Evaluation of Textural Retention of Pavement Surface Aggregates

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Skid resistance of bituminous surface courses is related to the components of the mixture and construction procedures. An important element of the mixture is the aggregate surface texture and shape. Aggregates for use in these wearing courses must retain sufficient microtexture over time to contribute to a safe, skid-resistant pavement for the motoring public. The Tennessee textural retention method (TTRM) is used to characterize the aggregate particle shape initially and at various aging intervals to predict the aggregate's ability to retain its microtexture. The TTRM uses single-size aggregate (6.35 to 9.52 mm), the Los Angeles abrasion device, and a modified version of the National Aggregate Association's Particle Shape Tester (ASTM C 1252) to provide particle shape and texture data. In a preliminary evaluation, the TTRM was able to discern two proven performers from several other siliceous limestones. The test method appears to have excellent repeatability and is virtually operator insensitive. The method may be helpful in identifying potential aggregates for use in bituminous surface courses by predicting their ability to resist the polishing action of traffic.

The safety of the motoring public is the central objective in highway design. Among the many design considerations necessary to achieve this objective is the need for providing a skid-resistant roadway during wet weather. The economics of designing for wet pavement conditions, which occur only a small percentage of the time, have long been the subject of debate by highway engineers. The general conclusion drawn from this debate is that pavement design engineers should always use the most economical materials that provide the required level of performance. This concept is particularly important in the choice of aggregates for producing bituminous surface courses that exhibit adequate skid resistance during wet weather.

Skid resistance of a bituminous surface is a function of macrotexture and microtexture. Macrotexture controls the thickness of the water film developed on pavement surface and affects the length of time it remains there. Macrotexture is a function of mix properties as well as placement and compaction techniques. Microtexture is essentially the angularity and surface roughness of individual aggregate particles in the mix. Although adequate macrotexture and microtexture are essential to skid resistance, this project focused on laboratory evaluation of aggregate microtexture.

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OBJECTIVES

This project was undertaken to achieve the following primary objectives:

- Ascertain what laboratory methods are currently available to prequalify aggregate polish-resistance for bituminous surface courses.
- Determine the relative effectiveness of the methods through a literature review.
- If no suitable methods are found, attempt to develop a test to characterize an aggregate's ability to retain microtexture over time. The test must also be inexpensive, repeatable, and not operator sensitive.
- Perform a preliminary evaluation of the new method.

QUESTIONNAIRE

To obtain information on laboratory test methods for characterizing aggregate polish-resistance currently available or being developed, a survey (*1*) of state departments of transportation throughout the country, along with associated industry and academia, was conducted. Only three standardized laboratory tests were commonly used by the respondents, the Percent Insoluble Residue (ASTM D 3042), Petrographic Analysis (ASTM C 295), and British Polishing Wheel/Pendulum (BPW/BP ASTM D 3319 and ASTM E 303).

LITERATURE REVIEW

The Highway Research Center at Auburn University studied Alabama limestone aggregates for use in bituminous wearing courses. In this study, the BPW/BP method was used along with insoluble residue, loss-on-ignition, and petrographic analysis for evaluation. Thirty-two types of limestone and 12 types of gravel aggregates were studied. The aggregate frictional properties were characterized by British pendulum polishing value (PV) at 0, 3, 6, and 9 hr of aging on the British polishing wheel. Kandhal et al. (*2*) found that the PV of typical limestones declines in a hyperbolic manner with increasing polishing time. Initially, the PV declined rapidly. Then, over time, the curves became asymptotic, indicating that the aggregates will reach an ultimate PV. This behavior is similar to that of highway skid numbers (measured with the locked-wheel trailer, ASTM E 274) because the pavement is exposed to more traffic repetitions. This indicates that aggregates reach an ultimate texture condition.

However, for routine testing, the British wheel, used with the British pendulum method, has several drawbacks. These include the time of testing, operator training, small sample size, and repeatability problems. Kulakowski et al. (*3*) found that there was considerable concern over the lack of agreement among the users of the British pendulum. The cause of the problem was considered to be the complex, cumbersome, and ineffective calibration procedure.

