LOW COST ASPHALT PAVEMENTS AND BASES EMPLOYING LIQUID ASPHALTS

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INTRODUCTION

STATEMENT OF THE STUDY

The construction or improvement of the road network is rightly regarded as one of the most effective ways of promoting economic development of a country. The state of a road network in a country and its economic development are therefore closely linked, and it is correct to say that the former is one of the conditions for the latter. The road must be designed to meet the needs in order to ensure the best return for the efforts made. Therefore, the road engineers have to discover how they can make the best use of their available resources, particularly the natural materials which can always be bought at a low price.

Low cost roads can be constructed by employing liquid asphalts, together with the naturally available mineral aggregate. Keeping this point in view, this report deals in how the liquid asphalts and mineral aggregate can be combined to produce economical pavements. The different liquid asphalts are explained, with brief discussions of their manufacture and application. Mineral aggregate is the most important part of an asphalt pavement, therefore it is shown which type of aggregate and how it is used in such flexible pavements. A brief description of the tests and specification of mineral aggregates is also given.

Soil stabilization is frequently used whenever it is necessary to improve the quality of the soil material in use. In this report, soil stabilization with asphalt is discussed, including the laboratory investigations that are in practice. How to make bases from soil treated with asphalt is explained next, that is, granular and cohesive soils. In the end two methods for constructing economical asphalt pavement surfaces are discussed. This report is limited to only rural roads, including, however, certain urban or suburban roads which have a rural character.

PURPOSE OF THE STUDY

With the development of modern road building machinary, it has become a regular affair to construct the less trafficed local rural roads in almost the same manner as the high type flexible pavements. This always results in spending an extra amount of finances, which otherwise can be saved if the methods for constructing low cost pavements were followed. The purpose of this report is to review all the pertinent literature, and put forward the different methods and uses of asphalt treated soil, in order to construct economical pavement bases and surfaces.

SCOPE OF THE STUDY

The scope of this study includes: a fairly intensive review of the pavement materials used in the construction of low cost roads, covering both the asphaltic materials and the mineral aggregates; soil-asphalt stabilization along with the required laboratory investigations; a discussion of asphalt treated pavement bases for cohesive, non-cohesive, and mixed soils; and two methods explaining the construction of economical asphalt pavings, namely, plant-mix and road-mix.

REVIEW OF LITERATURE

ASPHALT PAVEMENT MATERIALS

The materials used in the construction of a road are of intense interest to the highway engineer, who is always very deeply concerned with the properties of the materials being used. All roads have to be founded on the soil, and all require the efficient usage of locally available materials if economically-constructed facilities are to be obtained. This requires not only a thorough understanding of the soil and aggregate properties which affect pavement stability and durability, but also of the properties of the binding materials which may be added to improve these pavement features. Since here we are dealing with low-cost asphalt pavements, therefore we consider only the liquid asphalts. The liquid asphalts used are cutback asphalts, that is, rapid-curing (RC), medium-curing (MC), and slow-curing (SC), and emulsified asphalts, obtained by the combination of asphalt cement and water.

LIQUID ASPHALTS

In low-cost paving work, it is particularly convenient to work with an asphalt that is in liquid form at relatively low temperatures as compared to asphalt cement. Here, such liquid asphalts are discussed, like, the rapid-curing and medium-curing cutback liquid asphalts, the slow-curing cutback asphalts (road oils), and asphalt emulsions. The cutback materials are formed by combining with asphalt cement the volatiles obtained from the first distillation stage in the production of asphalt. Road oils are simply very soft (or liquid) asphalt cements, produced in the same manner as asphalt cement. Asphalt emulsion is obtained by physically combining asphalt cement with water, another method for obtaining a relatively free-flowing, liquid asphalt.

CUTBACK LIQUID ASPHALTS

In the manufacture of cutback liquid asphalts, a solvent is added to asphalt cement, which results in a liquid material that can be handled with equipment without the use of high temperatures. After the material is in place, it can revert to a normal penetration asphalt cement after the volatile component evaporates, that is, by the process of curing. Rapid-curing (RC) cutbacks are made by diluting with a typical naphtha or gasoline a base asphalt having a penetration ranging from 70 to 110 at 77°F. By using a base asphalt of this consistency, the asphalt residue that remains after loss of volatiles will have a penetration ranging from 80 to 120 at 77°F. Careful control of the naphtha or gasoline diluent will keep the flash point of the material above 80°F.

