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Asphalt Technology Program

Evaluation of Non-Polishing Aggregate Criteria for Various Traffic Levels and Low-Speed Road Conditions

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16. Abstract
West Virginia DOH requires approved skid resistant aggregates for the wearing course for all highways with an Average Daily Traffic of more than 3,000. Materials qualifying as skid resistant aggregate under the department's current requirements are becoming scarce and therefore very costly. The objective of this review was to evaluate the state of the practice with respect to specifications for skid resistant pavements, with particular attention to the states bordering West Virginia.

The practices of the WVDOH are inline with or more stringent than the bordering states. States with skid aggregate requirements generally use ADT as the controlling parameter for determining need. Several states have a stratified system where the quality of the aggregate is a function of ADT and the structural classification of the highway.

Treatments for remediation of skid problems are reviewed. Since skid resistance is solely a function of the tire-pavement interaction, the thickness of the layer with the skid resistant aggregate is not of a concern. The potential of providing skid resistant surfaces using thin and very thin wearing surfaces should be explored as a method for preserving the skid aggregate resources of the state.

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INTRODUCTION

The following review discusses existing skid resistance specifications observed by various states for the West Virginia Department of Transportation. The review gives background information on skid resistance, method of measuring skid resistance, and the development of a skid number and its uses. A survey is discussed that was conducted by Jayawickrama et al (1996) to classify how the lower 48 states address skid resistance. Information on state aggregate testing policies and test methods is also reviewed. The final proportion of the review covers various states specifications on skid resistance and final conclusions.

Problem Definition from WVDOT

The West Virginia Division of Highways currently requires the use of non-polishing aggregates in hot-mix asphalt surface mixes on all roads with an ADT of 3,000 or greater. The Division pays a premium cost for these aggregates, and local sources of this material are not as plentiful as they once were. The WVDOT has recently discussed the question on whether or not nonpolishing aggregates should be required on low speed limit roads through cities and towns. In addition, it would also be desirable to know how other state DOT's are specifying the use of non-polishing aggregates for various traffic levels.

SKID RESISTANCE

Skid resistance is defined by Huang as the force developed when a tire that is prevented from rotating slides along the pavement surface. Skid resistance is an extremely important parameter to the evaluation of a pavement because inadequate skid resistance will lead to higher incidents of skid related accidents. Frictional resistance characteristics that are desirable in a good pavement surface are described [Roberts et al, 1996] as:

- High frictional resistance. Ideally the frictional resistance when pavement is wet should be almost as high as that of the dry pavement.
- Little to no decrease of the frictional resistance with increasing speed. The frictional resistance of dry pavements is nearly independent of speed, but this is not the case for wet pavements.
- No reduction of frictional resistance with time, from polishing or other causes.
- Resistance to wear by abrasion of aggregate, attrition of binder or mortar, or loss of particles.
- Structural durability. Resistance to compaction, raveling, breakup, etc.
- Low tire noise generation.
- Low cost. Not necessarily low first cost, but cost per year of service with acceptable frictional resistance.

Skid resistance of wearing surfaces depends on two basic parameters. These two parameters are the aggregate and mixture characteristics. The following two sub-sections will discuss the effects that the aggregate and mixture characteristics have on skid resistance.

Aggregate Characteristics

The aggregate selected is extremely important to the level of skid resistance of a new pavement. The most desirable source of aggregate to maximize skid resistance is an aggregate that resists polishing and wearing. The texture, shape, and size also affect the level of skid resistance.

The ability to resist polishing is the most important characteristic of an aggregate to provide a safe roadway relating to skid incidences. When an aggregate polishes, the surface becomes smooth and poor skid resistances is created. Microtexture and macrotexture play an important role in the level of frictional resistance of a pavement. Microtexture is determined by the frictional properties of the aggregate which is the surface coarseness. It is governed by the individual size of the mineral grains and the matrix which the grains are cemented. Macrotexture is determined by the size, shape, and spacing of aggregate particles. Macrotexture is related to the angularity of the aggregate particles and the voids and pits in the surface of the pavement. Aggregates with hard grains and weak cementation will wear under traffic. This wearing will expose a continually renewed nonpolished surface. However, if the grains are tightly held together and the matrix of the aggregate is strong, the surface can be polished by traffic. This occurrence is controlled by using at least two mineral constituents of different hardness in order to wear the surface differentially and expose a new nonpolished surface.

The angularity of the aggregate affects the skid resistance of a pavement. Angular aggregates exude a more skid resistant surface as long as the aggregate remains angular under wearing. Weaker aggregates that are originally angular will crush into mostly flat and elongated particles which will result in poor skid resistance. The mineral composite of the aggregate source will determine if the aggregate will retain its angularity under wearing and polishing from traffic. The size of the aggregate also has a considerable effect on the skid resistance of a pavement.

The quality of the course aggregates has more effect on the skid resistance than the fine aggregates for hot mix asphalts. Therefore improving the aggregate source of the course particles will better improve the overall skid resistance [Huang].

Mixture Characteristics

The mixture design of a pavement plays a role in the development of adequate skid resistance. The mixture characteristics are controlled by selecting proper aggregate sizes and gradation along with the appropriate asphalt binder content.

Properly blending aggregates can help to achieve desired skid resistance when superior quality aggregates are expensive or limited in source. The skid resistance of a pavement can be substantially increased by using an open graded surface course or a porous pavement. Open graded mixes incorporate a skeleton of uniform aggregate sizes and minimum amount of fines. Open graded mixes or porous pavements increase frictional levels between tires and wet pavements along with the addition of reducing splash and spray during wet conditions. Hydroplaning and nighttime vision is also improved.

The binder content of the mix is generally based on the design criteria, but can have an effect on skid resistance. Too much asphalt binder will cause bleeding and result in a slippery surface when wet.

Measuring Skid Resistance

Measuring skid resistance of a pavement primary provides quality control during the construction process and values for assessment management during the pavements life. Skid fiction values are also taken when a particular pavement reveals potential road safety problems due to skidding.

