APPENDIX A: UNDERSTANDING UNPAVED ROAD MATERIALS

Source: Jones, D. 2017. *Guidelines for the Selection, Specification and Application of Chemical Dust Control and Stabilization Treatments on Unpaved Roads*. Davis and Berkeley, CA: University of California Pavement Research Center, (UCPRC-GL-2017-03).

A.1 Introduction

Unpaved road chemical treatments are best used for keeping a "good road in good condition" (Figure A.1), rather than trying to use them to correct serious material, construction, and/or maintenance deficiencies (Figure A.2). In addition to traffic and climate, unpaved road performance is also linked to subgrade, base, and wearing course layer properties, road geometry, road shape, and drainage, and to construction and maintenance quality. An understanding of all these factors is therefore required before an appropriate chemical treatment can be selected and a treatment program initiated. Using inappropriate materials in the wearing course will probably have the biggest impact on dust levels, slipperiness, all-weather passability, and how quickly the road deteriorates due to washboarding, raveling, and erosion. Consequently, considerable information is provided in this appendix on understanding material properties to ensure that the best possible road performance is achieved.

Figure A.1: Good gravel road.

Figure A.2: Poor gravel road.

How well an unpaved road performs depends on the materials used on it and how those materials are shaped and compacted to form a riding surface. It is important to consider that much of the imported aggregate used for base and wearing courses on unpaved roads in the United States comes from commercial sources whose primary focus is supplying materials for paved roads and building projects. Consequently, the aggregate commonly supplied for unpaved roads will meet the specifications for asphalt concrete, asphalt surface treatments (chip seals), portland cement concrete, or aggregate base for paved roads. Many practitioners mistakenly believe that if materials meet the specifications for aggregate base in a paved highway that they will work as well in an unpaved road wearing course. This is an incorrect assumption! For example, aggregate base used in paved roads is confined by the chip seal, asphalt concrete, or portland cement concrete on the surface, and therefore gradings are optimized for strength (and frost-heave protection where applicable) as the base is not directly subjected to traffic abrasion or the weather. Therefore, a different set of material selection criteria and specifications is needed for unpaved road wearing courses to compensate for this lack of surface containment. Adjustment of the fines content and clay content are usually the most important considerations.

A.2 Material Testing

Key material properties influencing unpaved road wearing course performance include the grading (or particle size distribution), particle shape, the fines content, the clay content, and the material shear strength. These are determined from basic material indicator tests including:

- A grading analysis (e.g., AASHTO T 27 or ASTM C136)
- A plasticity test (e.g., Atterberg limits [AASHTO T 89 and T 90 or ASTM D4318] or bar linear shrinkage [Caltrans CT 228, Texas Tex-107-E, or method provided in Appendix A.1]), and
- A strength test (e.g., California Bearing Ratio [AASHTO T 193 or ASTM D1883]).

Representative samples for the testing should be collected from the existing wearing course, underlying materials, if blending is anticipated, or from the quarry stockpile, if new aggregates are going to be imported prior to treatment. These samples should then be subjected to the tests listed above to check that they meet the required specifications. All of these tests are simple to perform and cost very little (at a commercial laboratory in 2017, grading analysis and Atterberg limit tests cost approximately $250 and $150, respectively, and a California Bearing Ratio [CBR] test cost approximately $750). These costs are negligible in terms of the costs of gravel replacement and selection of the correct chemical treatment, and can potentially be recovered many times over when better material selection results in extended road life and reduced grader maintenance requirements. The very small up-front savings enjoyed by skipping material testing will invariably mean higher costs later on because of early replacement of gravel and more frequent maintenance. Most unpaved road specifications are based on these or similar tests.

A.3 Unpaved Road Specifications

There is a range of recommendations, guidelines, and specifications available for the design of unpaved roads, covering geometry, thickness, shape, base and wearing course materials, and construction. Although this document discusses how these topics pertain to unpaved road chemical treatments, readers are referred to their organizations' in-house specifications or to the example documents listed below, for more information regarding unpaved roads in general. Note that national or general specifications must often be adapted to suit local conditions and material availability.

- *Stabilization and Rehabilitation Measures for Low-Volume Forest Roads*. (U.S. Forest Service) *(1)*
- *Unsealed Roads Manual: Guidelines to Good Practice*. (Australian Road Research Board) *(2)*
- *Unsealed Roads: Design, Construction and Maintenance*. (South African Department of Transport) *(3)*
- *Gravel Roads Construction and Maintenance Guide.* (Federal Highway Administration) *(4)*
- *Earth and Aggregate Surfacing Design Guide for Low Volume Roads. (U.S. Forest Service) (5)*
- *Guidelines for Surfacing Aggregate. (U.S. Forest Service) (6)*
- *Standard Specifications for the Construction of Roads and Bridges on Federal Highway Projects (Federal Highway Administration) (7)*
- *Guidelines for Geometric Design of Very Low-Volume Local Roads (ADT ≤ 400)* (American Association of State Highway and Transportation Officials [AASHTO]) *(8)*
- *Gravel Road Management: Implementation Guide.* (Montana Local Transportation Assistance Program) *(9)*

Examples of Federal Highway Administration (FHWA) specifications *(7)* and FHWA and US Forest Service (USFS) guidance *(4,5)* for unpaved road wearing course materials are shown in Table A.1.