Medium-curing (MC) cutbacks are manufactured by diluting a base asphalt having a penetration of 70 to 250 at 77°F with a kerosene-type diluent. After a distillation test an asphalt residue having a penetration of 120 to 250 must be left. Thus, there are two important differences between RC and MC liquid asphalts. Rapid-curing cutbacks have a hard-base asphalt and a solvent that will evaporate at low temperatures, resulting in a material that will cure rapidly. The medium-curing cutbacks have a softer-base asphalt and a less volatile solvent and thus will cure at a slower rate than RC materials. Either one of these distinguishing characteristics might be the basis of choice of material for a given use. For example, in the construction of a surface treatment in a northern region, one might well choose the medium-curing cut-back material because of its softer-base asphalt. The higher penetration-grade asphalt residue that would remain after the material had cured would become less brittle in winter and thus the surface treatment would be less

Table I Specifications for rapid-curing (RC) liquid asphalts*

Characteristics	AASHO test method	ASTM test method	Grades: RC-70	RC-250	RC-800	RC-3000
Kinematic viscosity at 140°F, cs†	T 201	D 2170	70–140	250–500	800–1,600	3,000–6,000
Flash point (open tag.), °F	T 79	D 1310	......	80+	80+	80+
Distillation						
Distillate (percent of total distillate to 680°F):						
To 374°F	T 78	D 402	10+	......	......	......
To 437°F			50+	35+	15+	......
To 500°F			70+	60+	45+	25+
To 600°F			85+	80+	75+	70+
Residue from distillation to 680°F, percent by volume			55+	65+	75+	80+
Tests on residue from distillation:						
Penetration, 77°F, 100 g, 5 sec	T 49	D 5	80–120	80–120	80–120	80–120
Ductility, 77°F, cm	T 51	D 113	100+	100+	100+	100+
Solubility in carbon tetrachloride, %	T 44‡	D 4‡	99.5+	99.5+	99.5+	99.5+
Water, %	T 55	D 95	0.2−	0.2−	0.2−	0.2−

General requirement: The material shall not foam when heated to application temperature recommended by the Asphalt Institute.

Note: When the heptane-xylene equivalent test is specified by the consumer, a negative test with 35% xylene after 1 hr will be required, AASHO T 102.

* From Asphalt Institute [5].

† As an alternate, comparable Saybolt-Furol viscosities may be specified.

‡ Except that carbon tetrachloride or trichloroethylene is used instead of carbon disulfide as solvent, method 1 in AASHO T 44 or procedure 1 in ASTM D 4.

Table 2 Specifications for medium-curing (MC) liquid asphalts*

Characteristics	*AASHO test method*	*ASTM test method*	*Grades*				
			MC-30	*MC-70*	*MC-250*	*MC-800*	*MC-3000*
Kinematic viscosity at 140°F, cs‡	T 201	D 2170	30–60	70–140	250–500	800–1,600	3,000–6,000
Flash point (open tag.), °F†	T 79	D 1310	100+	100+	150+	150+	150+
Distillation							
Distillate (% of total distillate to 680°F):							
To 437°F			25−	20−	0–10	....	....
To 500°F	T 78	D 402	40–70	20–60	15–55	35−	15−
To 600°F			75–93	65–90	60–87	45–80	15–75
Residue from distillation to 680°F, % by volume			50+	55+	67+	75+	80+
Tests on residue from distillation							
Penetration, 77°F, 100 g, 5 sec	T 49	D 5	120–250	120–250	120–250	120–250	120–250
Ductility, 77°F, cm§	T 51	D 113	100+	100+	100+	100+	100+
Solubility in carbon tetrachloride, %	T 44¶	D 4¶	99.5+	99.5+	99.5+	99.5+	99.5+
Water, %	T 55	D 95	0.2−	0.2−	0.2−	0.2−	0.2−

General requirement: The material shall not foam when heated to application temperature recommended by the Asphalt Institute.