Kandhal et al. (*2*) also found that mineralogical methods such as percent insoluble residue (ASTM D 3042), Loss-on-Ignition Method [Tennessee Department of Transportation (TDOT)], and Petrographic Analysis (ASTM C 295) tend to reflect the general trend of later polishing values but concluded that polishing values could not be statistically predicted from these tests. Their results suggest that mineralogical composition, when used alone, cannot easily discern various levels of polishing resistance but may identify aggregates with a low probability of performing well.

Aggregate size has a large influence on skid resistance. Gramling (*4*) found that while accumulating field skid resistance research data, the coarse aggregate in bituminous mixtures was more influential in determining skid resistance than other mix constituents. Factors such as type of gradation held minimal influence on aggregate polishing; however, aggregate gradation might have a major influence on macrotexture of the pavement surface.

The physical shape of an aggregate also plays an important role in polish resistance and textural retention. Although strong, hard, and angular aggregates are almost always preferred, other types can offer good skid qualities. Softer particles can sometimes be interspersed within a stone having good skid qualities. These softer particles wear away on the outside, leaving the harder particles exposed, while continuing to support those particles from the interior. Some types of aggregates, such as sandstones, tend to fracture instead of polish over time. Similarly, slag polishes away, but because of its vesicular nature, new and angular surfaces are constantly being exposed. Both types of aggregates offer a continually self-renewing, skidresistant surface over time (*4*).

DEVELOPMENT OF TENNESSEE TEXTURAL RETENTION METHOD (TTRM)

Rationale

Microtexture, as previously stated, depends on the surface texture and angularity of aggregate particles. What is needed is a means to quantitatively determine these properties and the aggregate's ability to retain them in service. The National Aggregate Association's (NAA's) Uncompacted Voids in Fine Aggregate (recently approved as ASTM C 1252) appears to be a promising method for determining initial angularity and surface roughness. Theoretically, as angularity and surface roughness decrease, a sample of uncompacted aggregate will contain fewer voids. Thus, unit weight can be indicative of angularity and surface texture. In addition, ASTM C 1252 equipment could be easily modified to test the more important coarse aggregate fraction of most surface mixes (6.35 to 9.52 mm).

Desirable aggregates not only must have good initial angularity and surface texture but should retain these attributes while aging in service. In the laboratory, aging could be simulated by abrasion of the aggregates in a device such as the Los Angeles Abrasion Machine (ASTM C 131). It was surmised that the initial voids of a potential surface aggregate could be measured, and then the aggregate could be subjected to aging in the Los Angeles Abrasion device and periodically tested in the NAA device. To ensure that no new particles in the size range to be tested would be created by fracture during aging, the sample would be made up of a single size and resieved after each aging procedure to eliminate all finer particles.

If this rationale was sound, then a developed and tested procedure would have many advantages over traditional methods. Such methods are expensive in initial equipment cost, labor intensive, time consuming, and operator sensitive, and typically have small sample sizes. This method has a much lower initial cost; almost every agency has Los Angeles Abrasion equipment, and the NAA device is priced below $200. The method is also rapid, requires minimal technician skills, and does not appear to be operator sensitive. Repeatability should improve because of the much larger sample size. Although the method should apply to any aggregate composition, carbonate aggregates would be given priority in this initial phase because of their abundance in Tennessee.

Equipment

The uncompacted void content (ASTM C 1252) apparatus consists of a reservoir to hold the aggregate and a funnel. The ASTM standard test apparatus was modified to test coarse aggregates (6.35 to 9.52 mm) by substituting a 101.6-mm diameter standard Proctor mold (ASTM D 698) for the nominal 100-mL cylindrical reservoir and by increasing the size of the funnel reservoir (see Figure 1). The approximate volume increase to the cylindrical reservoir was chosen by considering the present volume of the cylinder compared to the diameter of a No. 8 (2.38-mm) particle and by solving for the cylinder size needed to maintain the same proportion to a 9.52-mm particle. The funnel reservoir was chosen to have approximately the same shape of the standard funnel yet have a volume equal to twice that of the modified cylindrical reservoir. No significant adjustment was made to the height of free-fall of the particles.