Skid resistance is most often determined by the force generated when a locked tire slides along a pavement surface. This force is generally determined by the locked-wheel-trailer method or ASTM Method E 274. The method is prescribed to standardize the size of the tire, the method for applying the water to the pavement, and the speed which is 40 miles per hour. The frictional resistance retrieved from the device will characterize the level of skid resistance that a particular pavement will exude.

Skid Number

The level of skid resistance is generally categorized using a measured value of friction which is developed into a skid number. A skid number is developed from surface friction. The surface friction is described as the tractive force applied to the tire F, which is determined from the coefficient of friction μ, and the dynamic vertical load of the tire W. With the value of surface friction the skid number can be determined. The skid number is derived by the following equation.

$$F = \mu W \quad (1)$$

$$SN = 100\mu = 100\,(F/W) \quad (2)$$

where

F = Tractive Force Applied to Tire

μ = Coefficient of Friction

W = Dynamic Vertical Load on Tire

Skid numbers provide an approximation of the level of skid friction that a pavement will provide. The higher the skid number values are, the better the skid friction of the pavement. Generally skid numbers of 30 or higher are accepted for low volume roads and skid numbers of 35 or higher are accepted for high volume roads. Although some states use cutoff values as high as 40 for high volume roads [Jayawickrama et al, 1996]. Table 1 is a summary of general recommendations for actions needed based on the skid number of a pavement when tested according to ASTM E274 standards.

Table 1: General Recommendations for Skid Numbers

Skid Number	Recommendations
< 30	Take Measures to Correct
≥ 30	Acceptable for Low Volume Roads
31-34	Monitor Pavement Frequently
≥ 35	Acceptable for Heavily Traveled Roads

State Survey of Skid Control

A nationwide survey was conducted by Jayawickrama et al (1996) on design methods for achieving adequate skid resistance on asphalt pavements. A survey was sent to and returned from 48 states on how each state's department of transportation addresses skid resistance. As shown in Table 2, the survey revealed that the state DOTs varied considerably in the approach to maintain adequate levels of skid resistance on asphalt pavements. The survey was conducted using five categories of practice:

- I – No specific guidelines to address skid resistance;

- II – Skid resistance is accounted for through mix design;
- III – General aggregate classification procedures are used;
- IV – Evaluate aggregate frictional properties using laboratory test procedures;
- V – Incorporates field performance in aggregate qualifications.

Table 2: Categories of Design Procedures Used by State DOTS

State DOT	Category					State DOT	Category				
	I	II	III	IV	V		I	II	III	IV	V
Alabama				X		Nebraska		X			
Arizona		X				Nevada	X				
Arkansas			X			New Hampshire		X			
California	X					New Jersey				X	
Colorado	X					New Mexico	X				
Connecticut	X					New York				X	
Delaware			X			North Carolina	X				
Florida				X	X	North Dakota	X				
Georgia			X			Ohio	X				
Idaho	X					Oklahoma				X	
Ilinois			X			Oregon		X			
Indiana				X		Pennsylvania				X	X
Iowa				X		Rhode Island	X				
Kansas			X			South Carolina				X	
Kentucky				X	X	South Dakota		X			
Louisiana				X		Tennessee				X	
Maine		X				Texas				X	X
Maryland	X					Utah				X	
Massachusetts	X					Vermont		X			
Michigan				X		Virginia			X		
Minnesota				X		Washington		X			
Mississippi				X		West Virginia			X	X	
Missouri	X					Wisconsin				X	
Montana		X				Wyoming	X				

The results show that of the 48 states surveyed, 14 of those states took no consideration on controlling skid resistance in the design of new pavements and another 10 states assume that adequate skid resistance may be ensured through proper mix design. Therefore, 24 of the 48 states that were surveyed did not consider skid resistant aggregate selection in the design of their pavements. Table 3 shows the distribution of states in each category.

Table 3: Summary of Survey Results

	Category				
	I	II	III	IV	V
Total States	14	9	7	19	4

Skid Resistant Aggregate Testing

Laboratory aggregate testing is used to evaluate frictional properties of aggregates and to group these aggregates based on anti-skid qualities. The basic laboratory procedures for general aggregates are the Los Angeles abrasion test [ASTM C535], soundness by the sodium sulfate test [ASTM C88-05], and deleterious material tests. Other laboratory tests which characterize an aggregates nonpolishing charateristics are the acid insoluble residue (AIR) test [ASTM D 3042-86], the polish value (PV) test [ASTM D 3319-90], the Moh's hardness test, and petrographic analysis.

The Los Angeles abrasion test is used to characterize toughness and abrasion resistance. A portion of the aggregate that is retained on a 1.70 mm (No. 12) sieve is placed inside a large rotating drum that contains a shelf plate attached to the outer wall. A specified number of steel spheres are then placed inside the drum and the aggregate is added. The material is then agitated for 500 revolutions at a speed of 30-33 revolutions per minute. The aggregate is then removed and is separated by percentage of what passes or is retained by the 1.70 mm sieve. The retained material is weighed and compared to the original weight of the sample. The difference in weight is recorded as the percent loss and is the known as the percentage of wear.

The sodium sulfate test, ASTM C88-05, estimates an aggregate's soundness when subjected to weathering action in a pavement. The test is meant to simulate the action of freezing and thawing. This is accomplished by repeated immersion in saturated solutions of sodium or magnesium sulfate. The sample is then oven dried to partially or completely dehydrate the salt precipitated in permeable pore spaces. The process is generally repeated five times. The internal expansive force caused by the salt simulates the expansion of water freezing.

Testing for deleterious material is done to determine that amount of shale, friable particles, coal, and other lightweight deleterious materials in an aggregate source. Amounts of these materials are to be kept at a minimum according to standard specifications.

The AIR test is conducted by using dilute hydrochloric acid to estimate the percentage of noncarbonate insoluble residue in carbonate aggregates. The acid dissolves the carbonate portion of the aggregate and separates the noncarbonates from the carbonates. The skid resistance qualities of the aggregate are based on the differential hardness of the minerals in carbonate aggregates. The results of the AIR test help to identify carbonate aggregates that are prone to polishing and poor skid resistance.