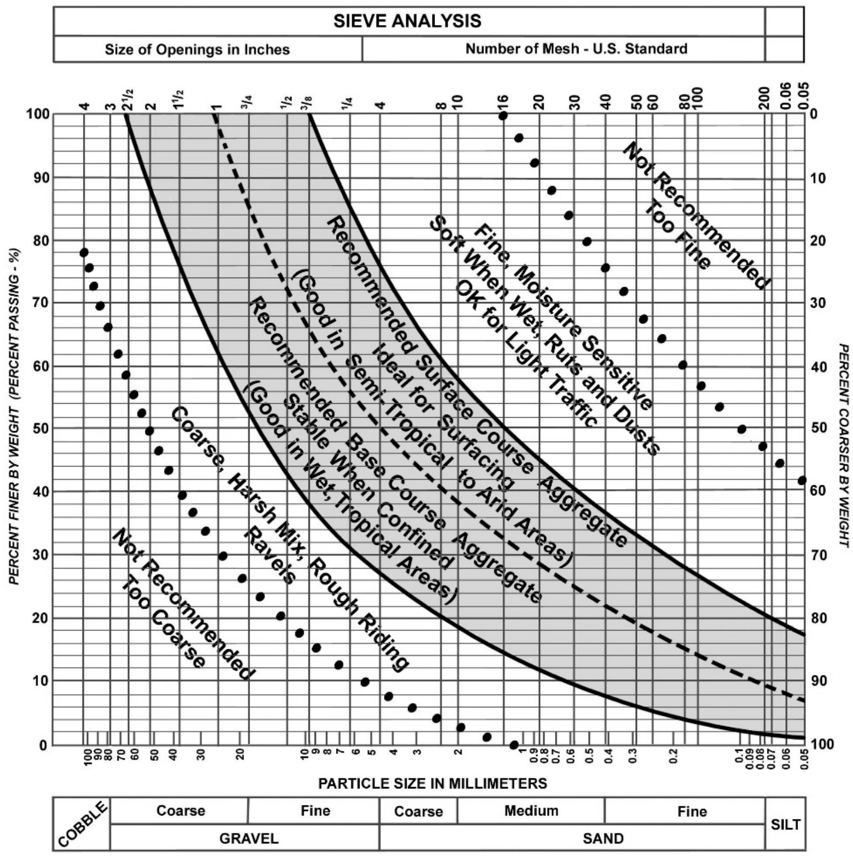
Table A.1: Example Specifications/Guidelines for Unpaved Road Surfacing Materials

Parameter			FHWA Specification *(7)*		FHWA and USFS Guidelines		
			Target	Tolerance	FHWA *(4)*	USFS *(5)*	
						Haul	General Use
Sieve size	1	(25)	100	--	100	97 – 100	100
(U.S. [mm])	3/4	(19)	97 – 100	--	90 – 100	76 – 89	97 – 100
	#4	(4.75)	41 – 71	±7	50 – 78	43 – 53	51 – 63
	#8	(2.36)	--	--	37 – 67	23 – 32	28 – 39
	#40	(0.425)	12 – 28	±5	13 – 35	15 – 23	19 – 27
	#200	(0.075)	9 – 16	±4	4 – 15	10 – 16[1]	10 – 16[1]
Plasticity Index			8	±4	4 – 12	2 – 9 if passing #200 is <12% <2 if passing #200 is >12%	
[1] Range for #200 (0.075 mm) sieve is 6.0 to 12.0% if the PI is greater than 0							

A.4 Influence of Material Properties on Performance

A.4.1 Current Approach for Interpreting Laboratory Test Results in the United States

Interpreting laboratory test results in terms of understanding actual performance on the road is difficult when grading analysis and plasticity index results are simply listed in guidance and specifications, as shown in Table A.1. Uncertainty also arises when guidance and/or specifications from two or more reputable organizations are compared and the proposed ranges differ considerably (e.g., the FHWA and USFS guidance shown in Table A.1), which can lead to confusion in determining which one is “correct” or more appropriate for a given set of climate, traffic, and road alignment conditions. The problem is worsened when an aggregate supplier cannot meet the specification or when a road owner uses gravel from a source located on their own property (i.e., will the material still provide satisfactory performance if it does not meet the specification and/or will the costs of maintenance on the road be higher?). To overcome these problems, a number of procedures have been developed for interpreting grading analyses in terms of expected performance of the material on the road; an example of the grading interpretation chart used by the USFS is shown in Figure A.3 *(1)*.

<table>
<tr><th>Grain Size Distribution</th><th>Plasticity</th></tr>
<tr><td>


</td><td>As a surfacing material, crushed aggregate should provide structural support, but it also needs to be very well graded and have some plastic binder to reduce raveling and washboarding. Maximum density is achieved with between 6 and 12% fines. Ideally aggregate used for road surfacing materials or a wearing surface should have 10 to 15% fines and a Plasticity Index (PI) of 2 to 9. In a wet climate the PI requirement is less critical, and too many clay fines can contribute to local water quality degradation. In a wet region, the ideal PI range may be 0 to 5. In a dry, semi-arid climate a PI range of 5 to 9 appears more desirable</td></tr>
</table>

Figure A.3: Example guidance for interpreting grading and plasticity test results *(1)*.

In most available guidelines, the recommendations for grading and plasticity are usually presented separately (USFS example also provided in Figure A.3), which can be misleading since the influence of plasticity on unpaved road performance is always linked to the fines content (i.e., the higher the fines content, the greater the influence of the plasticity on road performance). Very few of these methods, including the USFS guide, combine the grading analysis and plasticity test results in a single performance prediction chart, and therefore they often tend to give a wider range of potentially "acceptable" materials that do not necessarily always relate to year-round good performance on the road.

A.4.2 An Alternative Approach for Interpreting Laboratory Test Results

Research in southern Africa in the 1980s and 1990s *(3,10,12)*, which entailed a comprehensive statistical analysis of results from the long-term monitoring of more than 100 test sections selected according to a scientific experimental design and from the laboratory tests on materials sampled from each road during the evaluation, found that unpaved road performance can be better understood if the grading analysis and plasticity test results are interpreted together instead of being considered independently. A simple three-step procedure, based on this research and described below, can be used to interpret test results, assess the applicability of local material specifications, and understand how an unpaved road is likely to perform if a particular material with a specific grading and plasticity index is used. The procedure can also be used to make a decision regarding material choice, road design specifications, and chemical treatment selection. Although this approach is used as the basis for specifications in many countries worldwide, in this guideline it is only proposed as a guide for interpreting test results from individual projects and refining current specifications and NOT necessarily as a new specification; nor is it intended that it necessarily replace existing specifications. This approach may need to be refined for particular situations and calibrated for local conditions, specifically traffic and climate. Although the South African approach has been widely published, and adopted and implemented in numerous countries worldwide *(2,3,13-15)*, it has not been formally evaluated or implemented in the United States.

