Discussion of Aggregate Properties for Untreated Road Surfaces

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Historically, engineers have assumed that an untreated aggregate road surface behaves in substantially the same way as a bituminous paving mixture. Test criteria and construction specifications have been derived by loosening normal bituminous pavement criteria. The paper argues that, although most or all of the properties of aggregate that are important for bituminous applications are also important in untreated surfaces, the relative degrees of importance are probably different. Some additional properties, such as natural cementation used in the design of early macadam pavements, should be revived and studied. A comprehensive review of aggregate properties has never been made to determine whether assumptions based on flexible pavement practices are valid for untreated aggregate surfaces. Some agencies and individuals have made piecemeal investigations. Practical experience suggests that, for most low-volume roads, present practices are only marginally adequate. Present specifications and test criteria are reviewed and commonly specified values are compared with experience, primarily in the Rocky Mountain Region of the U.S. Department of Agriculture Forest Service. Suggestions for revised criteria are offered. The utility of some of the present tests or criteria, as applied to untreated aggregate surfaces, is questioned. Attention is called to the sometimes complex interrelations among several properties.

Most of the road mileage in the world is surfaced with either native soil, naturally occurring sand and gravel, or crushed aggregate. Even in the United States, a major fraction of the road mileage is not hard surfaced. Yet there is almost no technology for the design of untreated aggregate (or gravel) surfaces. Before World War II, aggregate surfaces were often maintained into existence. A minimum thickness of aggregate was placed. When traffic produced mudholes or ruts, these were improved with additional aggregate until the problem was cured. Design was primarily derived from experience and judgment.

More recently, the need for some sort of design approach was recognized. Engineers seem to have begun with the assumption that an aggregate surface is essentially the same as a bituminous concrete surface, except for the color. Flexible pavement design techniques have been applied. Construction specifications are derived from flexible pavement base or surface course specifications, usually by loosening the quality requirements. All of the properties considered important for bituminous mixtures, such as abrasion and gradation, are assumed to be equally important for untreated aggregate surfaces. A systematic effort to determine whether this is actually true has never been made.

On the basis of long experience with the low-volume road system of the Rocky Mountain Region of the U.S. Forest Service, I have concluded that these assumptions are not completely valid. All of the properties usually considered are important; however, their relative degrees of importance are evidently different from those in bituminous surfaces. There is a property, herein called natural cementation, of which little is known at present, that appears to be very significant in the performance of untreated aggregate surfaces. Other important properties or characteristics may currently be little known or as yet undiscovered. In addition, many of the limit values frequently specified are too conservative; others may not be sufficiently restrictive.

This paper breaks no new ground. It is offered to stimulate discussion and, possibly, some new research.

FUNCTIONS OF ROAD SURFACE

A road surface, of any type, must perform several functions. Some of these are as follows:

1. Load distribution and load transfer to the lower layers and the roadbed; surface layer must be strong enough to prevent overstressing of the lower layers;
2. Stability under the three-dimensional loads applied; surface must resist raveling, shoving, rutting, and consolidation caused by vertical, longitudinal, and lateral forces applied by tires;
3. Reasonable smoothness without excessive maintenance;
4. Skid resistance; in aggregate surfaces, this requires both friction between the tires and the surface and the absence of loose gravel that might roll under the wheels;
5. Reasonable control of dust;
6. Maintainability by using normal technique; and
7. Surface drainage to sides or ditches.

A properly designed aggregate surface can fulfill all of these functions economically. Of course, different kinds or volumes of traffic require different designs or points of emphasis. Where high-quality aggregates are in limited supply, they should be reserved for the most heavily used roads and lower-quality material used for the lower-class roads.

PROPERTIES OF AGGREGATES

Standard specifications for aggregates are used by many agencies for some or all of the following reasons:

1. Material that conforms to the specification will usually perform satisfactorily in normal use situations, provided the proper specification is chosen for the project;
2. Sophisticated design or quality assurance testing is not usually feasible for various reasons;
3. Specifications are balanced between ease of production and the ideal; tolerances are broad enough to cover normal production variability and testing accuracy;
4. Items or tests specified are simple enough for easy control in the field; and
5. Materials must not be unusually difficult to handle, place, and compact by using normal construction practices.

Adherence to standard specifications is logical so long as high-quality materials are plentiful in the work area. However, many materials that would perform satisfactorily in service will be rejected or overlooked because they do not completely fit the standard specifications. Some roads will be severely overbuilt with respect to the real need.

Grading

Gradation is perhaps the most important single property of an aggregate because it directly or in-directly affects several other properties and behaviors. Many textbooks present the advantages and disadvantages of the open-graded, dense-graded, gap-graded, and over-sanded (excessive fines) cases (1).

