EVALUATION OF MINERAL FILLERS FOR ASPHALT PAVING MIXTURES

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Rigden's fractional volume voids was used in the evaluation of three fillers. The filler of specified weight (10 g) is compacted in a small cylinder under a definite compactive effort given by a rammer (350 g in weight) falling from a fixed height (4 in.) a specified number (100) of times. After compaction, the volume of voids in the compacted bulk volume of filler is calculated and is expressed as a fraction of unit volume. The amount of asphalt in excess of the volume of voids in the compacted filler is used by Rigden as a measure of the stiffness of the filler-asphalt mix. In the compaction of asphalt and filler to form a mastic, the asphalt content imparts a fluid or solid character to the mix. Observation of the behavior of a mixture of asphalt with different types of fillers leads to the concept that a portion of the asphalt gets fixed up in the inter- or intra-granular pores of the filler forming a solid phase with the filler, and the excess asphalt, termed fluid phase, acts as a binder on the solid phase. Maximum stiffness results as a particular proportion of the fluid phase or excess asphalt. If the demand for additional asphalt, because of the inclusion of the fine aggregate, is kept constant, the comparison of the optimum binder (filler and asphalt) contents for maximum strength of sheet-asphalt mixes can be made in terms of the optimum fluid phases for the filler-asphalt mastics alone.

•MOST of the asphalt paving specifications in use today specify the inclusion of fine powders, such as portland cement, that are referred to as mineral fillers.

Although the quantity of a filler for a paving mix is specified as a percent fraction of the aggregate, no distinction is drawn among the fillers on the basis of physical characteristics such as fineness, specific gravity, and surface area. Because it is difficult to assess the effectiveness of a filler in quantitative terms based on these individual properties, a simple filler characteristic that bears a direct relation to its performance in a paving mix is of significant value. Rigden's fractional volume voids is one such characteristic.

The present investigation refers to the study of three fillers with different fineness characteristics that were evaluated by Rigden's test for use in paving mixes. The differences in the effectiveness of the fillers are interpreted in terms of Rigden's fractional volume voids. It has been observed that, by comparing the dry compaction characteristics of fillers, the optimum filler content of a given filler for a paving mix can be ascertained without resorting to strength tests.

Fillers are included in paving mixtures to impart greater stability and strength. As the literature on this subject indicates, there are two viewpoints to explain the stabilizing influence of fillers. According to the first one, filler (because of its fine particle size distribution) serves to fill the voids in the fine aggregate or coarse and fine aggregate combinations, thereby increasing the density and strength of the compacted mixture. The second viewpoint presumes that the fine particles of filler become suspended in the asphaltic binder forming a mastic. The suspended filler particles adsorb

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asphalt components, giving rise to increased viscosity of the binder and, consequently, to tougher mixes.

It is reasonable to presume that, in the case of any filler, both functions come into play. Either of the two functions predominates, depending on the characteristics of the aggregate, the fineness characteristics of the filler, and the relative proportions of filler and asphalt in the mix.

EVALUATION OF FILLERS FOR PAVING MIXTURES BY RIGDEN'S TEST

Regardless of which is the predominant function, what must be known is the extent to which a filler affects the strength and stability of a paving mix. A simple filler characteristic that bears a direct relation to its performance in a paving mix is of essential value. Studies by other investigators (1, 2) toward such an end have indicated that, in a general way, the influence of a filler on an asphaltic binder can be assessed by their bulking or packing properties. Researchers have expressed this in various ways, for example, by the bulk density in benzene and the fractional volume voids in dry compacted filler. Rigden, who devised the latter test, claimed (3) that it gives a direct indication of the viscosity of filler-asphalt mixtures for all types of fillers. Heukelom (4) explained the quantitative differences in the effects of fillers on paving mixtures with the help of this test parameter.

The fractional voids test is one in which filler of a specified weight (10 g) is compacted in a small cylinder under a definite compactive effort given by a rammer (350 g in weight), falling from a fixed height (4 in.), for a specified number (100) of times. After compaction, the volume of voids in the compacted bulk volume of filler is calculated and expressed as a fraction of the unit bulk volume.

OPTIMUM ASPHALT CONTENT FOR A FILLER-ASPHALT MASTIC

The packing properties of a filler depend on its physical and geometric properties, such as particle shape, size distribution, and surface texture. Under a given compaction, a filler will enclose some voids depending on these properties. If filler and asphalt are mixed and compacted to form a mastic, the asphalt will go into the voids of the filler. If the quantity of asphalt is less, a stiff dry product is obtained without adequate bond between the filler particles. If the asphalt content is excessive, it imparts a fluid character to the mixture. The amount of asphalt in excess of the volume of voids in the compacted filler is adopted by Rigden as a measure of the stiffness of the filler-asphalt mix. Mixtures of asphalt with different types of filler gave a rather uniform viscosity when this excess amount of asphalt was of the same proportion of the total volume of filler and asphalt in each case, irrespective of the actual volumes of fillers used. This concept supposes that a portion of the asphalt gets fixed up in the inter- and intra-granular pores of the filler, forming a sort of solid phase with the filler, and the excess asphalt, which may be termed the fluid phase, acts like a binder on the solid phase. This is shown in Figure 1A.