Note: When the heptane-xylene equivalent test is specified by the consumer, a negative test with 35% xylene after 1 hr will be required, AASHO T 102.

* From Asphalt Institute [5].

† Flash point by Cleveland open cup may be used for products having a flash point greater than 175°F.

‡ As an alternate, comparable Saybolt-Furol viscosities may be specified.

§ If penetration of residue is more than 200 and its ductility at 77°F is less than 100, the material will be acceptable if its ductility at 60°F is 100+.

¶ Except that carbon tetrachloride or trichloroethylene is used instead of carbon disulfide as solvent, method 1 in AASHO T 44 or procedure 1 in ASTM D 4.

subject to cracking. Also when an asphalt deteriorates to a penetration of less than 40, it becomes particularly susceptible of cracking, and the soft base of an MC material would take longer to deteriorate to a penetration of less than 40.

Conversely in the deep South, the choice might well be a rapid-curing cutback in order to obtain a harder-base asphalt. The harder-base asphalt should provide a more stable surface treatment under high summer temperatures. Thus, in these examples, the differences in curing rate were ignored. However, there can be circumstances when the choice would be made on the basis of curing rate, depending upon the particular circumstances of the job. It might be important that the material cure very rapidly so that traffic could proceed quickly on the new surface treatment or so that the damaging effects of a rainstorm could be avoided. On the other hand, owing to the nature of the project, it may be important to delay curing in order to allow time for sufficient rolling of the stone in the surface-treatment application; thus, a medium-curing cutback might be selected.

Cutback liquid asphalts are graded by viscosity. For many years it has been questioned whether so many grades of cutback liquid asphalts are needed. Also it has been felt that there would be less confusion if the grading viscosities were based upon a single temperature. As a result, the majority of state specifications now base the cutback liquid asphalt grading system on the kinematic viscosity test. This viscosity test is run at 140^{o}F for all grades of cutbacks. In this grading system, both RC and MC asphalt cutbacks are in the following grades: 70, 250, 800, and 3000. In addition, the MC is often specified for a grade 30. These numbers refer to the minimum of an allowable range of viscosity as determined by the kinematic viscosity test, in the units of centistokes. The grade 70, for example, has a kinematic viscosity range of 70 to 140 cs at 140°F. In each grade the top viscosity limit is double the minimum grade designation. For example, grade 3000 has a range of 3,000 to 6,000 cs. A cutback asphalt provides a means of using an asphalt of the desired viscosity, curing rate, and, at the end of the curing process, having residual asphalt of the desired penetration. The specifications for these materials are well standardized, obtaining similar materials from different manufacturers is not difficult.

SLOW CURING LIQUID ASPHALTS

Road oils, or the slow-curing liquid asphalts originally were manufactured by straight-run distillation and in every sense of the word were liquid-asphalt cements; that is they were manufactured in the same manner as asphalt cements except that the distillation process was cut off earlier so that many of the lubricating oil fractions remained in the asphalt residue. In more recent years, the slow-curing road oils (SC) are actually cutback asphalts, but instead of being asphalt cements cut back with a highly volatile solvent such as naphtha or kerosene, they are merely asphalt cements fluxed with some of the nonvolatile oils that are taken off in the second stage of the distillation process.

The same grades of SC liquid asphalts exist as for RC and MC materials; thus an SC-70 will have the same viscosity as an MC-70 or an RC-70. However, as can be seen from the method of manufacture, the SC road oil material differs from the other cutback liquid asphalts. The road oils are used primarily in the upper Midwest and Far Western regions of the United States. Principal uses are in road-mixing and dust-laying applications. They are also used in stockpile patching mixes, plant mixing with graded aggregates, and occasionally for priming. They are particularly useful in the type of road work where construction involves seasonal tearing and relaying of the existing SC oil mat.