Most modern specifications establish target values for each sieve size and allow a tolerance on each side of the target value. The target values must be selected in relation to the function of the aggregate and the material available in the proposed source. These relations are often overlooked when standard specifications are used arbitrarily. The tolerance should consider the degree of control that can be reasonably expected from a normally well-run production operation and on the skill and intensity of the quality assurance effort. However, the tolerance must also preserve the intent of the designer. For example, the U.S. Forest Service standard specifications (2), which are typical, allow tolerances of 4-15 percentage points on either side of the target value for surfacing aggregates. Many engineers consider a tolerance of 15 percentage points to be excessive.

Of course, individual producers vary in efficiency and one might suspect that those usually associated with low-volume road projects are less efficient than larger operators, on the average. If one tightens the tolerance, he or she should expect to pay for it, because all but the most efficient producers will need to change their operations to conform to the tighter limits. An accurate estimate of the cost per ton of aggregate for each percentage point by which the tolerances are tightened beyond the generally used criteria is difficult, especially when dealing with portable operations and on-site pits. Many engineers think that the improvement in performance derived from aggregates that are very close to the theoretically perfect gradation is worth a significant price increase. Reliable data on production costs relative to specification tolerances for field operations would be valuable.

Likewise, few or no reliable data exist that relate performance and maintenance costs to relatively more or less restrictive construction specifications. The logical assumption is that lower construction quality leads to higher maintenance costs and vice versa. Reasonably accurate data would be valuable.

Cementation

Some aggregates possess a property herein called natural cementation. Cementation was recognized before 1912 (3, pp. 1-3) when a test called the Page Cementing Value was employed in the design of macadam pavements. In a 1916 paper, Lord (3, pp. 1-3) stated that, "The cementing value of road materials is conditioned chiefly by the colloidal products of rock decay and increases in a general way proportionately with these products, reaching a maximum in rocks free of quartz."

After World War I, rubber tires and motorcars rapidly replaced steel tires and wagons, and engineers shifted their attention to the new bituminous and concrete pavements. Cementation apparently disappeared from the literature. Because of a continued lack of attention, the property is not now well understood. The extensive literature on aggregate degradation suggests that the entire subject is extremely complex.

Two cementation test procedures are currently available. Both are inexpensive and simple to perform. Neither is completely satisfactory. Aggregates sent to the Federal Highway Administration (FHWA) laboratory in Denver are tested by using a procedure that is loosely derived from AASHTO T106 (4). A representative portion of the sample passing the number 10 sieve is compacted in three 2-in cube molds at optimum moisture and AASHTO T99 maximum density. After drying to constant weight at 230°F, the three cubes are broken in a compression machine and the average of the strengths is taken as the cementation value, expressed in pounds per square inch.

This test is simple and uses a small sample. However, it tests only the material that passes the number 10 sieve, not the total aggregate. Thus, one must extrapolate from the cementation value to the behavior of the total aggregate. A cementation value of 200 lb•f/in² has been found to be generally satisfactory, but lower values may prove to be acceptable, especially when the total aggregate is very well graded.

The Willamette National Forest uses a procedure based on AASHTO T99, D (5). Fresh portions of the total aggregate are compacted in three T99 cylinders at optimum moisture. After drying to constant weight, they are broken in a compression machine and the average strength taken as the cementation value. A strength of 75 lb•f/in² is considered satisfactory. This test requires more material than the cube test but uses the total aggregate and so should be more representative. However, the FHWA laboratory in Denver has observed severe problems with sample segregation and very wide scattering of data in a trial use of the procedure in a production laboratory. Testing problems could indicate that the gradations used are faulty; however, the procedure should be more fully tested.

Limited attempts have been made to correlate the cementation value with other properties, including the Atterberg limits, sand equivalent, percentage passing the number 40 and 200 sieves, and the dust ratio. No strong correlation was found except that, in about 100 samples, all high cementation values occurred with sand equivalents less than 45. The presence of high cementation values in a number of aggregates that have low or unmeasurable liquid limit and plasticity index (PI) values is conspicuous. The reverse has also been occasionally noted. There may be a weak correlation with the dust ratio. The performance of the aggregate on the road has often been more accurately predicted by the cementation value than by PI.

The evidence and experience strongly suggest that natural cementation is an independent property that could be useful in the design of untreated aggregate surfaces. Research is needed to confirm this, determine the mechanism involved, develop a simple and more reliable test procedure, and establish desirable values based on the performance of road surfaces.