Procedure

The funnel opening was blocked to allow the reservoir to fill. After filling, the aggregate was allowed to flow through the funnel opening, free-falling several centimeters into a cylindrical measure. The measure was then struck off, and the retained aggregate was weighed. That weight, along with the aggregate's specific gravity and volume of the measure, was used to calculate the void content. The equation for U is given as (ASTM C 1252)

$$U = \frac{V - \left(\frac{F}{G}\right)}{V} * 100$$

where

U = percentage of uncompacted voids in material,
V = volume of cylindrical measure (ml),
F = net mass (g) of aggregate in measure (gross mass minus mass of empty measure), and
G = bulk dry specific gravity of aggregate.

Three 10-kg samples of each aggregate were sieved to the gradation requirements of Table 1 and oven dried. Each sample was tested for initial particle shape using the modified uncompacted voids apparatus. After initial testing, the sample was then subjected to 100 revolutions in the Los Angeles Abrasion Machine. The combined

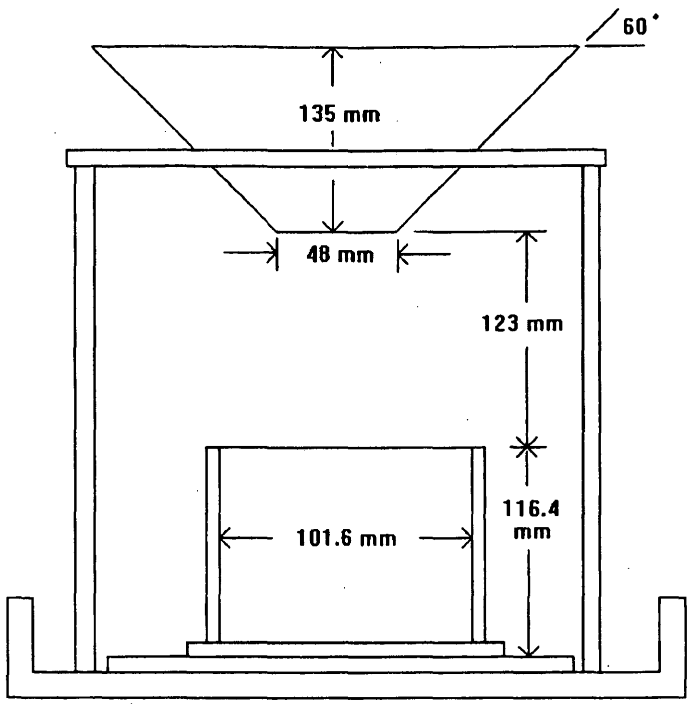

FIGURE 1 Modified ASTM device.

actions of abrasion (attrition), impact, and grinding in a rotating steel drum containing eight standard steel spheres changed the particle shape and surface texture. The sample was then resieved to initial grading and tested in triplicate using the modified uncompacted void content device. Triplicate samples were used to ensure repeatability.

This process was repeated for 12 cycles to compare change in shape and texture over time. A 10-kg sample size was chosen to allow sufficient sample left for triplicate testing to six cycles. After six cycles, the surviving portions of the three original 10-kg samples were combined to obtain a single sample. If the combined sample after six cycles exceeded 10 kg, it was reduced by wasting to 10 kg.

PRELIMINARY EVALUATION

Materials

Twenty-five aggregates have been selected by the TDOT Steering Committee for the second phase of the study. Of these aggregates, 21 were siliceous limestones. The four remaining aggregates were noncarbonates. The aggregates selected included several aggregates approved by the TDOT and the Kentucky Transportation Cabinet for use in bituminous surface courses at various average daily traffic (ADT) levels, several aggregates believed to be poor performers, and several aggregates of unknown performance. All samples were obtained by TDOT personnel following standard sampling procedures, and all tests for a particular aggregate were performed on the same sample.

The aggregates were characterized by bulk dry specific gravity and absorptions (ASTM C 127) and Loss-on-Ignition (TDOT method) tests. Loss-on-Ignition values were obtained by determining the percentage of weight loss when a 600-g sample of the aggregate was subjected to 900°C for 8 hr in a muffle furnace.

TDOT personnel are evaluating the selected aggregates with the British Pendulum/British Polishing Wheel and the percentage of insoluble residue and gathering available field data from locked-wheel trailer skid tests.

