as the ALD be known. Additionally, the density of beads filling the mold of fixed cross-sectional area and height must be carefully determined by precisely measuring the volume of the mold, the height of the mold and weighing the mass of beads that will fill it.

To determine embedment percent, the chip seal specimen is placed in the mold. The mold is filled with glass beads to overflowing, and the level top of the mold is struck flush. The total mass of beads that fills the space above the specimen is determined and its volume is calculated using its density. Knowing the average height of the chip seal aggregate, the excess volume of glass beads between the top of the struck mold and the top of the average particle is calculated from the following:

$$\text{Excess Volume of Beads} = (M - H) * A \tag{4}$$

Where:

M = max height of mold (mm),
H = average particle height (mm), and
A = plan area of chip seal (mm^2).

By subtracting the result of equation 4 from the total volume of beads the measured void volume, between aggregate particles, which is filled with beads (to the average particle height) is determined. The texture and percent embedment are respectively determined using equation 2 and 3.

The theoretical void volume is determined for assumed embedment percentages from:

$$\text{Void Volume} = (H * A) * (-e\%) * V \tag{5}$$

Where:

H = average particle height (mm),
A = known plan area of chip seal (mm^2),
e% = percentage embedment (equation 3), and
V = the known void ratio

The known void ratio, the specimen's plan area and theoretical void volume are then used in equation 2 to calculate theoretical textures.

Results of Constant Diameter Submerging Experiment

Figure 4 shows the measured volumes of glass beads that fill the voids between particles, compared with theoretical values for void volume. These measured results, obtained using the same chip seal specimens as those used for the constant volume procedure, indicate that the spreading procedure is indeed flawed at higher embedment percentages. The submerging procedure is able to provide results that are very similar to the theoretical void volumes and texture depths at high embedment percentages as shown in Figure 5.

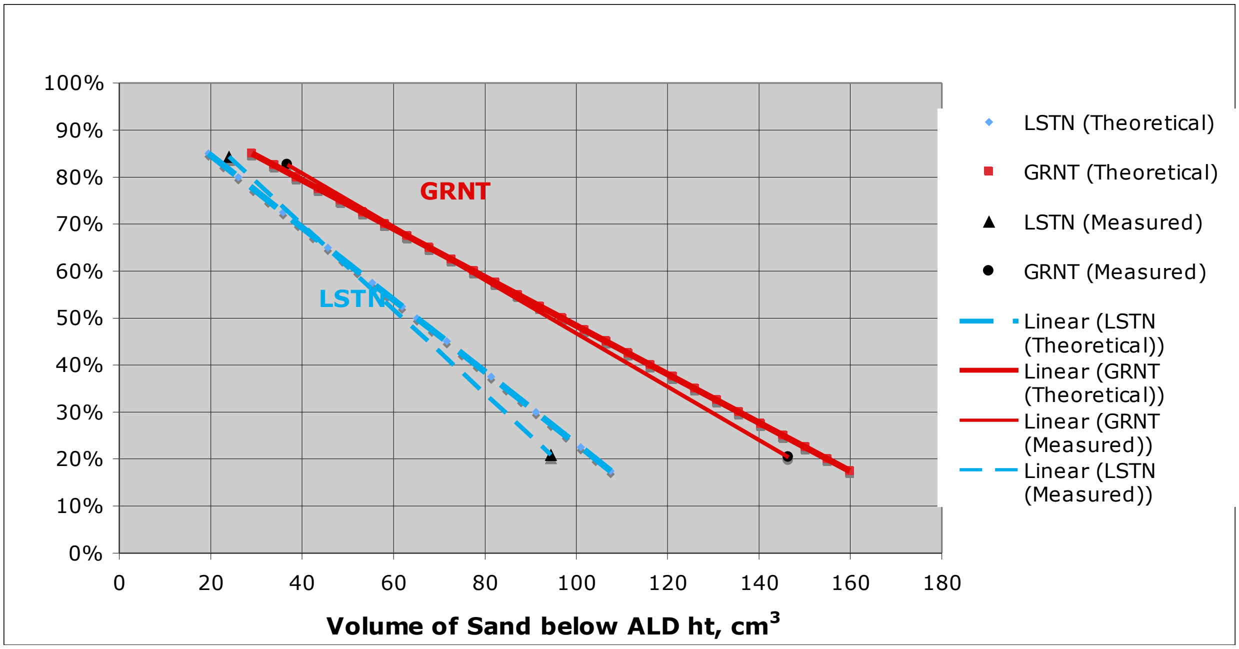

Figure 4. Estimating Embedment Depth With Fixed Sand Diameter

At 20 percent embedment, the measured values are some 10 percent smaller than the theoretical. At approximately 80 percent embedment, the deviation is less at 5 percent larger than theoretical. Deviations were similar for LSTN and GRNT at both levels of embedment.