The PV test subjects an aggregate sample to accelerated polishing for 9 hours using a British wheel. Following the 9 hours of polishing, a polish value is calculated by using a British pendulum tester, ASTM E 303-83. The 9 hours of polishing is used to represent a quantitative value of the terminal frictional characteristics of the aggregate that would be used as a pavement surface course.

The Moh's hardness test is used to evaluate an aggregate's frictional characteristics. The higher the hardness number on a scale of 0 to 10, the better the potential for good frictional characteristics. The Moh's hardness values are used to determine if an aggregate should be used for high volume or low volume roads.

Petrographic analysis is an aggregate examination to determine the mineral content. It involves using a microscope to study the mineral content and textural relationships within the rock. The mineral content and texture characteristics will provide information on the susceptibility of polishing of an aggregate.

From the state survey analysis, 19 states reported that their skid control specifications included laboratory aggregate evaluations. These 19 states are listed under category IV of the state survey analysis. Table 4 displays each states laboratory procedures to evaluate aggregates with respect to skid resistance.

STATE SPECIFICATIONS

The following sections of the review evaluates West Virginia's specifications regarding skid resistance along with other state's specifications on skid resistance based on average daily traffic. The study concluded that other state DOTs did not include specifications pertaining to low speed roads and streets through cities and town to determine the need for nonpolishing aggregates. Therefore the determination for the need of skid resistance is based solely on average daily traffic in this review. The specifications will discuss the appropriate selection of aggregates to meet all state requirements for skid resistance and aggregate polishing and comparable testing related to skid resistance.

Table 4: Laboratory Aggregate Evaluation Procedures by State DOT

State DOT	Acid Insoluble Residue	Polish Value Test	Petrographic Analysis	Moh's Hardness Number	Other Test Methods
Alabama		X			
Florida	X				
Indiana					X
Iowa				X	
Kentucky	X				
Louisiana		X			
Michigan	X		X		
Minnesota	X				
Mississippi			X		X
New Jersey		X			
New York	X				
Oklahoma	X				
Pennsylvania	X	X	X		
South Carolina					X
Tennessee	X	X			
Texas		X			
Utah		X			
West Virginia	X	X			X
Wisconsin					X

West Virginia

The West Virginia DOT requires projects with a current ADT of 3,000 or more vehicles per day to provide a wearing course with a skid resistant mixture. The skid mixture shall consist of gravel, slag, or other acceptable polish resistant aggregates or combination thereof and meet all specifications listed in Section 402 which can be found in the Appendix of this report. The wearing course must be Wearing I or Wearing IV, or Superpave Type 9.5, Type 12.5, or Type 19. Wearing IV and Type 19 wearing courses are intended for use on pavements with heavy truck traffic.

The WVDOT requires that all course aggregates meet the standard requirements for deleterious material, percentage of wear, and soundness. The total amount of deleterious materials, including shale, coal and other light weight materials and friable particles is limited to a maximum of three percent. The percent of flat and elongated particles is limited to 10% using a 5:1 ratio for Superpave and 5% using a 4:1 ratio for Marshall mixes. The durability or percent wear of the course aggregates is evaluated by the Los Angeles abrasion test, ASTM C 535. The crushed stone aggregate shall have a percentage of wear not to exceed 40. The soundness of the aggregate is determined by the sodium sulfate test, MP 703.00.22. When the aggregate is subjected to five cycles of the sodium sulfate test, the weighted percentage of loss shall not be more than twelve.

In addition to standard testing for course aggregates, other tests are performed to judge the aggregate's potential to resist polishing. All potential aggregate sources are subjected to testing by the British Wheel and a polish index number is derived. Aggregates must have an index number of 30 or greater to be considered as a polish resistant aggregate.

All aggregates are subjected to the standard quality tests, but some aggregate types require no further testing for prequalification approval as a polish resistant aggregate. Those aggregate types include sandstones, some slag, and trap rocks. Additional testing for nonpolishing aggregate approval is determined by the type of aggregate. Aggregates must adhere to the following considerations:

- River gravel require 80 percent two face fracture and contain no more than 15 percent carbonate particles on the No. 4 sieve.
- Limestone sources must have an insoluble residue content of at least 10 percent.
- Dolomite sources must have an insoluble residue content of at least 10 percent, but dolomite may be used with less than 10 percent insoluble residue if the magnesium content is at least 10 percent.

Acceptable dolomite is permitted as the lone course aggregate or part of the course aggregate blend for roadways with an ADT of 10,000 or less. For roadways that exceed an ADT of 10,000, acceptable dolomite is permitted as part of the total course aggregate blend, but can not exceed 50% of that blend.

The West Virginia road system currently consists of 36,260 miles of roadway. Those roads are classified as Interstate, US Routes, WV Routes, County, and other. Table 5 shows the distribution of roads by mileage, vehicle miles of travel (millions), and average daily traffic [WVDOT – Traffic Analysis Section].

Table 5: West Virginia Road Travel Statistics 2001

Route Type	Miles[1]	% Total	Vehicle Miles of Travel (Millions)	% Total	Average Daily Traffic
Interstate	555	2%	5,335	29%	26,400
US	1,828	5%	4,637	25%	7,000
WV	3,602	10%	4,943	27%	3,800
County	28,852	79%	3,204	17%	300
Other	1,423	4%	399	2%	750
State Total	36,260	100%	18,518	100%	

[1] The mileage includes unpaved roads. These roads should be ignored for skid aggregate consideration.

The statistics show that the Interstate, US, and WV route types generally have an average ADT over 3,000 vehicles which is the threshold for requiring skid resistant aggregates in asphalt mix design. The three route types that generally require skid resistant aggregates due to ADT values, account for 81% of the total vehicle miles of travel. Therefore only 19% of the miles traveled in West Virginia are on surfaces that do not require skid resistant aggregates. Based on the number of miles in the route type designation, the Interstate, US, and WV routes account for nearly 6,000 miles of roadway which is approximately 17% of the total system and generally requires skid resistant aggregates.