Table 3 Specifications for slow-curing (SC) liquid asphalts*

Characteristics	*AASHO test method*	*ASTM test method*	*Grades* SC-70	SC-250	SC-800	SC-3000
Kinematic viscosity at 140°F, cs†	T 201	D 2170	70–140	250–500	800–1,600	3,000–6,000
Flash point (Cleveland open cup), °F	T 48	D 92	150+	175+	200+	225+
Distillation:						
Total distillate to 680°F, % by volume	T 78	D 402	10–30	4–20	2–12	5–
Float test on distillation residue at 122°F, sec.	T 50	D 139	20–100	25–110	50–140	75–200
Asphalt residue of 100 penetration, %	T 56	D 243	50+	60+	70+	80+
Ductility of 100 penetration asphalt residue at 77°F, cm	T 51	D 113	100+	100+	100+	100+
Solubility in carbon tetrachloride, %	T 44‡	D 4‡	99.5+	99.5+	99.5+	99.5+
Water, %	T 55	D 95	0.5–	0.5–	0.5–	0.5–

General requirement: The material shall not foam when heated to application temperature recommended by the Asphalt Institute.

Note: When the heptane-xylene equivalent test is specified by the consumer, a negative test with 35% xylene after 1 hr will be required, AASHO T 102.

* From Asphalt Institute [5].

† As an alternate, comparable Saybolt-Furol viscosities may be specified.

‡ Except that carbon tetrachloride or trichloroethylene is used instead of carbon disulfide as solvent, method 1 in AASHO T 44 or procedure 1 in ASTM D 4.

EMULSIFIED ASPHALTS

An asphalt emulsion is a mixture of asphalt and water where asphalt is usually the dispersed phase and water the continuous phase. Asphalt emulsification is merely another means of liquefying an asphalt for use. There are many advantages in the use of asphalt emulsions, such as: can be used with cold as well as hot aggregate, can be used with aggregate that is dry, damp, or wet. It also eliminates the fire and toxicity hazards that attend the use of cutback asphalts. Emulsions also have disadvantages, one of which is that they are easily subject to washing by rain. Also, their manufacture is not as standardized as that of other liquid asphalts.

Emulsions are made by mechanically dispersing a hot asphalt cement in water that has been treated with an emulsifying agent. This is usually accomplished by a colloid mill, which in principle consists of a high-velocity rotating element within a stationary cylinder. Emulsifying agent can be any one of a variety of soaps that are introduced along with water and asphalt in the mill, which breaks the asphalt into colloid-size particles. Usually the emulsifying agent is polar in nature, resulting in an emulsion with certain electrical surface characteristics. For normal asphalt emulsions the penetration-grade asphalts ranging from 50 to 300 penetration are used.

The two most commonly used types of emulsified asphalts are anionic and cationic. The type of asphalt emulsion is determined by the kind of emulsifying agent or soap used. The organic part of the emulsifier, adheres to the asphalt particle and imparts a positive or negative charge to the surface of the asphalt-emulsifier complex. With an anionic emulsion this asphalt surface charge is negative and for a cationic emulsion it is positive. There are three general grades for each of the two common types of emulsions. These

Table 4 Specifications for anionic emulsified asphalts*

Characteristics	AASHO test method	ASTM test method	Grades: Rapid setting RS-1	Rapid setting RS-2	Medium setting MS-2	Slow setting SS-1	Slow setting SS-1h
Tests on emulsion							
Furol viscosity at 77°F, sec	T 59	D 244	20–100	....	100+	20–100	20–100
Furol viscosity at 122°F, sec			....	75–400	....	....	......
Residue from distillation, % by weight			57+	62+	62+	57+	57+
Settlement, 5 days, % difference			3−	3−	3−	3−	3−
Demulsibility:							
35 ml of 0.02 N $CaCl_2$, %			60+	50+	....	....	......
50 ml of 0.10 N $CaCl_2$, %			....	....	30−	....	......
Sieve test (retained on No. 20), %			0.10−	0.10−	0.10−	0.10−	0.10−
Cement-mixing test, %			....	....	....	2.0−	2.0−
Tests on residue							
Penetration, 77°F, 100 g, 5 sec	T 49	D 5	100–200	100–200	100–200	100–200	40–90
Solubility in carbon tetrachloride, %	T 44†	D 4†	97.5+	97.5+	97.5+	97.5+	97.5+
Ductility, 77°F, cm	T 51	D 113	40+	40+	40+	40+	40+

* From Asphalt Institute [5].