TABLE 1 Testing Parameters

100 % Passing (sieve)	9.52 mm (3/8")
100 % Retained (sieve)	6.35 mm (1/4")
Sample Size kg. (lbs)	10 (22.1)
# of Spheres	8
Test Freq. (# rev's)	100
Number of Testing Cycles	12
Device	Modified ASTM C 1252

Presentation and Analysis of Preliminary Results

Uncompacted voids versus aging revolutions curves were plotted for each aggregate tested. An example plot for three project aggregates is show in Figure 2. The data generated appeared to follow a hyperbolic relationship with aging as suggested by Kandhal et al. (*2*). The following factors were selected to characterize each curve:

1. Area between the curve and the 44 percent uncompacted voids line from 200 to 1,200 revolutions,
2. Uncompacted voids value after 1,200 aging revolutions, and
3. Loss in uncompacted voids from 200 aging revolutions to 1,200 aging revolutions.

For Factors 1 and 3, the 200 to 1,200 limits were established to maximize the impact of aggregate properties and lessen the effect of crushing technique. The 44 percent uncompacted voids value chosen for Factor 1 was for convenience; this value approximated the lower limit for the aggregates tested. By taking the area above 44 percent voids instead of the entire area under the curve, the magnitude of the area factor was similar to the magnitude of Factors 2 and 3.

Using the factors enumerated and performance assumptions about three carbonate aggregates familiar to TDOT personnel, a three-by-three matrix was developed and solved for coefficients. The coefficients were then applied to Factors 1, 2, and 3 for each aggregate to generate a preliminary aggregate textural retention rating. Preliminary aggregate textural retention ratings (PATRR), Loss-on-Ignition values, bulk dry specific gravities, absorptions in percent, and maximum coefficients of variation for voids testing in percent for the aggregates tested to date are presented in Table 2. As more field and laboratory data become available, this relationship will be further refined.

From the aggregates tested, some preliminary observations can be made. However, this is a complex problem and correlations with additional field and laboratory data need to be completed before any final conclusions can be drawn. The TTRM was able to discern TDOT proven performers (C–4, C–5) from several other siliceous limestone aggregates. In addition, the low coefficients of variation appear to indicate a high degree of repeatability. Multiple operator coefficient of variation studies have recently been completed.

The shape of the curves produced is not only similar to those produced by Kandhal et al. (*2*) with the BPW/BP but also similar to curves of skid number (locked-wheel trailer) versus traffic for pavements in service. This similarity suggests that the same type of information may be attained using the more economical and probably less operator-sensitive TTRM.

The results of this phase of the study have shown the TTRM to be a logistical success. Ease of performance, repeatability, substantially reduced initial and operating costs, and substantially increased productivity are advantages indicating that this test may be an ideal addition to normal aggregate prequalification tests. The time required to produce one complete curve (three complete tests) for an aggregate is approximately 6 to 8 hr (excluding loss-of-ignition determination, oven drying, and specific gravity determination). Repeatability problems were almost nonexistent as indicated by the low coefficient of variation for all aggregates. The operator must be sure to completely and correctly sieve the aggregate before and during testing. Single tests that stop (because of clogging of the funnel) should be repeated. In addition, sources of vibration should be kept to a minimum during voids testing.