A.4.3 Step-1 – Test Result Analysis

<u>Grading Analysis</u>

In this recommended approach, five key sieve sizes from a standard laboratory grading analysis test are required for understanding material performance and selecting an appropriate chemical treatment. These key sieve sizes are 1.0 in., #4, #8, #40, and the #200 (~25 mm, 4.75 mm, 2.36 mm, 0.425 mm, and 0.075 mm). The first three are used to check for an appropriate mix of coarse, intermediate, and fine particles using the following simple formula known as the *grading coefficient* (G_c) *(3,12)*:

G_c = ((P1.0 in. – P#8) × P#4) / 100 or

G_c = ((P25 mm – P2.36 mm) × P4.75 mm) / 100

where P is percent passing

The percentage of material passing the #200 (0.075 mm) sieve is also a useful indicator of how an unpaved road will perform, and will influence the decision of what chemical treatment to use. High percentages of material passing this sieve (i.e., more than 20 percent) signal that the road will be dusty when dry and may become slippery when wet. Low percentages (i.e., less than 10 percent) signal that the road will likely washboard and require frequent grader maintenance. Many unpaved road wearing course specifications that are based on paved road base course specifications limit this fines content to a maximum of about five to eight percent in the mistaken belief that this will reduce dust. However, determining the percent passing the

#200 sieve (usually done using a wet process as part of a standard grading analysis) is not as simple as determining the percent passing the #8 (2.36 mm) sieve (which can be done in a dry sieve analysis, if necessary, as a quick indicator in the field). Consequently, to obtain a basic understanding of how materials are likely to perform, this approach factors the #200 material into the grading coefficient equation as part of the material passing the #8 sieve. The percent passing the #200 sieve is, however, still required for chemical treatment selection procedures.

The percentage of material passing the #40 (0.425 mm) sieve is used together with a plasticity test to understand the effects of clay in the material and is discussed in the following section.

Although the grading coefficient is determined using material passing the 1 in. (~25 mm) sieve, and many specifications list this as a maximum size, some larger aggregate (1½ in. to 1¾ in. [40 mm to 45 mm]) is usually acceptable to provide adequate all-weather passability. The use of aggregates larger than this will reduce ride quality, make the road noisy to travel on, and cause problems for the maintenance grader operator. As a general rule, the maximum aggregate size should never exceed one-third of the thickness of the compacted layer.

The angularity of the aggregate should also be visually checked during the sieve analysis. Cubic/angular material (Figure A.4) has better interlock than rounded material (e.g., uncrushed alluvial aggregates [Figure A.5]), and consequently rounded aggregate should be crushed to obtain at least two fracture faces to enhance interlock and prevent raveling.

Figure A.4: Cubicle aggregate.

Figure A.5: Rounded aggregate.

<u>Clay Content</u>

The plasticity index, determined from the Atterberg limit tests (or preferably the less commonly used bar linear shrinkage [BLS] test), is used together with the percent passing the #40 sieve (0.425 mm, i.e., the material on which the Atterberg limit and BLS tests are conducted) to evaluate the influence of clay content on likely performance, using the following simple formula known as the *shrinkage product* (S_p):

S_p = (PI × 0.5) × P#40 if plasticity index is used (P#40 = 0.425 mm), or

S_p = BLS × P#40 if the bar linear shrinkage is used

Note that using the bar linear shrinkage to determine the shrinkage product is more accurate than using the plasticity index, especially for silty non-plastic or slightly plastic materials. These materials often have a plasticity index of zero, and consequently also a shrinkage product of zero if the formula is used with plasticity index results. However, these materials will usually have some measurable linear shrinkage [i.e., BLS > 1], thereby providing a non-zero number to work with to better estimate expected performance. Recommendations for dealing with these situations when only plasticity index values are available are as follows (Figure A.6):

- If the PI of the material is equal to or greater than one, use the actual PI value without modification.
- If the material is non-plastic (i.e., PI = 0) and the percent passing the #200 sieve is less than 20 percent, set the PI to zero in the shrinkage product equation.
- If the material is non-plastic and the percent passing the #200 sieve is more than 20 percent, set the PI to 1 in the equation.
- If the material is termed "slightly plastic" in the laboratory test results and the percent passing the #200 sieve is less than 20 percent, set the PI to 1 in the equation.
- If the material is termed "slightly plastic" and the percent passing the #200 sieve is more than 20 percent, set the PI to 2 in the equation.

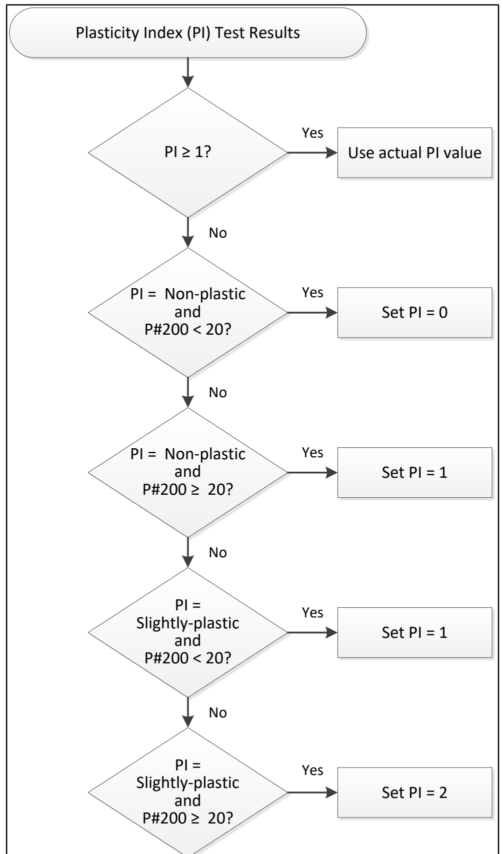


Figure A.6: Plasticity Index result interpretation.