† Except that carbon tetrachloride is used instead of carbon disulfide as solvent. Method 1 in AASHO T 44 or procedure 1 in ASTM D 4.

Table 5 Specifications for cationic emulsified asphalts*

Characteristics	AASHO test method	ASTM test method	Grades					
			Rapid setting		Medium setting		Slow setting	
			RS-2K	RS-3K	SM-K	CM-K	SS-K	SS-Kh
Tests on emulsion								
Furol viscosity at 77°F, sec	T 59	D 244	....	....	....	....	20–100	20–100
Furol viscosity at 122°F, sec	T 59	D 244	20–100	100–400	50–500	50–500	....	......
Residue from distillation:								
Residue, % by weight	T 59	D 244	60+	65+	60+	65+	57+	57+
Oil distillate, % by volume of emulsion	T 59	D 244	5−	5−	20−	12−	....	......
Settlement, 7 days, % difference	T 59	D 244	3−	3−	3−	3−	3−	3−
Sieve test (retained on No. 20), %	T 59†	D 244†	0.10−	0.10−	0.10−	0.10−	0.10−	0.10−
Aggregate coating—water resistance test	.....	D 244						
Dry aggregate (job), % coated			....	....	80+	80+	....	......
Wet aggregate (job), % coated			....	....	60+	60+	....	......
Cement-mixing test, %	T 59	D 244	....	....	....	....	2−	2−
Particle charge test	T 59A	D 244	Positive	Positive	Positive	Positive	....	......
pH	T 200	E 70	....	....	....	....	6.7−	6.7−
Tests on residue								
Penetration, 77°F, 100 g, 5 sec	T 49	D 5	100–250	100–250	100–250	100–250	100–200	40–90
Solubility in carbon tetrachloride, %	T 44‡	D 4‡	97.0+	97.0+	97.0+	97.0+	97.0+	97.0+
Ductility, 77°F, cm	T 51	D 113	40+	40+	40+	40+	40+	40+

* From Asphalt Institute [5].
† Except that distilled water is used instead of sodium oleate solution.
‡ Except that carbon tetrachloride is used instead of carbon disulfide as solvent, method 1 in AASHO T 44 or procedure 1 in ASTM D 4.
Note: (1) "K" in grade designations signifies cationic type.
(2) In medium setting grades:
"SM" indicates sand mixing grade.
"CM" indicates coarse-aggregate mixing grade.

grades are, rapid-setting (RS), medium-setting (MS), and slow-setting (SS). The rate of setting is controlled by the amount and type of emulsifying agent used.

Although all three grades of emulsions are produced in at least two viscosity ranges, the choice of grade depends upon the use to which the emulsion is put. Occasionally RS emulsions are used for very light seal coats. Basically RS emulsions are rather unstable, that is they contain relatively little emulsifying agent and slight disturbance will cause them to break or set. Thus, this emulsion cannot be used where it would be exposed to a large amount of aggregate surface area. Medium-setting grades of asphalt emulsions are used for mixing with fairly open-graded aggregates and can be used for penetration work in which the liquid asphalt is permitted to penetrate through a layer of aggregate, for seal coats and for surface treatments. These emulsions are more stable than those of the RS type; they contain more emulsifying agent and will not set up before mixing and compacting operations are completed when open-graded aggregates are used.

Slow-setting emulsions are used whenever high mixing stability is required. A common use of SS emulsions is in road mixes where the emulsion is mixed with existing roadbed material that may be granular but that may have many fines. The large amount of surface area presented to the emulsion by the fines would cause either an RS or an MS emulsion to break or set before construction could be completed. Only an emulsion with the amount and type of emulsifying agent to produce great stability is capable of this kind of work.