Pennsylvania

The Pennsylvania Department of Transportation determines the aggregate quality for a pavement wearing course based on the average daily traffic for a particular roadway. This organization has separated the average daily traffic into five basic categories of ranging values. According to each value of ADT, a specific skid resistance level is determined. Table 6 shows the skid resistance level designations and the acceptable aggregates for a particular pavement for the given values of average daily traffic.

Table 6: Pennsylvania Skid Resistance Level Guidelines for Wearing Courses

Maximum Average Daily Traffic Count (ADT)	Skid Resistance Level (SRL)	Comments
>20,000	E (Excellent)	Only SRL E aggregate can be used.
20,000	H (High)	SRL E or H acceptable. Blends of SRL E and M or E and G are also acceptable.
5,000	G (Good)	SRL E, H, or G acceptable. Blends of SRL H and M or E and L are also acceptable.
3,000	M (Medium)	SRL E, H, G, or M acceptable. Blends of SRL H and L, G and L, or E and L are also acceptable.
1,000	L (Low)	Any rated material is acceptable.

Aggregates are classified based on the result of petrographic analysis, accelerated polishing test, and acid insoluble residue test. The three types of tests are used to control the quality of aggregate and rate the aggregates by rock type to be used in pavement construction. The rock type for each skid resistance level is listed below in Table 7.

Table 7: Pennsylvania Rock Type for SRL Values

Skid Resistance Level (SRL)	Rock Type
E (Excellent)	Gravel and Sandstone
H (High)	Gravel with over 10% carbonate, Quartzite, Siltstone, Argillite, Gneiss, Diabase and Blast Furnace Slag
G (Good)	Siliceous Dolomite and Limestone, Gravel with over 25% carbonate
M (Medium)	Dolomites and some types of Limestone
L (Low)	Limestone and few finely textured Dolomites

Aggregates can also be upgraded in SRL classification based on past performance in the field. The performance history for at least 10 projects is required to apply for classification upgrade and the period must be at least 2 years of service to be eligible for performance testing.

Iowa

The Iowa DOT determines the aggregate quality for a pavement wearing course based on the total ADT which is separated into four levels along with truck ADT. The two levels of ADT determine the friction level that must be used on a particular pavement. The highest classification of friction level is used when the total ADT and truck ADT fall into separate frictional classifications. Table 8 shows the distribution of friction levels used by the Iowa DOT.

Table 8: Iowa Skid Resistance Selection Guide

Total ADT	Truck ADT	Friction Level
0-2000	0-300	No Special Friction Required
2000-5000	300-500	L-4
5000-10000	500-2000	L-3
>10000 All Interstates	>2000 All Interstates	L-2

The friction levels are based on a three tier system – L-2, L-3, and L-4. For frictional classification L-2, the course aggregate, defined as combined aggregate retained on the No. 4 (4.75mm) sieve, must have at least 80% Type 4 or better friction aggregate and of the total at least 25% must be Type 2 or better friction aggregate. For frictional classification L-3, the course aggregate must have at least 80% Type 4 or better friction aggregate and of the total at least 45% must be Type 3 or better. If Type 2 is used in place of Type 3, the minimum shall be 30% of the course aggregate. For frictional classification L-4, at least 50% of the course aggregate shall be Type 4 or better aggregate.

Iowa classifies the frictional aggregates into six main functional types in accordance to their frictional characteristics and they are Type 1, Type 2, Type 3, Type 4, Type 4D, Type 5. Type 1 has the greatest amount of friction and the friction decreases as the type number increases. The frictional classifications types are determined by the Moh's hardness test and LA abrasion. The frictional classifications types are described by the Iowa Department of Transportation under General Aggregate Source Information Materials IM T203 in the Appendix.

Illinois

The Illinois DOT determines the aggregate quality for a pavement wearing course based on the ADT and number of lanes for a particular road. The skid mixtures are broken up into four levels – Mixture C, Mixture D, Mixture E, and Mixture F. The low threshold for Class I skid resistant mixtures is any road with an ADT less than 5,000 regardless of the number of lanes. The ADT levels are then distributed according to the number of lanes constructed for that roadway. Table 9 shows the ADT distribution and the resulting frictional mixture that is required. Table 10 displays the aggregate requirements for each mixture designation.

Table 9: Illinois Skid Resistant Mixtures (Class I)

Number of Lanes	Frictional Requirements (ADT)			
	Mixture C	Mixture D	Mixture E	Mixture F
≤ 2	≤5,000	>5,000	NA	NA
4	≤5,000	5,001-25,000	25,001-100,000	>100,000
≥ 6	NA	5,001-60,000	60,001-100,000	>100,000

Kentucky

The Kentucky Department of Transportation controls skid resistance based on laboratory aggregate testing and field performance evaluations. The laboratory tests used are the acid insoluble residue test and magnesium content for dolomite. The values from this test are used to classify skid resistant aggregates. Kentucky determines the aggregate quality by separating the polish resistant aggregates into two separate classifications: Class A and Class B. The Class A aggregate has demonstrated the highest polish resistance. Unlisted sources can be upgraded to Class B and Class B can apply for Class A status according to guidelines shown in the Appendix set forth by the Kentucky Transportation Cabinet. Table 11 shows minimum requirements for determination of Class A and Class B

Table 10: Illinois Aggregate Requirements for Mixture Types

Mixture	Aggregates Allowed
C	Gravel (only for 9.5mm mixes) Crushed Gravel Crushed Stone Crushed Sandstone Crushed Slag Crushed Steel Slag (except when used at leveling binder)
D	Crushed Gravel Crushed Stone (other than Limestone) Crushed Sandstone Crushed Slag Crushed Steel Slag (except when used at leveling binder) Limestone may be used in Mixture D if blended by volume in the following coarse aggregate percentages: Up to 25% Limestone with at least 75% Dolomite. Up to 50% Limestone with at least 50% any aggregate listed for Mixture D except Dolomite Up to 75% Limestone with at least 25% Crushed Slag or Crushed Sandstone
E	Crushed Gravel Crushed Stone (other than Limestone) Crushed Sandstone No Limestone Dolomite may be used in Mixture E if blended by volume in the following coarse aggregate percentages: Up to 75% Dolomite with at least 25% Crushed Sandstone, Crushed Slag, or Crushed Steel Slag. When Crushed Slag or Crushed Steel Slag are used in the blend, the blend shall contain a minimum of 25% to a maximum of 75% of either slag by volume. Up to 50% Dolomite with at least 50% of any aggregate listed for Mixture E. Crushed Gravel or Crushed Stone may be blended by volume in the following coarse aggregate percentages: Up to 75% Crushed Gravel or Crushed Stone (other than Limestone or Dolomite) with at least 25% Crushed Sandstone, Crushed Slag, or Crushed Steel Slag. When Crushed Slag or Crushed Steel Slag are used in the blend, the blend shall contain a minimum of 25% to a maximum of 50% of either slag by volume.