Shear Strength

The California Bearing Ratio (CBR), which is performed on material in the laboratory, is the most commonly used shear strength or bearing capacity test for granular materials used in unpaved roads *(1)*. No formulas are required to interpret the results from this test.

A.4.4 Step-2 – Test Result Interpretation

Optimal unpaved road performance will usually be achieved when the wearing course materials meet the following criteria *(3,10,11,12)*:

- The grading coefficient is between 15 and 35. Although fines content is not directly measured in the grading coefficient formula, a fines content (material passing the #200 [0.075 mm] sieve) of between 12 and 20 percent is typically required to meet optimal grading coefficient requirements.
- The shrinkage product is between 100 and 365 (or between 100 and 250 if dust is a major concern and no dust control treatment is planned). Depending on the fine material fraction (percent passing the #200 sieve), the lower limit can usually be relaxed for lower traffic volumes (e.g., the shrinkage product can be relaxed to 50 and 75 for traffic volumes of 50 and 75 vehicles per day, respectively, provided that the fines content is between 12 and 20 percent). Many unpaved road specifications based on those for paved road base courses limit or exclude any clay content, incorrectly assuming that this will reduce dust. On the contrary, small amounts of clay bind aggregate particles together, preventing washboarding and reducing dust.
- Assuming that the road has a quality base course with adequate soaked CBR, the soaked CBR of the wearing course should be above a minimum of 15 percent (determined at 95 percent of AASHTO T 180 or ASTM D1557 compaction). If truck traffic predominates and the road is in a high rainfall area or storms of high intensity are common, a higher soaked CBR may be desirable if passability problems are an issue. However, higher soaked CBR materials tend to have low clay contents and consequently washboarding may be a problem. Therefore, a balance between soaked CBR and shrinkage product must be determined for optimal performance for specific traffic scenarios. Experience has shown that material complying with the grading coefficient and shrinkage product limits discussed above will invariably have a soaked CBR strength (compacted to 95 percent of the laboratory-determined maximum dry density [AASHTO T 180 or ASTM D1557]) in excess of about 20 percent *(11)*.

A simple chart plotting grading coefficient (x-axis) and shrinkage product (y-axis) along with the optimal limits described above can be used to obtain an indication of the expected performance of the material on the road (example in Figure A.7). Local calibrations of the grading coefficient and shrinkage product ranges may be needed. Examples of local refinements could include but are not limited to lowering the upper level of the shrinkage product range (e.g., to 250) on roads with high truck traffic volumes, roads that are shaded for most of the day, and roads in areas with high annual average rainfall and/or high-intensity storms. The lower level of the shrinkage product range can be reduced (e.g., to 50 or 75) for roads with very low traffic volumes and/or slow-moving vehicles, and also for roads that are shaded most of the day, and roads in areas with high annual average rainfall and/or high-intensity storms. For local calibrations, practitioners can sample materials from good and poor performing roads in their jurisdiction, test these materials, analyze the results according to Step-1 above, and plot the results on the chart shown in Figure A.7. The grading coefficient and shrinkage product ranges can then be adjusted to accommodate these local performance observations. Future material acquisitions can be based on these new defined ranges.

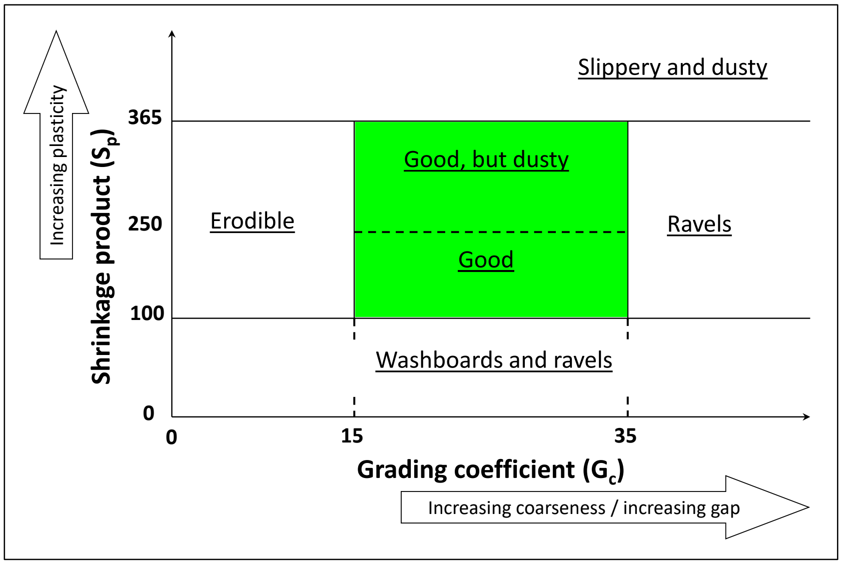


Figure A.7: Material performance predictor chart (adapted from Paige-Green *[3,12]*.)

The factors that contribute to each of these predicted material performances are discussed below.

- Erodible materials are typically fine-grained and have some plasticity. They generally perform well when used in roads on flat terrain or in areas with very low rainfall. In other areas, they will quickly erode during rainfall, leaving channels in the road that are dangerous and unpleasant to drive over and expensive to maintain. Examples of roads built with materials falling in this area of the chart are shown in Figure A.8 and Figure A.9; grading coefficients and shrinkage products for the materials shown in the photographs are plotted on the chart in Figure A.10. The eroded material usually ends up where it is not wanted (e.g., blocking drains, or flowing into streams or onto adjacent land).

Figure A.8: Transverse erosion.

Figure A.9: Longitudinal erosion.