TESTS FOR LIQUID ASPHALTS

There are many tests used to control the quality of liquid asphalts. The kinematic viscosity test (ASTM D 2170) is used on liquid asphalts to test their viscosity. This viscosity test is essentially the same for liquid asphalts as for asphalt cements, the major difference being the temperature, which is 140°F instead of 275°F.

The test for distillation of cut-back asphaltic products, ASTM D 402-67, is a test that is performed to determine the type and quantity of both the volatile distillate and the asphalt residue of cutback asphalts and slow-curing road oils. Approximately 200 ml of material to be tested is placed in a distillation flask and a distillation process is carried out by heating the material according to a prescribed procedure. In the case of RC and MC materials, quantities of distillate are recorded for temperatures of 374°F, 437°F, 500°F, 600°F, and 680°F, at which time the test is terminated. For SC road oils, the only measurement made is at the 680°F level. For emulsified asphalt the 200 gm sample of emulsion is distilled in an iron still to a temperature of 500°F.

The Float test for asphalt materials, ASTM D 139-49, is a consistancy test that is used for materials that are too soft for the standard penetration test and generally too hard for use with the Saybolt-Furol viscosity test. The Cleveland open-cup flash-point test (ASTM D 92-66) is normally specified for slow-curing road oils and occasionally for the higher-viscosity medium-curing cutbacks. These flash-point tests are used to determine the temperature to which asphalt materials may be safely heated. Water content of asphalt materials is determined by the test for water in petroleum and other asphalt materials, ASMT D 95-62. As far as liquid asphalts are concerned, the purpose of the test is to determine the purity of the product. In the water content test for emulsified asphalt, a smaller sample is taken because of the large amount of water present in an asphalt emulsion.

MINERAL AGGREGATES

Mineral aggregates are the basic materials of highway pavement construction. In asphalt pavements they constitute 88-96% by weight, or something more than 75% by volume. Therefore, their influence on the properties and performance of asphalt mixes is great. There are many types of asphalt mixtures; still, it is possible to formulate a concept of an ideal aggregate for most uses. The ideal aggregate would have proper particle size and gradation, be strong and tough, and consist of angular, nearly equidimensional or "chunky" particles with moderatley low porosity and surfaces that are clean, rough, and "hydrophobic". Aggregate size, gradation, strength, toughness, and shape are primarily for stability, as with base-course materials. However, porosity and nature of the aggregate surface are important to aggregate-asphalt interaction. The asphalt must adequately cover the aggregate and adhere to the aggregate surface. Coverage without the use of excessive asphalt material may be difficult for highly porous aggregates, or, with adequate coverage, an excessive amount of volatiles in the asphalt may be absorbed by the aggregate.

A lack of proper asphalt-aggregate adhesion may occur with smooth aggregate surfaces of very low porosity or those that do not bond well to asphalt because of surface chemistry. Adhesion is particularly important during periods when the mix is exposed to water. If the aggregate is of a type that wets easily with water, water may successfully compete with the asphalt for adsorption onto the aggregate surface and aggregate-asphalt separation, known as stripping, results.

It is known that, as control over quality and gradation of mineral aggregate is decreased, the overall cost of the pavement is decreased too. Therefore, it depends upon the type of pavement; a cheap pavement would not require strict control over quality and gradation of aggregate, while a high type would definitely require. Certain general requirements should be met by all mineral aggregates for pavements. For example, those given by AASHO for dense-graded asphalt plant-mix surface course (AASHO designation M62-64) are representative:

> Aggregates shall be of uniform quality, crushed to size as necessary, and shall be composed of sound, tough, durable pebbles or fragments of rock or slag with or without sand or other inert finely divided mineral aggregate. All material shall be free from clay balls, vegetable matter and other deleterious substances, and an excess of flat or elongated pieces. Slag shall be air-cooled blast-furnace slag of reasonably uniform density and quality. Excess of fine material shall be wasted before crushing.

A typical specification for mineral aggregates for road mix is that of the Illinois Division of Highways. It requires that 100% pass the 1½ inch sieve, 90-100% pass the 1 inch, 60-90% pass the ½ inch, 35-55% pass the No. 4, 10-40% pass the No. 16, and 4-12% pass the No. 200. From this example we can see, how fairly broad the range is set for mineral aggregates, or in other words how less stringent controls are applied.