Table 10: Illinois Aggregate Requirements for Mixture Types (continued)

Mixture	Aggregates Allowed
F	Crushed Sandstone No Limestone Crushed Gravel or Crushed Stone may be used in Mixture F if blended by volume in the following coarse aggregate percentages: Up to 50% Crushed Gravel or Crushed Stone with at least 50% Crushed Sandstone, Crushed Slag, or Crushed Steel Slag. When Crushed Slag or Crushed Steel Slag are used in the blend, the blend shall contain a minimum of 50% to a maximum of 75% of either slag by volume.

aggregates based on acid insoluble residue and magnesium content. Kentucky bases the need for nonpolishing aggregates in surface mixtures on facility category and average daily traffic. The facility category and ADT specifications indicate a specific polish resistant aggregate designation. Table 12 shows the distribution of polish resistant aggregate designations based on facility category and traffic count.

Table 11: Kentucky Aggregate Requirements for Class A and Class B

	Minimum Acid Insoluble Residue Content		Minimum Magnesium Carbonate
	Crushed Gravel	**Limestone**	**Dolomite**
Class A	50%	50%	37%
Class B	15%	15%	NA

Table 12: Kentucky Polish Resistant Aggregate Designation According to Facility Category and Average Daily Traffic

Facility Category/Traffic Count	Polish Resistant Aggregate Designation
All Interstates; Parkways with ADT ≥5,000; and all other roads with ADT >15,000	Type A
Parkways with ADT <5,000 and all other roads with ADT between 5,000 and 15,000	Type B
All roads with ADT <5,000	Type D

The polish resistant aggregate designations are separated into three levels – Type A, Type B, and Type D. The type designation determines how much Class A or Class B aggregate is required. The aggregate requirements for each designation is listed below in order of highest, Type A, to the lowest, Type D.

- Type A. Provide 100 percent of the coarse aggregate from Class A sources and ensure that 20 percent of the total combined aggregate is Class A polish resistant fine aggregate.
- Type B. Select either of the 2 following options. A) Provide 100 percent of the coarse aggregate from Class B sources. B) Provide a combined aggregate, retained on the No. 4 sieve, that is a minimum of 50 percent from any Class A polish resistant source. From option A or B ensure one of the following:
    - 20 percent or more of the total combined aggregate is Class A polish resistant fine aggregate.
    - 30 percent or more of the total combined aggregate is Class B polish resistant fine aggregate.

- 30 percent or more of the total combined aggregate is a combination of Class A and Class B polish resistant fine aggregate.

- Type D. No restriction on aggregate type.

Maryland

The Maryland State Highway Administration (SHA) uses laboratory testing to approve aggregates for state projects. The tests used to characterize nonpolishing aggregates are the polish value test and the acid insoluble residue test. Standard specifications for soundness by the sodium sulfate test and abrasion by the Los Angeles abrasion test also apply. The specifications have limit values for deleterious materials such as friable particles, coal and lignite, and flat and elongated materials. The Maryland SHA does not require specific nonpolishing aggregates based on ADT values. The specifications only require specific requirements for acceptable aggregates for asphalt mixes. The specifications for an acceptable aggregate for an asphalt mix are consistent for each criterion with a few variations to the polish value which are listed in Table 13.

Table 13: Maryland Aggregate Requirements for Asphalt Mixes

	Sodium Sulfate Soundness % max	Friable Particles % max	Coal and Lignite % max	Flat and Elongated % max	Los Angeles Abrasion % max	Polish Value min
HMA Superpave 4.75mm	12	3.0	0.5	10	45	5
HMA Superpave 9.5, 12.5, & 19.0mm HIGH ESAL	12	3.0	0.5	10	45	5
HMA Superpave 9.5, 12.5, & 19.0mm LOW ESAL	12	3.0	0.5	10	45	5
HMA Superpave 9.5, 12.5, & 19.0mm Polish Value = 8	12	3.0	0.5	10	45	8
Gap Graded HMA Superpave 9.5, 12.5, & 19.0mm	12	3.0	0.5	10	45	8

The table shows values for the standard aggregate testing and polish resistant characterization by the polish value. The polish value listed in the table is calculated by MSMT 411 which is derived from the British Pendulum Number. In addition to the above requirements, aggregates suitable for asphalt wearing courses are also controlled by the acid insoluble residue test. The test limits the amount of carbonate particles that are permitted in an asphalt wearing course. When carbonate rock is used it shall have a minimum of 25 percent insoluble residue retained on the No. 200 sieve.

Virginia

The Virginia Department of Transportation establishes requirements for fine and course aggregates to be used in asphalt concrete. Fine or coarse aggregates that tend to polish under traffic are not permitted in any final surface exposed to traffic except in areas where the two-way average daily traffic is less than 750 vehicles per day. For all surface mixes, except in special cases determined by engineer, no more than 5 percent of the aggregate retained on the No. 4 sieve and no more than 20 percent of the total aggregate may be polish susceptible [VA Road and Bridges Specifications].

The specifications require limits on standard tests for aggregates such as deleterious material, soundness, and abrasion. Tables 14 and 15 indicate the permissible levels of deleterious materials and losses due to soundness and abrasion which are calculated by the sodium sulfate test and Los Angeles abrasion test, respectively.