- Materials that washboard (corrugate) and ravel are usually poorly graded or gap-graded (absence or insufficient quantities of certain sizes leading to poor aggregate interlock) and lack fines and plasticity. Consequently, the particles do not bind together, leading to washboarding, raveling, and, ultimately, to gravel loss, and thus to a poor and unsafe ride on a surface requiring regular maintenance. These materials are also prone to erosion during rainfall. Examples of roads built with materials falling in this area of the chart (Figure A.10) are shown in Figure A.11 and Figure A.12.

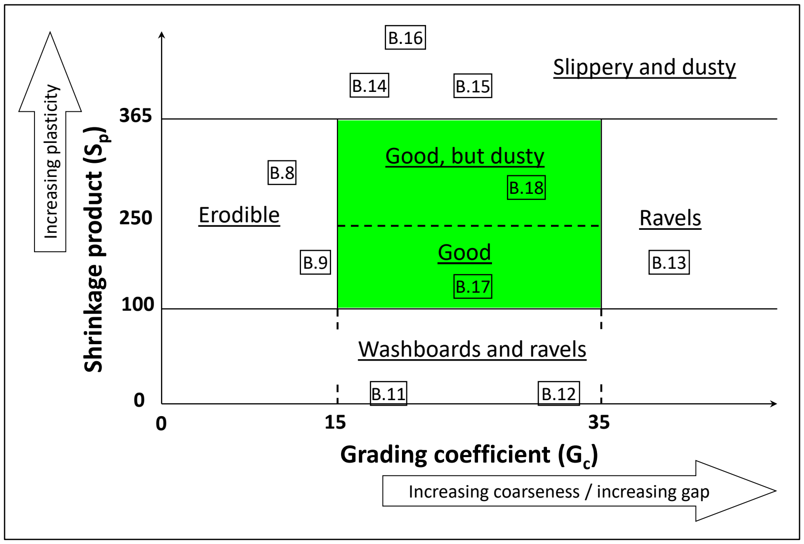


Figure A.10: Plot of materials for road examples in Figures A.8, A.9, and A.11 through A.18.

Figure A.11: Washboarding (corrugation).

Figure A.12: Washboarding and raveling.

- Materials that ravel, but do not usually washboard, have some plasticity, but are gap-graded. The presence of clay usually limits washboarding but does not prevent raveling. An example of a road built with materials falling in this area of the chart (Figure A.10) is shown in Figure A.13. Windshield damage from loose stones is a major problem on these roads.
- Materials that are both very dusty when dry and slippery when wet typically have high fines (and silt and/or clay) contents. Increasing clay content also results in decreasing CBR, leading to poor passability in addition to slipperiness during wet conditions. Examples of roads built with materials falling in this area of the chart (Figure A.10) are shown in Figure A.14 through Figure A.16.
- Well-graded materials with a small percentage of clay will perform well with a minimum of maintenance. Well-graded materials with moderate clay contents will also perform well, but may be dusty during dry conditions if the percent passing the #8 (2.36 mm) sieve is high. Examples of roads built with materials falling in this area of the chart (Figure A.10) are shown in Figure A.17 and Figure A.18.

Figure A.13: Raveling.

Figure A.14: Dusty when dry.

Figure A.15: Slippery when wet.

Figure A.16: Impassable.

Figure A.17: Good but dusty.

Figure A.18: Good material.

A.4.5 Step 3 – Material Selection Decision

If materials that fall within the good-performing area on the chart are readily available, the decision is easy: use these materials to construct a good road and keep the road in a good condition with appropriate maintenance, and if justified apply a suitable chemical treatment. If these materials are not readily available, then decide on an appropriate course of action as follows:

- Weigh the potential consequences of the problems listed above with the probability of them occurring, taking the following into consideration:
  - + <u>Erodible</u> materials can be used in flat areas and areas with low rainfall or low intensity rainfall events. Chemical treatments may reduce the erosion problem, but are unlikely to prevent it.

  + Materials that <u>washboard or ravel</u> can be used on roads with low traffic volumes traveling at low speeds or where the road carries mostly laden heavy vehicles traveling at low speeds. They can also be used if a road owner is prepared to regularly blade the road or to level the washboarding with a tire drag or similar device. The costs of this frequent maintenance should be compared with mechanically stabilizing the existing material with more fines or some clay, or importing better wearing course gravel from elsewhere. If the road is generally only used to access residences, the homeowners may be willing to tow a simple tire drag themselves to smooth out washboarded and raveled areas. Chemical treatments will retard the rate of washboarding, but will not prevent it. Nor will they prevent raveling.
  + Materials that are <u>slippery or impassable</u> can be considered for low-traffic volume roads in low rainfall areas if the road can be closed during problem rainfall events. Some chemical treatments can be used to modify or "waterproof" the clay particles causing the slipperiness. Appropriate signs warning of potential slipperiness should be provided.
  + <u>Good but dusty materials</u> can be used with appropriate speed restrictions or a suitable dust suppressant.
- Use the material "as is," but adjust maintenance programs accordingly:
  + Blade the road more frequently to remove erosion channels or washboarding and redistribute raveled material.
  + Close the road during slippery or impassable conditions.
- Seek alternative aggregate suppliers who can provide the requested material.
- Blend two materials to meet the required grading coefficient and shrinkage product. This is often achieved by mixing some of the subgrade or side drain material into the wearing course using a grader or pavement recycler, and then reshaping and compacting the road. Alternatively, add small amounts of clay (e.g., bentonite) to typical base course-type aggregates (i.e., aggregate that meets base course specifications for paved roads) to raise the shrinkage product. Optimal ratios can be determined using Steps 1 and 2 above.
- Use a chemical treatment at higher than normal application rates to provide additional binding to the material, but remember that it is usually cheaper to use fines to fill voids (i.e., meet the grading coefficient and shrinkage product requirements) than to use a chemical.