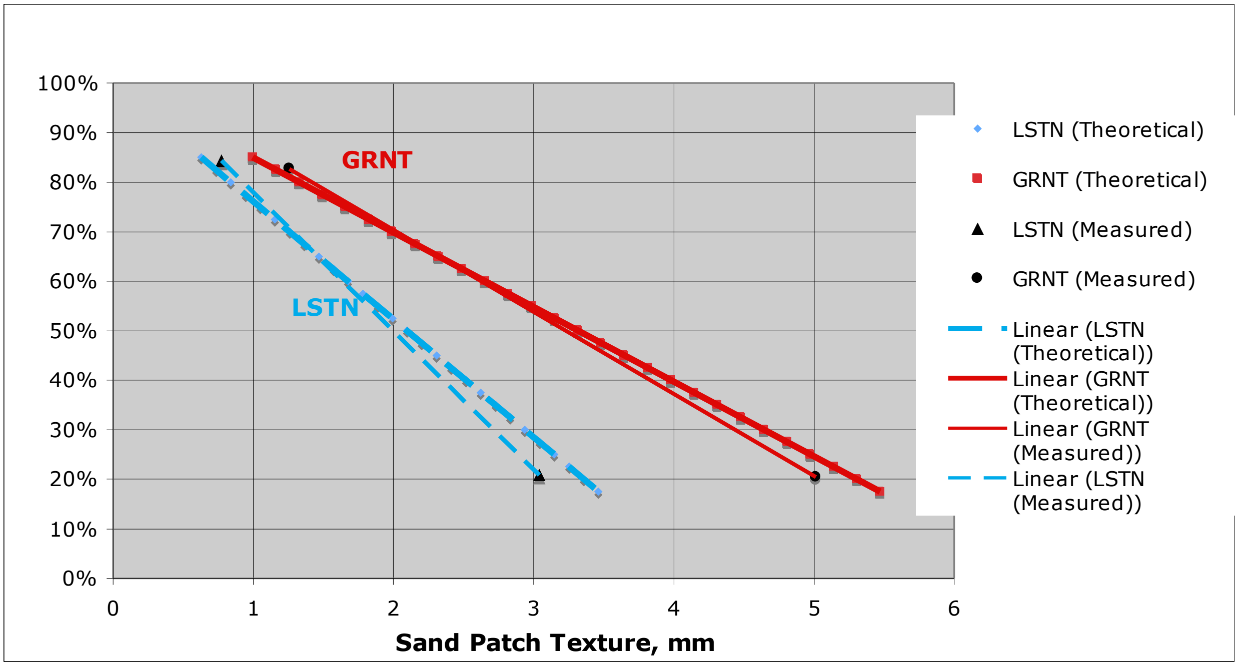

Figure 5. Estimating Embedment Depth From Texture

Measured values deviated, from theoretical values, positively at approximately 80 percent embedment and negatively at approximately 20 percent embedment, a similar trend to that observed with the results of the spreading procedure. It is important to note that the results are very sensitive to small changes in density of glass beads. This suggests that determination of density should be performed in the same manner that bead placement on chip seal specimens is expected to occur. It is possible to rectify the deviations from the theoretical values by employing a lower actual density of glass beads for the 20 percent embedment specimen and a higher actual density for the 80 percent embedment specimen. It would seem plausible to make such adjustments, however it is unknown whether such adjustments would reflect the actual densities.

Conclusions

The two methods to estimate embedment depth of aggregate chips in chip seals resulted in one method that predicts the embedment with acceptable accuracy compared with theoretical values. The first method, or submerging procedure, uses a constant diameter to which glass beads are added and the volume required to just submerge the chips is determined. The other method places a constant volume of beads on the chip seal surface and spread in a circle. The diameter of the circle is measured and the embedment determined. This method was less accurate than theoretical values at high embedment depths.

Where trusted values for average particle height and void ratio exist, and where it is possible to perform the submerging procedure, better results may be possible, particularly at higher embedment percentages. To use the submerging procedure in the field, the level of the bottom of the chip seal layer must be precisely established in order to determine the height of a level plane to which the chip seal test area may be filled with glass beads to submerge the chip seal and evaluate embedment.

The constant volume procedure may be more practical although the accuracy that is possible at high embedment levels appears to be very low. At lower embedments, however, especially when only a rough check is required, the constant volume procedure is promising for its simplicity.

References

1. Arizona Department of Transportation (2006), AZ 233, "Flakiness Index of Coarse Aggregates".

2. Benson, F., & Gallaway, B. (1953). Retention of cover stone by asphalt surface treatments. Texas Engineering Experiment Station, 133, 1-58

3. Epps, J. A., Gallaway, B. M., and Hughes, C. H., (1981). "Field Manual on Design and Construction of Seal Coats", Texas Transportation Institute, Research Report 214-25.

4. Hanson, F. M., (1934-35). "Bituminous Surface Treatments on Rural Highways", Proceedings of the New Zealand Society of Civil Engineers, Vol. 21, p 89.

5. Janisch, D. & Gaillard, F. (1998). Minnesota Seal Coat Handbook, MN/RC-1999-07, *Minnesota Department of Transportation*, Maplewood, 112.

6. Kearby, J. P., (1953). "Tests and Theories on Penetration Surfaces", *Proceedings, Highway Research Board*, Vol 32.

7. Major, N. G. (1965). A basis for selection of binders for chip sealing. *New Zealand Engineering*, Vol 20, Issue 12, pp 521-528.

8. Marais, C. P., (1981). "Rational Design of the Single Surface Treatment Technique for Road Maintenance, *The Civil Engineer in South Africa*, August.

9. McLeod, N. (1960). Basic Principles for the Design and construction of Seal Coats and Surface Treatments. *Proceedings of the Association of Asphalt Paving Technologist*, 29, 1-150.

10. Potter, J. L., and Church, M., (1976). "The Design of Sprayed Seals", *Proceedings of the Australian Road Research Board*, Vol 8, pp 18-23.

11. Texas Test Method Tex-224-F (2008), "Flakiness Index".

12. Washington State Department of Transportation. (2003). Asphalt Seal, *Technology Transfer*, 1-30.