Table 14: Virginia Deleterious Material Requirements

Material	% by Weight	Test Method
Coal and Lignite	0.25	T113
Clay lumps	0.25	T112
Material passing No. 200	1.00	T11

Table 15: Virginia Soundness and Abrasion Requirements

	Maximum Soundness Loss (%)		Maximum LA Abrasion Loss (%)	
	Sodium Sulfate	Freeze and Thaw	Sodium Sulfate	Freeze and Thaw
Use	**5 Cycles**	**100 Cycles**	**100 Rev.**	**500 Rev.**
Wearing Course	15	6	12	45

The Virginia Department of Transportation only requires these standard tests for all aggregates. There are no additional tests to qualify an aggregate as a nonpolishing aggregate. Instead Virginia defines polish susceptible aggregates by geology. They have determined that limestone is considered as a polish susceptible aggregate and therefore is not permitted in wearing courses where skid resistant aggregates are to be used [Bailey].

Ohio

The Ohio Department of Transportation uses basic laboratory testing for it aggregate sources. The standard tests for soundness and abrasion apply to all aggregates. These tests are conducted by the sodium sulfate test and the Los Angeles abrasion test. The Ohio specifications have limit values for deleterious materials such as coal and lignite, clay lumps, shale and shaly material, and friable particles.

The Ohio DOT does not specify specific usage of skid aggregate aggregates. The specifications do require stricter values for abrasion, soundness, and levels of deleterious materials for asphalt wearing courses. Tables 16 and 17 display the acceptable values that are permitted by the Ohio DOT for asphalt wearing courses.

Table 16: Ohio Deleterious Material Requirements

Material	% by Weight
Coal and Lignite	1.00
Clay lumps	0.25
Shale and shaly material	2.50
Friable Particles	2.50

Table 17: Ohio Abrasion and Soundness Requirements

	Asphalt Wearing Course	
	LA Abrasion Test max %	**Sodium Sulfate Test max %**
Fine Aggregate	-	15
Course Aggregate	40	12

REMEDIATION OF SKID PROBLEMS

Roadways that do not perform adequately with skid resistance require remediation. Skid related problems are specific to the tire-pavement contact area. An treatment that improves the texture of the pavement will improve skid resistance. Hence, skid resistance can be improved by an overlay, milling, open graded friction courses (OGFC), or cold surface treatments. Blending high skid and low skid aggregates in situations where higher skid resistance is needed may provide adequate skid resistance.

An overlay is the typical practice of most state DOTs to restore skid resistance to a pavement surface. The overlay provides a new surface wearing course that exhibits proper skid resistance. A thin overlay is up to 1-inch in thickness and a thick overlay generally ranges up to 3-inches in thickness. With respect to skid resistance, there is no advantage to the thicker overlay. In fact to preserve skid aggregate resources, the final lift of an overlay project should be as thin as possible. The Federal Highway Administration (FHWA, 2002) has documented thin and ultra-thin paving practices throughout the world. Table 18 demonstrates the use of a 6 to 10 mm (0.25 to 0.4 inches) thick hot-mix pavement surface used in France.

Table 18. Typical hot-mix pavements in France.

Type	**Top Size (mm)**	**Thickness (cm)**	**Bitumen Type**	**Modifier**
Thin	6-14	3-4	Pure Bitumen	
Very Thin	6-10	2	30-50/50-70 pen	SBS, EVA, EMA, SBR, FIBERS
Ultra Thin	6-10	Equals Maximum Size	30-50/50-70 pen	SBS, EVA, EMA, SBR, FIBERS
Porous Asphalt		4		
High Modulus		6-8	10-20/15-25 pen	

Cold milling is a process where a milling machine with a rotating drum and grinding bits grind the surface of a pavement to remove material to a desired depth. Milling machines have many advantages, it eliminates the need for wedge-shaped leveling courses, provides a *temporary* highly skid resistant surface for traffic until final surface course is placed, provides reclaimed asphalt pavement material for recycling operations, and restores skid resistance to a slippery pavement such as one experiencing aggregate polishing.

An OGFC is a high void wearing course which can remediate asphalt pavements that have lost skid resistance due to aggregate polishing. An OGFC contains a high percentage of one-sized course aggregates which creates a high void content in the mix. Since the mix has a high void content, it is highly permeable to water which allows water to drain over and through the surface to minimize hydroplaning and wet pavement accidents [Roberts et al, 1996].

Robert Y. Liang conducted a study of blending high skid aggregates with low skid aggregates to meet nonpolishing requirements. The experiment took sources of high skid aggregates and low skid aggregates and blended them in percentages of (High Skid/Low Skid) 80/20, 70/30, 60/40, and 50/50. The aggregates used for this experiment were from a limestone source. The skid resistance of the blends where tested using a British wheel to develop a polish value in terms of a British Pendulum Number (BPN). The following table shows analysis from Liang of individual BPN values of high and low skid aggregates and the resulting polish values from the blending percentages.

Table 20: High and Low Skid Aggregate Polish Values

Aggregate Type	Residual BPN
High Skid #1	31.25
Low Skid #1	20.7
High Skid #2	32.5
Low Skid #2	23.39

Table 21: Polish Values for Blended High and Low Skid Aggregates

Aggregate Type	Residual BPN
50/50-1	25
60/40-1	26.05
70/30-1	27.57
80/20-1	31.44
50/50-2	27.08
60/40-2	29.25
70/30-2	29.42
80/20-2	30.54

From the results Liang concluded that blending low and high skid aggregates together can achieve improvements in polish values of the low skid aggregate. The analysis shows that the polish values of the aggregate blend can be approximated by the weight based average of the high and low skid aggregate BPN. This means that when a high skid BPN of 31.25 and a low skid BPN of 20.7 is blended as a 50/50 percentage, the resulting BPN can be estimated to increase the low skid polish value 50 percent of the difference between the two BPN values which is approximately 25 as seen in the table.