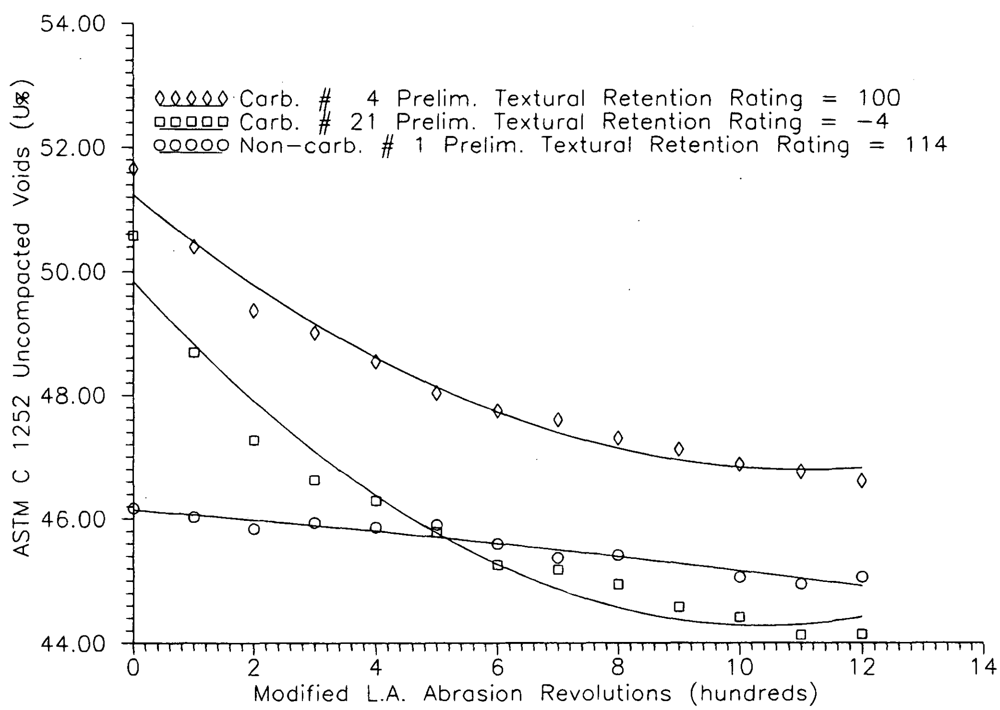

FIGURE 2 Three project aggregates.

TABLE 2 Aggregate Properties and Preliminary Ratings

AGG	BSG	ABS(%)	LOI(%)	MCV(%)	PATRR
C-1	2.674	0.68	33.8	0.78	141
C-2	2.579	1.52	23.0	0.82	130
C-3	2.693	0.26	31.9	0.68	117
NC-1	2.139	9.09	2.6	0.86	114
C-4	2.617	1.33	17.0	0.87	100
C-5	2.615	1.59	21.8	0.76	98
NC-2	2.270	5.53	1.3	1.14	79
C-6	2.731	0.40	41.7	0.89	69
C-7	2.739	0.42	41.0	0.83	65
C-8	2.610	1.61	18.4	0.81	60
C-9	2.752	0.31	42.9	0.81	59
C-10	2.746	0.85	35.3	0.73	55
C-11	2.731	0.53	31.5	0.81	50
C-12	2.768	0.45	41.1	0.78	47
C-13	2.739	0.48	40.5	0.92	30
C-14	2.690	0.87	34.4	1.02	27
C-15	2.705	0.73	39.9	0.82	18
C-16	2.657	1.02	36.3	0.85	13
C-17	2.708	0.85	34.9	0.71	11
C-18	2.727	0.27	39.3	0.74	10
C-19	2.597	1.29	41.3	0.66	7
C-20	2.689	1.09	37.8	0.93	5
C-21	2.663	0.92	39.4	0.69	-4

C = carbonate
NC = non-carbonate

PLAN FOR REMAINDER OF PHASE II

Although these preliminary results seem promising, the evaluation process is far from complete. The curves generated will be grouped into families of curves representing similar expected skid performance. Probable performance levels will determined by comparison with TDOT aggregate performance records.

The information obtained from the families of curves produced will be combined with laboratory test values, such as Loss-on-Ignition, percentage of insoluble residue, and British Pendulum Number PV. The combined information will be correlated with field skid numbers obtained by TDOT on new and existing pavements constructed using these aggregates to determine which criteria, or combination of criteria, are superior predictors of pavement skid performance.

The ultimate goal of the project is to pair aggregate performance with the functional needs of the pavements (based on ADT) so that all Tennessee aggregate sources can be used most efficiently.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the aggregate tested to date and the preliminary analysis conducted, the following conclusions and recommendations are made:

- The TTRM was able to discern two TDOT proven performing aggregates from other siliceous limestones.
- The TTRM appears to provide results that are comparable to the British Pendulum and British Polishing Wheel Method. However, additional evaluations are needed.
- A correlation of testing length in cycles to ADT needs to be addressed. In particular, the traffic volume corresponding to the particle shape factor at 1,200 abrasion revolutions should be studied to determine if U_{1200} is comparable to expected pavement life.
- More noncarbonate aggregates need to be tested before any meaningful conclusions about the applicability of the TTRM can be drawn.

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