> It has been clearly shown internationally that roads constructed with materials that are processed to meet the requirements of "good" materials identified in Figure A.7, and when constructed according to specification, result in significant improvements in performance as well as up to 60 percent reductions in gravel loss compared to what are considered more "conventional" strategies *(17)*. Entirely new maintenance strategies have evolved around these findings in road agencies that have adopted this alternative approach *(18,19)*.

A.4.6 Comparing Alternative Approach with FHWA and USFS Guidance

As the previous section made clear, presenting unpaved road material selection parameters as independent grading and plasticity index ranges (e.g., current FHWA and USFS guidance) can be less descriptive and useful than grading coefficient and shrinkage product envelopes in conjunction with a plot of the results (i.e., alternative approach described above), even though the information used in both approaches is derived from the same sources (i.e., grading analysis and Atterberg limit test results). To further illustrate the limitations of using tabulated grading and plasticity ranges for interpreting test results from projects without weighting the plasticity value, the FHWA and USFS guidelines listed in Table A.1 *(4,5)* were analyzed in terms of grading coefficient and shrinkage product. Low, middle, and high ranges were calculated from Table A.1 as follows and the results plotted on the chart in Figure A.19.

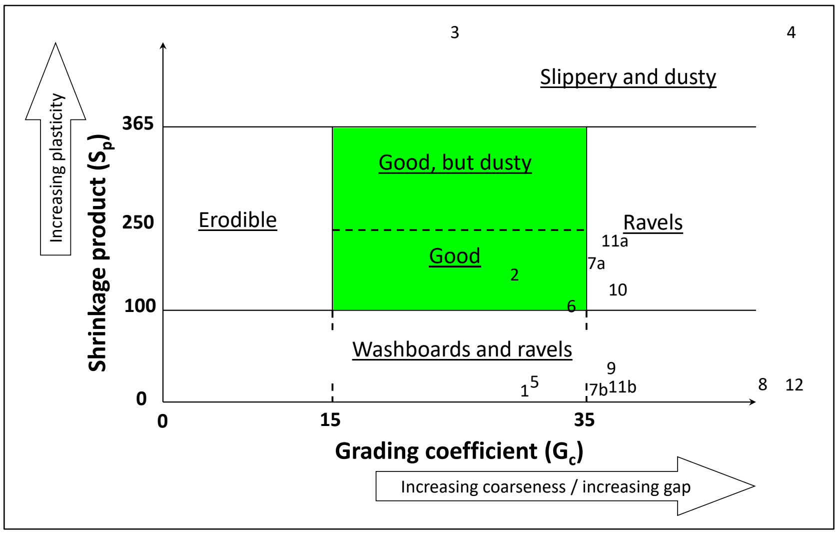


Figure A.19: Plot of FHWA and USFS unpaved road material selection envelopes.

<u>FHWA *(4)*</u>

- Low range of envelopes (number 1 in Figure A.19)
  - Grading coefficient: ((100 – 37) × 50) / 100 = 32
  - Shrinkage product: 2 × 13 = 26
- Mid-range of envelopes (number 2 in Figure A.19)
  - Grading coefficient: ((100 – 52) × 64) / 100 = 31
  - Shrinkage product: 8 × 24 = 192
- High range of envelopes (number 3 in Figure A.19)
  - Grading coefficient: ((100 – 67) × 78) / 100 = 26
  - Shrinkage product: 12 × 35 = 420
- Example worst case (number 4 in Figure A.19)
  - Grading coefficient: ((100 – 37) × 78) / 100 = 49
  - Shrinkage product: 12 × 35 = 420

<u>USFS Haul Roads *(5)*</u>

- Low range of envelopes (number 5 in Figure A.19)
  - Grading coefficient: ((97 – 23) × 43) / 100 = 32
  - Shrinkage product: 2 × 15 = 30
- Mid-range of envelopes (number 6 in Figure A.19)
  - Grading coefficient: ((99 – 28) × 48) / 100 = 34
  - Shrinkage product: 5.5 × 19 = 105

- High range of envelopes (numbers 7a and 7b in Figure A.19)
  - Grading coefficient: ((100 – 32) × 53) / 100 = 36
  - Shrinkage product: 9 × 23 = 207 if percent passing 0.075 mm is <12%
  - Shrinkage product: 1 × 23 = 23 if percent passing 0.075 mm is >12%
- Example worst case (number 8 in Figure A.19)
  - Grading coefficient: ((100 – 23) × 53) / 100 = 41
  - Shrinkage product: 1 × 23 = 23

USFS General Use *(5)*

- Low range of envelopes (number 9 in Figure A.19)
  - Grading coefficient: ((100 – 28) × 51) / 100 = 37
  - Shrinkage product: 2 × 19 = 38
- Mid-range of envelopes (number 10 in Figure A.19)
  - Grading coefficient: ((100 – 34) × 57) / 100 = 38
  - Shrinkage product: 5.5 × 23 = 126
- High range of envelopes (numbers 11a and 11b in Figure A.19)
  - Grading coefficient: ((100 – 39) × 63) / 100 = 38
  - Shrinkage product: 9 × 27 = 243 if percent passing 0.075 mm is <12%
  - Shrinkage product: 1 × 27 = 27 if percent passing 0.075 mm is >12%
- Example worst case (number 12 in Figure A.19)
  - Grading coefficient: ((100 – 28) × 63) / 100 = 45
  - Shrinkage product: 1 × 27 = 27

The chart in Figure A.19 clearly shows that materials selected for a project that meet the guidance listed in Table A.1 may not necessarily perform well when used as wearing course materials on that unpaved road. Only two of the 14 potential material sources are likely to provide good performance. Most of the materials are likely to washboard and/or ravel, leading to expensive maintenance and gravel replacement requirements. Two of the materials are likely to be very slippery and possibly impassable when wet, indicating that the use of a weighted plasticity factor (i.e., multiplying the plasticity index or bar linear shrinkage value by the percent material passing the sieve that the test is conducted on [typically #40 (0.425 mm)]) is very important when interpreting likely performance.