According to current West Virginia specifications aggregate sources must have a BPN of 30 or greater to be considered as a potential source of nonpolishing aggregate. The analysis from the blending experiment shows that blending the high and low skid aggregate at a ratio of 80/20 resulted in a BPN greater than 30 for those particular aggregate sources. The 70/30 and 60/40 percentage for the high skid #2 and low skid #2 nearly had values of 30 which 29.42 and 29.25, respectively. This could be used to develop blending guidelines for aggregate of low skid resistance to be improved to a level of acceptable usage for roadways requiring skid resistant aggregates. It could also be considered for use on roadways with relatively low ADT values, yet high enough daily traffic to require skid resistant aggregates in the mix.

In addition to hot-mix overlays, cold treatments can be used to improve skid resistance. Surface treatments are the most common cold treatment, but they have several issues that can make them undesirable for higher traffic volume roads. These include loose chips following construction, higher tire noise than hot mix, and the perception that the quality of the surface is objectionable to the public. Alternatives to the traditional single chip treatment are available, such as a double chip seal, where the second application of chips is half the size of the first layer and the use of pretreated chips. Other types of cold treatments are being successfully applied in other states including slurry and microsurfacing.

CONCLUSIONS

States such as Ohio and Maryland to not formally address requirements for skid resistant aggregates based on ADT values. As reported by Jayawickrama and from further research, these two states only require specific guidelines for all asphalt wearing courses. The specifications do require specific levels of losses for abrasion and soundness and amounts of deleterious material. Maryland does require wearing courses to have a specific polish value and it must maintain a specific percent of insoluble residue when carbonate rock is used in the mixture, but does not formally address the need to control skid resistance.

The states that address skid resistance, base the need for nonpolishing aggregates on ADT levels. For determining the need for nonpolishing aggregate, West Virginia's cutoff point of ADT for using nonpolishing aggregate falls in the middle for the overall range of states surveyed. West Virginia requires nonpolishing aggregate for any roadway with an ADT greater than 3,000. States such as Illinois and Kentucky use cutoff points of 5,000 before skid resistant aggregates are required, although states such as Iowa, Pennsylvania, and Virginia use cutoff points as low as 2,000, 1,000, and 750, respectively. A difference between the West Virginia standards and the other states is that West Virginia is the only state to use a one cutoff point for need of nonpolishing aggregates, with the exception of Virginia. The remaining states that determine the need for skid resistant aggregates based on ADT have a system of at least three separate classifications for ADT levels and appropriate aggregates for each level.

A solution to reducing the amount of need for skid resistant aggregates in West Virginia is adopting an ADT level distribution system similar to a state with the closest related levels of traffic. Of the states with an ADT distribution system, Kentucky and Iowa would best represent the same levels of traffic as to that of Pennsylvania or Illinois which have much larger cities and higher ADT levels.

Kentucky has a three level system which requires the highest level of skid resistant aggregates for all interstates, parkways with an ADT greater than 5,000, and all other roads with ADT greater than 15,000. The second level for skid resistant aggregates are intended for parkways with an ADT less than 5,000 or any roadway with and ADT between 5,000 and 15,000. The low cutoff is for roadways with an ADT less than 5,000 which do not require any specific aggregate type.

Iowa has a four level system which requires the highest level of skid resistant aggregates for all interstates and all other roadways that have an ADT greater than 10,000. The second highest level for skid resistant aggregates is for an ADT ranging from 5,000 to 10,000 and the lowest classification that still requires skid resistant aggregates is from 2,000 to 5,000. Any roadway with an ADT less than 2,000 does not require skid resistant aggregates for the state of Iowa.

Another consideration for lowering the need for skid resistant aggregates is blending high skid aggregates with low skid aggregates to achieve a marginally acceptable skid resistant aggregate. The study by Robert Y. Liang shows the approximation of skid resistant qualities when an aggregate with high skid qualities is blended with low skid qualities.

These considerations could ultimately reduce the amount of skid resistant aggregates needed while providing safe roadways for travelers. This would ultimately save the state money from paving premium costs for skid resistant aggregates.

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APPENDIX

West Virginia Department of Transportation
Hot Mix Asphalt Skid Resistant Pavement
Standard Specifications Section 402

SECTION 402
HOT-MIX ASPHALT SKID RESISTANT PAVEMENT

402.1 - DESCRIPTION:

This work shall consist of constructing a Hot-Mix Asphalt (HMA) Skid Resistant Wearing Coarse or a Superpave HMA Skid Resistant Wearing Coarse in accordance with the requirements of the Section 401 Asphalt Specification with the following exceptions and additions:

402.2 - MATERIALS:

The coarse aggregate shall consist of gravel, slag, or other acceptable polish resistant aggregate, or combinations thereof, meeting the requirement of Subsections 703.1 through 703.3, except as amended in this subsection.

When stone or gravel is specified in the contract, the coarse aggregate shall consist of gravel or other acceptable polish resistant aggregate, or combination thereof meeting the requirements of 703.1 through 703.3,

contract, the coarse aggregate shall be slag which meets the requirements of 703.3, except as amended in this subsection.

Acceptable dolomite may be used alone or as a part of a coarse aggregate blend on roadways with an ADT of 10,000 or less. On roadways exceeding 10,000 ADT, acceptable dolomite may be used only as a part of the coarse aggregate blend and shall not exceed 50% of that blend.

The total of shale (determined by MP 703.00.27), coal and other lightweight deleterious material (determined by ASTM C123) and friable particles (determined by MP 703.01.20) shall not exceed three percent.

402.2.1 - Marshall Mix Designs: For Marshall mix designs, the coarse aggregate or blends thereof shall have a minimum of 80 percent two-face fracture, and, except for those carbonate rocks which may be designated as acceptable polish resistant aggregate, the portion obtained on the No. 4 (4.75 mm) sieve shall contain no more than 15 percent carbonate particles.

The total thin and elongated pieces, when tested as per MP 703.00.25, shall not exceed five percent.

402.2.2 - Superpave Mix Designs: For Superpave mix designs, the coarse aggregate or blends thereof shall have a minimum angularity requirement as specified in MP 401.02.28, Table 401.02.28C and, except for those carbonate rocks which may be designated as acceptable polish resistant aggregate, the portion obtained on the No. 4 (4.75 mm) sieve shall contain no more than 15 percent carbonate particles.