Binder

The term binder has different meanings in different localities. Generally, it can be defined as one or more properties, usually found in soil and aggregate particles finer than the number 200 sieve, that tend to hold the coarser particles in place. Natural cementation just described is probably only one of several such properties.

The need for a binder in surfacing aggregates has been recognized and many specifications define it in terms of a range of desired PI values. PI requirements of 2-4 on the low end of the scale or 9-10 on the upper end are common in the United States, though in other nations much higher upper limits are used. For example, British engineers working for the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in Africa (6) recommend the following PIs for surfacing aggregates:

Climate	PI
Moist temperate and wet tropical	4-9
Seasonal wet and tropical	6-15
Arid	15-30

I think that PIs less than 6 are not significant and values as high as 12-15 are not harmful in most cases. The binding power defined by PI seems to be different from natural cementation, since no correlation between the two has been found.

Abrasion

In the early bituminous pavements, it was thought that abrasion was not important, but research in the last 20 years has shown that all aggregates degrade and the mechanism and products are extremely variable and complicated (3). The Los Angeles abrasion test, AASHTO T96, has evolved and is accepted as a reliable indicator of aggregate response to abrasion and impact, especially under construction handling, placement, and compaction equipment. It does not adequately predict the later chemical degradation and production of plastic fines that occur in some aggregates in the presence of water. Many agencies require a Los Angeles abrasion loss of 40 percent or less for surfacing aggregate. In many areas, this quality is not hard to achieve.

Four major faults with aggregates that have higher abrasion losses are as follows:

1. Shorter service life due to physical degradation; this can be compensated by greater thicknesses or more frequent replacement;
2. Excessively smooth surfaces, sometimes leading to slippery conditions in wet weather; this is also noticed in high PI aggregates; it does not seem serious so long as vehicle tires have a fairly good tread;
3. Excessive dust, which can be controlled with various palliatives; and
4. Surface erosion during rains, which results from the disappearance of coarse aggregate; this can be a local maintenance problem.

In general, the 40 percent maximum for Los Angeles abrasion loss seems valid for arterials and heavily used collector roads. For local roads and collector roads that have small traffic volumes, an acceptable loss of 50 percent is more reasonable. Aggregates that have losses in excess of 50 percent have performed satisfactorily in some cases. When use of such aggregates is planned, the gradation should be made coarser than usual to compensate for degradation of the coarse fragments. Crushing on the road by grid roller is economical and frequently adequate.

In the early years of road building, when dry macadam pavements were common, a certain amount of aggregate abrasion was considered essential to the performance of the pavement. Continued production of fines replaced those lost to dust and rainwash and so maintained the desired dense gradation at the surface. This reasoning, and the frequently observed poor performance of very hard aggregates, suggest that minimum, as well as maximum, Los Angeles abrasion losses should be specified for untreated aggregate surface materials.

Abrasion is influenced by the grading and binding capability of the aggregate. Both open-graded and over-sanded aggregates will experience greater abrasion losses than will the same aggregate in the dense-graded case because the particles in a dense gradation are more tightly bound than those in either of the other cases, and so are less subject to wear.

Durability

Early in the Interstate program, engineers became aware that many pavements were failing long before their anticipated life span, even though they had been well designed and built by using aggregates that met all of the quality standards then in use. An enormous amount of research has shown that all aggregates degrade differently, and some may produce different residues or a greater volume of residue in the presence of water than they do in the dry state. Rocks that produce small amounts of nonplastic fines in the Los Angeles abrasion test may produce a higher volume or highly plastic fines if water is present. These fines are a major cause of bituminous pavement failures, but these same fines usually will improve the performance of an untreated aggregate surface. Wet abrasion tests are still undergoing development, but AASHTO T210 seems to be gaining general acceptance. More work is necessary to establish limit values for acceptable performance, but it seems likely that a maximum durability index, together with a range of abrasion losses, should be specified for untreated surfaces. The limit values remain to be determined.

Dust Ratio

The dust ratio is defined as the ratio of the percentage passing the number 200 sieve to the percentage passing the number 30 sieve. It is a means of controlling the shape of the grading curve in the fine end, since there are often no sieves specified between the number 30 and the number 200. It is possible for an aggregate to be comparatively high in material passing the number 30 and low in the percentage passing the number 200; in other words, gap graded in the area where good grading is important to stability. The usually specified dust ratio of two-thirds helps ensure that the fine fraction of the aggregate is well graded. However, it is often considered to be an unimportant specification and is very frequently ignored in quality assurance testing. The dust ratio should be given more attention.