A.5 Effect of Chemical Treatments on Unpaved Road Performance

Unpaved road chemical treatments will agglomerate fine materials and/or provide some level of shear strength improvement or "waterproofing," which in turn can improve all-weather passability. Although the best possible materials should be used for wearing courses on unpaved roads, the use of an appropriate chemical treatment can lead to acceptable performance over a larger range of shrinkage products and grading coefficients due to this agglomeration and/or waterproofing. Expanded expected-performance predictor charts for the different chemical treatment categories are shown in Figure A.20 and can be used to better understand the selection of appropriate treatments for a specific material. Guidance on how various chemical treatment categories perform in terms of the material grading coefficient and shrinkage product is as follows *(10)*:

- Erodible materials: The problems with erodible materials are usually related to grading and/or drainage, both of which are difficult to overcome with chemical treatments. Non-water-soluble polymer emulsions or bituminous-based treatments can be tried on gentle to moderate slopes in combination with drainage improvements. Water-soluble treatments (for example, chlorides and plant-based polymers such as lignosulfonate) will reduce dust but not prevent erosion. Neither will concentrated liquid stabilizers, as the clay content is usually insufficient for a reaction that will bind the particles satisfactorily to prevent the shear action of flowing water. Increased compaction (often enhanced by some of the chemical treatments that also perform as compaction aids) in combination with optimal drainage design and control will also assist in reducing erosion.

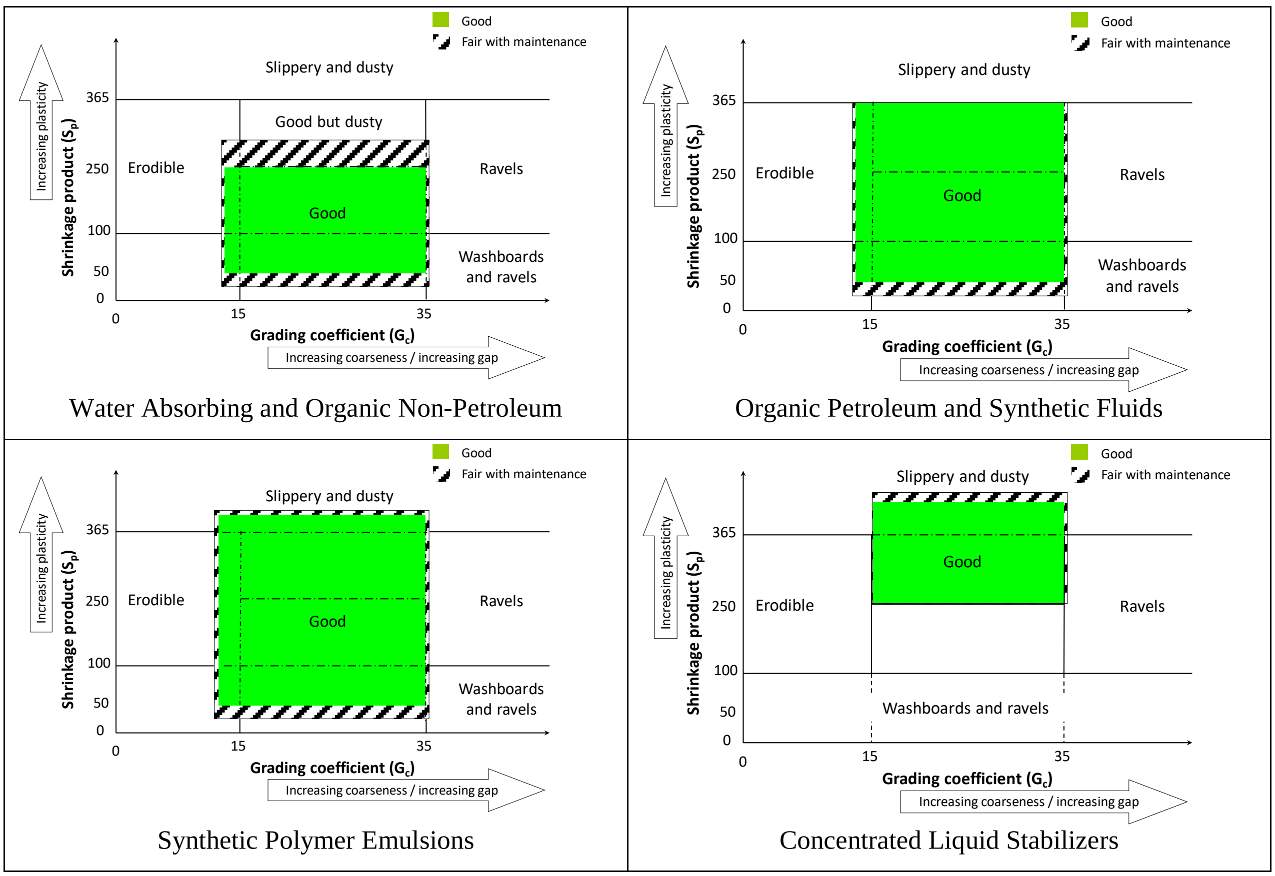


Figure A.20: Expected performance of unpaved roads after chemical treatment.

- Materials that washboard and ravel: These materials lack fines and plasticity. Depending on the traffic, chemical treatments lose effectiveness if the shrinkage product is less than 50 because uneconomically high application rates are required to fill the voids between the particles. Wind-shear and tire-shear forces usually also exceed the binding ability of the treatments used under these circumstances, leading to continued problems. If the shrinkage product is above 50, most chemical treatments except concentrated liquid stabilizers (these products typically require much higher plasticity to react effectively) can be used to improve the materials by enhancing binding, which will lead to significant reductions in dust and washboarding. Incorporating a clay additive or other source of fines (often readily available from adjacent landowners or waste piles at quarries), can be considered to raise the shrinkage product to 50 before applying an appropriate chemical treatment.