Flat and elongated particles shall be tested in accordance with ASTM D4791 and the procedure modification referenced in AASHTO MP2. The

total flat and elongated particles, measured at a 5:1 ratio, shall not exceed ten percent by weight for all pavements where the estimated traffic level is greater than or equal to 0.3 million ESALs.

402.3 - FINE AGGREGATE:

402.3.1 - Marshall Mix Designs: Fine aggregate shall meet the requirements of 702.3.

402.3.2 - Superpave Mix Designs: Fine aggregate shall meet the requirements of 702.3 along with the addition of the fine aggregate angularity and sand equivalent requirements noted in MP 401.02.28, Table 401.02.28C.

Iowa Department of Transportation
General Aggregate Source Information
Materials IM T203

HOT MIX ASPHALT AGGREGATES

Aggregates for HMA construction have been classified into six main functional types in accordance with their frictional characteristics. Those aggregates with the potential to develop the greatest amount of friction under traffic conditions are classified as Type 1 with the potential for friction decreasing as the type number increases. One or more friction types may be specified for use in pavement surface courses. If a type is not specified in the contract documents, Type 5 or better will be acceptable.

When aggregates of friction Type 1 through Type 4 are specified for construction, a source approval including bed limitations is required for each project. Tentative bed limitations are shown in this publication.

The frictional classification types are listed and defined in order of descending quality as follows.

Type 1: Aggregates, which are generally, a heterogeneous combination of minerals with coarse-grained microstructure of very hard particles (generally, a Mohs hardness range of 7 to 9) bonded together by a slightly softer matrix. These aggregates are typified by those developed for and used by the grinding-wheel industry such as calcinated bauxite (synthetic) and emery (natural). They are not available from Iowa sources. Due to their high cost, these aggregates would be specified only for use in extremely critical situations.

Type 2: Natural aggregates in this class are crushed quartzite and granites. The mineral grains in these materials generally have a Mohs hardness range of 5 to 7. Synthetic aggregates in this class are some air-cooled steel furnace slags and others with similar characteristics.

Type 3: Natural aggregates in this class are crushed traprocks, and/or crushed gravels. The crushed gravels shall contain 40% or more igneous and metamorphic particles. Synthetic aggregates in this class are the expanded shales with a Los Angeles abrasion loss less than 35 percent.

Type 4: Aggregates crushed from dolomitic or limestone ledges in which 80 percent of the grains are 20 microns or larger. The mineral grains in the approved ledges for this classification generally have a Mohs hardness range of 3 to 4. For natural gravels, the Type 5 carbonate (see below) particles, as a fraction of the total material, shall not exceed the non-carbonate particles by more than 20 percent.

Type 4D: A subgroup of the Type 4 category comprised of those aggregates near, but exceeding, the 20-micron minimal grain size. Type 4D aggregates are not acceptable for use in any HMA surface courses requiring the use of Type 4 or better material.

Type 5: Aggregates crushed from dolomitic or limestone ledges in which 20 percent or more of the grains are 30 microns or smaller.

Kentucky Transportation Cabinet
Department of Highways
Division of Materials

POLISH-RESISTANT AGGREGATE SOURCE LIST AND GUIDELINES

Aggregates supplied for Polish-Resistant Surfaces shall meet the applicable requirements of the Standard Specifications sections 804 and 805, Special Notes, and restrictions contained in the attached listing. In addition to Class A or Class B (See subsection: 403.03.03 A) sources listed herein, Polish-Resistant Fine Aggregate includes (but is not limited to) natural sands, conglomerate sands and crushed gravel sands which are on the Aggregate Source List.

CLASS A POLISH-RESISTANT AGGREGATE SOURCES

The sources listed herein have demonstrated satisfactory polish-resistant qualities or satisfactory performance as skid-resistant aggregates for polish-resistant surface mixes. In addition to meeting the list requirements, sampling and testing on a project basis will also be required. The continued acceptance of individual sources shall be based on satisfactory performance. Blending of aggregates from 2 or more Class A sources may be approved on a project-by-project basis upon request to the Division.

Upon request additional aggregate sources may be added to this list on the basis of satisfactory skid-resistant performance in another state, laboratory testing, and/or experimental test sections.

CLASS B POLISH-RESISTANT AGGREGATE SOURCES

Sources listed under "Class B Polish-Resistant Aggregate Sources" may be used only if the bid item in the project proposal permits their use. These sources may be promoted to the Class A Polish-Resistant Aggregate Source List by establishing a satisfactory history of performance. Individual sources may be removed from the Class B Polish-Resistant Aggregate Source List based on poor performance.

GUIDELINES FOR CLASS B POLISH-RESISTANT SURFACE MIXES (INCLUDING BLENDS)

Contractors may elect to supply Class B polish-resistant aggregates or an aggregate blend utilizing any unrestricted Class A Polish-Resistant Aggregate. Any proposed Class B blend will be reviewed upon submission of the mix design by the contractor.

PERFORMANCE TESTING BY SPECIFIC PROJECT APPLICATION

Sources other than these listed will be considered for polish-resistant surface mixes on a project by project basis. A change order request subsequent to bid letting shall be submitted to the Engineer for review.

UNLISTED SOURCES APPLYING FOR CLASS B STATUS

Approval of such requests will be limited to roads with less than 15,000 ADT and more than 6,000 ADT which have travel speeds equal to or greater than 55 mph (suitable for skid testing) and without other existing adverse safety considerations. The project length shall be sufficient to accommodate a one mile test section. Any one source will be limited to three project applications until an evaluation of skid data is completed. Three one mile applications will be required prior to consideration of a change in status.

CLASS B SOURCES APPLYING FOR CLASS A STATUS

Sources considered must have proven performance as a Class B source and identify a change in production or material that could result in improved skid resistance. Approval of such requests will be limited to roads with less than 40,000 ADT, suitable for testing and without other existing adverse safety considerations. The project length shall be sufficient to accommodate a one mile test section of the Class B aggregate and a one mile section of Class A aggregate for comparison. More than one test section may be placed if project length permits. Any one source will be limited to three one mile project applications until an evaluation of skid data is completed. Three applications will be required prior to consideration of a status change.