SIZE AND GRADATION

Depending upon the use or purpose of the mix, a wide variety of sizes and gradations of aggregate may be used. Asphalt mix used for the surface of heavily traveled roads generally contains densely graded aggregate, that is, materials that are well graded from coarse to fine. In actual practice the specifying engineer should be acquainted with the gradation that the local aggregate producers are capable of economically producing and should select a gradation that will show satisfactory results in the laboratory and the field.

STRENGTH AND TOUGHNESS

Since the aggregate in an asphalt mixture supplies most of the mechanical stability, it must have a certain amount of strength and toughness to prevent breakdown under traffic and subsequent loss of stability. Open-graded mixes, for a given load, are probably subject to greater forces of breakdown than aggregate in dense-graded mixes. Thus, when working with a material with minimal strength or crushing resistance, a denser gradation perhaps would be more desirable than one which is open graded. The most commonly used test for measuring the strength and toughness of an aggregate, is the Los Angeles Rattler Test (AASHO designation T96-731). This test is both an impact and an abrasion test.

PARTICLE SHAPE

Particle shape is another very important property. Angular aggregate characteristics give aggregate interlock properties that increase the stability of open-graded materials. In fact, it is very difficult to use well-rounded gravels in an open-graded asphalt mixture because of the lack of stability of the resulting mix. Additions of crushed angular fine aggregate have produced marked increases in stability in all types of mixes.

When rounded gravels must be used to produce highly stable surface mixtures, generally the specification will require that a certain percentage of the coarse aggregate be crushed. A typical specification might require a minimum of 40% of the particles retained on the No. 4 sieve to have at least one fractured face. It is known that crushing rounded gravels adds significantly only to the stability of one-sized aggregate mixes, to open-graded mixes a very little, and to mixes that are dense graded, not at all. Thus gradation control would seem to be most important in the production of a highly stable gravel surface mixture. In most cases, thin and elongated aggregate pieces are also potentially troublesome.

POROSITY

Porosity is of less importance than other properties of aggregates in asphalt mixtures, but it strongly affects the economics of a mix. Except for the requirements of a certain amount of porosity available in an aggregate so that proper adhesion between the aggregate and asphalt will result, high porosities generally do not affect the quality of a mix. However, the higher the porosities, the more asphalt will be absorbed into the aggregate, thus causing a higher percent asphalt required in the mix design.

SURFACE TEXTURE

A rough finish on an aggregate surface makes it more difficult for forces imposed by the pavement loadings to cause the displacement of one particle upon another. Surface texture is also important to adhesion between the aggregate and asphalt material. A smooth glossy aggregate is easy to coat with an asphalt film but offers little adhesion to hold the film in place. Thus, the rougher the surface texture, generally the higher the stability and durability of the asphalt mixture. The crushing of rounded gravels not only produces a more desirable particle shape but also produces a rougher surface texture.

SURFACE CHEMISTRY

The surface chemistry of aggregate particles plays an important role in the design of asphalt mixtures. One of the problems involving aggregates in asphalt mixtures is the stripping of the aggregate from the asphalt during service. The greater the attraction the asphalt has for the aggregate, the less likely that water will get between the film of asphalt material and the aggregate particle, thus permitting the aggregate particle to be whipped out from the surface by the action of traffic.

The term hydrophobic is generally applied to aggregates that have great attraction to asphalt. The basic aggregates, such as limestone, are generally more easily wetted by asphalt than water, and these aggregates are called hydrophobic aggregates. Perhaps a better description as revealed by more recent research is to say that these aggregates are electropositive in nature; that is, they have a positive surface charge which tends to repel water. This so-called dislike of water is implied in the term hydrophobic.

Acidic or siliceous aggregates, such as quartz, more often than not are wetted more easily by water than by asphalt. They are termed hydrophyllic or water-liking, and the term electronegative is now being applied to such aggregates.

SPECIFIC GRAVITY

The specific gravity of aggregates is quite important from the standpoint of mixture calculations such as for the determination of void contents in compacted asphalt mixtures.