- Materials that ravel: Chemical treatments are generally ineffective on these materials because of their coarse- or gap-grading. They will control dust initially, but will not prevent raveling (Figure A.21). Some success may be achieved at very high application rates (i.e., using the chemical to fill the voids before a satisfactory bond is obtained). Alternatively, the addition of the “gap” material can be considered to adjust the grading coefficient before treatment. If the grading is not adjusted, dust levels will increase as the coarse material gets displaced to the side of the road under traffic.

Figure A.21: Raveling on road surface after applying a chemical treatment.

- Slippery or impassable materials: Chemical treatments used on these materials need to either chemically alter the clay minerals to reduce the plasticity or “waterproof” the clay particles to prevent them from expanding/shearing when wet. Synthetic polymer emulsions, synthetic fluids with binders, and concentrated liquid stabilizers can all be considered. Atterberg limits and soaked California Bearing Ratio (CBR) tests should be carried out to check that a suitable reduction in plasticity and/or sufficient increase in soaked shear strength (e.g., CBR) is achieved with the selected treatment before it is applied on the road. Depending on the material grading, it may also be necessary to increase the percentage of coarser aggregate to improve tire/road traction and friction. Chlorides and other water-soluble treatments (e.g., most organic nonpetroleum treatments) should not be considered for treating slippery or impassable materials.
- Good and good but dusty materials: Most chemical treatments can be effectively used on roads with these materials to minimize dust and limit fines loss, reduce the rate of gravel loss, and increase the intervals between grader maintenance. All chemical treatment categories except concentrated liquid stabilizers (clay contents are typically too low for these to work effectively) can be considered.

A.6 Summary

Numerous, often contradictory, specifications and guidance exist for the selection of unpaved road wearing course materials in the United States, and they often provide little information on what research and data were used to compile them. Consequently, it is very difficult for practitioners to decide what specification or guideline to follow to select the most appropriate materials for a given unpaved road project. The discussion in this appendix proposed the use of a simple procedure, using the results from routine, inexpensive laboratory tests, to obtain an indication of the likely performance of unpaved road wearing course materials. The procedure can also be used to select, modify, or compile an appropriate specification (grading envelope and plasticity index combination) if a traditional specification format is required, as well as to guide the selection of chemical treatments.

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APPENDIX A-1: BAR LINEAR SHRINKAGE TEST METHOD

SCOPE

This method covers the determination of the linear shrinkage of soil when it is dried from a moisture content equivalent to the liquid limit to the oven-dry state.

DEFINITION

The linear shrinkage of a soil for the moisture content equivalent to the liquid limit, is the decrease in one dimension, expressed as a percentage of the original dimension of the soil mass, when the moisture content is reduced from the liquid limit to an oven-dry state.

APPARATUS

- Bar linear shrinkage (BLS) mold, stainless steel or brass (Figure A.22), with inside dimensions of 150 mm ± 0,25 mm long by 10 mm ± 0,25 mm wide, and 10 mm ± 0,25mm deep
- Flat stainless steel or brass plate 200 mm by 200 mm by 6 mm
- Flexible spatula, with a blade approximately 100 mm (4 in.) long × 19 mm (0.75 in.) wide
- Pair of dividers and a millimeter scale ruler
- Drying oven, maintained at 110°C ± 5°C (230°F ± 9°F)
- Small, thick-bristle paint brush, about 6 mm (0.25 in.) wide

Figure D.1: Bar linear shrinkage mold.

MATERIALS

- Petroleum jelly
- Distilled or deionized water

PREPARING THE MOLD

Prepare the mold by spreading a thin, even layer of petroleum jelly over inside of the mold using the paint brush. Place the prepared mold on the plate.

PREPARING THE SAMPLE

The bar linear shrinkage test is done on material passing the 0.425 mm (#40) sieve and should be done in conjunction with the Atterberg limit tests (AASHTO T 89 and T 90 or ASTM D4318). The moist soil sample remaining after the completion of the liquid limit test (AASHTO T 89) should be used to form the soil bar. This should be done immediately so that the moist material can be used without further mixing. If insufficient material is available, prepare a new sample as described in AASHTO T 89.

PROCEDURE

1. Fill one half of the mold with the moist soil by taking small pieces of soil on the spatula and pressing the soil down against one end of the mold and working along until the whole side is filled and the soil forms a diagonal surface from the top of one side to the bottom of the opposite side.
2. Turn the mold around and fill the other portion in the same manner.
3. Fill the hollow along the top of the soil in the mold so that the soil is raised slightly above the sides of the mold.
4. Remove the excess material by drawing the blade of the spatula once only from the one end of the mold to the other. Press down on the blade with an index finger so that the blade moves along the sides of the mold. Gently push the wet soil back into the mold with the spatula if it pulls away from the end of the mold during this process. **The soil surface should on no account be smoothed or finished off with a wet spatula.**
5. Air dry the soil bar at room temperature until the soil color starts to change, then place the mold and plate with wet material in the drying oven and dry at a temperature of between 105°C and 110°C (221°F and 230°F) until all shrinkage has stopped and constant mass has been reached. As a rule, the material is dried out overnight (12 hours), but three hours is usually sufficient.
6. Remove the mold and plate from the oven and allow to cool in the air.
7. If the bar has curved after drying, gently press it back into the mold, blow any dust and loose particles away, and then gently push the pieces together at one end of the mold to ensure that the individual pieces fit together tightly but without causing any further abrasion.
8. Measure the length of the dry bar with a steel ruler or dividers together with a steel ruler to the nearest 0.5 mm.

CALCULATIONS

1. Determine the linear shrinkage as a percentage of the original length of the bar using the following formula:

$$LS = 100 \times (L_W - L_D) / L_W$$

where:
L_W = length of the wet soil bar (150 mm)

L_D = length of the dry soil bar in mm

REPORT

Report the linear shrinkage to the nearest whole percent.