Sand Equivalent

The sand equivalent (SE) test, AASHTO T176, began as an attempt to develop a shortcut for the Atterberg limit tests in aggregate. It is quick, easy, and reasonably accurate. Though not an exact substitute for the Atterberg limits, an SE value greater than 35 usually correlates with a PI of less than 6. When this is the only item of concern, as in an aggregate for bituminous paving mixture, it is a satisfactory substitution.

However, it is not possible to develop a broad correlation between definite values of PI and SE. Thus, when a minimum PI is specified, a sand equivalent cannot be substituted. The test is not of much use at this time in specifying aggregates for untreated surfaces except that the technique is a part of AASHTO T210. Some evidence exists, though not conclusive as yet, that good values of natural cementation, based on the FHWA test, occur with sand equivalents less than 45 (4).

The sand equivalent also correlates with the percentage passing the number 200 sieve.

Compaction

Engineers working under nonengineering managers are often asked to defend the practice of thorough compaction of untreated aggregate surfaces during construction. We confidently reply that it is well worth the cost because compaction preserves the distribution of fines, prevents segregation, and improves the structural support of the layer--all arguments firmly based on bituminous pavement experiences.

Yet, most aggregate surfaces will fluff or loosen with frost cycles or wet seasons, then settle down again under traffic; this behavior continues throughout the life of the surface. I believe that compaction is beneficial but find it hard to convince skeptics in the absence of positive data. Indeed, many low-volume logging roads are built with only traffic compaction of the surfacing aggregate and seem to perform as well as others built with controlled compaction. If the performance of untreated aggregate surfaces built with and without controlled compaction could be compared with type and volume of traffic, the resulting data would be very useful to engineers and managers.

CONCLUSION

The foregoing shows that the properties of aggregates for untreated road surfaces are complex. Specifications must be influenced not only by the characteristics of the rock but also by the climate, the purpose of the road, and nature and volume of traffic. Many complex interactions occur that are not predictable on the basis of laboratory test procedures. Even the characteristics defined by tests are not independent of each other. Yet, there is a strong tendency for engineers who are not well trained in materials to look at each property in a list of specifications as an abstract value and discard or modify those that do not seem satisfactory without consideration of the effects of that property on the overall behavior of the aggregate. This discussion presents no firm recommendations for numeric values because I do not have access to research facilities and personnel. The values cited are based on observation and experience in a particular environment. The objective of this discussion has been to call attention to some of the considerations involved and to stimulate some systematic investigations directed specifically at untreated aggregate road surfaces.

Safety, maintenance cost, user cost, economy, and riding quality all are affected by the aggregate used. Current research, particularly the huge Brazil project (_7_, pp. 304-340), is showing that fuel consumption and user costs in general are more strongly related to road surface conditions, especially smoothness, than has been recognized up to this time even with untreated surfaces. Long experience has proven that small investments in investigation, design, and quality assurance pay big dividends. However, many road-building agencies are caught in a personnel and budget squeeze that makes such work difficult or impossible. With renewed interest in low-volume roads, rapidly inflating costs, decreasing availability of quality aggregates, and tight environmental controls, it is no longer reasonable to ignore the design factors involved in untreated aggregate surfaces. We must understand the properties of aggregates and derive highly efficient specifications for even very low standard roads.

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Fabric-Reinforced Aggregate Roads–Overview

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The purpose of this paper is to present an overview of the use of fabrics in aggregate-surfaced roads. Specific areas addressed in the paper are (a) general performance characteristics of aggregate-fabric-soil (AFS) systems, (b) mechanisms that contribute to the fabric-related benefits, (c) various factors that exert a major influence on the performance of AFS systems, and (d) methods of analyzing and designing AFS systems. Data and information sources used in the discussion include pertinent literature and results from a study being conducted in the School of Civil Engineering at the Georgia Institute of Technology. Based on the discussion presented in this paper, use of an interlayer of fabric in an aggregate-surfaced road can lead to either better performance or to substantial reductions in aggregate layer thickness. It is also shown that the behavior of AFS is complex and difficult to analyze with theoretical models. Although numerous thickness design methods are available, most are for specific commercial fabrics and are empirical in nature. No general design procedure is available that can accommodate a variety of fabrics of widely differing properties and, thus, it is difficult for potential fabric users to make economic decisions in selecting fabrics and design thicknesses for various job requirements.

Synthetic engineering fabrics or geotextiles have become increasingly important in civil engineering applications in recent years. The main applications include drainage, erosion control, separation, and reinforcement. Fabrics that perform these functions are termed geotextiles and are defined by the American Society for Testing and Materials (ASTM) as any permeable textile used with geotechnical materials as an integral part of a man-made project, structure, or system.

In railroad and highway support systems, fabrics