It is obvious that a filler with large compacted bulk volume fixes up a large proportion of asphalt because of the large fraction of voids in it; the same proportions of solid and fluid phases can be obtained (and, hence, the same stiffness according to Rigden) where a small quantity of the former is sufficient when mixed with the same quantity of asphalt. It then remains to be seen at what proportions of solid and fluid phases a filler-asphalt mastic gives the maximum stiffness. The following reasoning appears to be valid in this connection.

When the asphalt content is just sufficient to fill the voids in the compacted filler (that is, when the fluid phase is zero), the mix cannot have the maximum stiffness because, in this condition, the amount of asphalt is not adequate to envelop the filler particles fully. The asphalt only occupies the void spaces available in the particles. The increased stiffness of a filler-asphalt mastic over simple asphalt must be partly due to the filler particles adsorbing layers of asphalt around them (1, 5). This condition can be achieved by coating fully the filler particles. In this case, more asphalt is needed than is necessary just to fill the voids. On the other hand, if the asphalt content is too much, the coated filler particles cannot have close packing but are pushed apart and kept floating in the abundant asphalt, thus decreasing the stiffness of the mix. It may be construed that, when the amount of excess asphalt is of such a proportion as to coat the filler particles fully and permit a close packing of them, the mix offers maximum resistance to deformation. A greater or lesser asphalt content results in a weaker mix. This means that the maximum stiffness results at a particular proportion of the fluid phase or excess asphalt. This may be termed the optimum fluid phase (Fig. 1B).

Optimum Binder Content for a Paving Mix

A filler-asphalt mastic, proportioned to have maximum stiffness in accordance with the preceding plan when mixed with fine aggregate (as in the case of this investigation) to form a paving mix, does not impart maximum strength to the mix because the asphalt content that was just adequate to coat the filler particles and to fill its voids would now be required to coat the particles of fine aggregate and fill the additional voids created by its inclusion. This would create a deficit in the asphalt content, lowering the strength. In terms of functional volumes, it means that the inclusion of sand has increased the solid phase, and, for maximum strength of the mix, the asphalt content and the fluid phase should correspondingly be increased. It may be construed that, in this case, the fluid phase or excess asphalt has to serve as a binder to the sand, filler, and fixed-asphalt solid-phase system.

In the present investigation, the amount and grading of sand are kept the same for all the sheet-asphalt mixes prepared with different filler-asphalt mastics. The increased solid phase in each case is thus the same, and the excess asphalt necessary to cover the increased solid phase for maximum strength of sheet-asphalt mixes is also the same. If the demand for additional asphalt, because of the inclusion of the fine aggregate, is kept constant, the comparison of the optimum binder (filler and asphalt) contents for maximum strength of sheet-asphalt mixes can be made in terms of the optimum fluid phases for the filler-asphalt mastics alone.

Study Purpose and Scope

The object of this investigation is to ascertain whether the reasoning given previously is valid and to assess Rigden's test as a tool for evaluation of fillers for paving mixtures.

For this purpose, three fillers with different fineness characteristics were selected and used in sheet-asphalt mixtures. The sheet-asphalt mixtures were designed on a volumetric basis, so that each one of them has the same volumes of sand and binder (filler and asphalt). Thus, the voids in the sand were filled by a fixed volume of filler and asphalt, regardless of the proportions of filler and asphalt (F-A ratios) in the mixes. Six different mixes were formed with each filler by varying the F-A ratio within the constant volume of filler-asphalt binder.

In order to eliminate densification as a variable, all the mixes were compacted to have the same volume fraction of air voids by using different compactive efforts.

It was felt that creep tests, rather than quick tests like Marshall stability, would reveal the influence of the binder more appropriately. The sheet-asphalt mixtures, formed into cylindrical specimens, were thus tested in unconfined compression creep, under four different loads. The minimum rates of deformation from the creep curves were taken as a measure of the mixture resistance to the applied loads.

The fractional voids content for each of the three fillers was determined by Rigden's test. These values were used to determine the functional volumes (the solid and fluid phases) for the filler-asphalt binder of each of the sheet-asphalt mixtures. The binders of those mixes giving maximum resistance to deformation with each of the fillers were then compared in terms of their functional volumes.

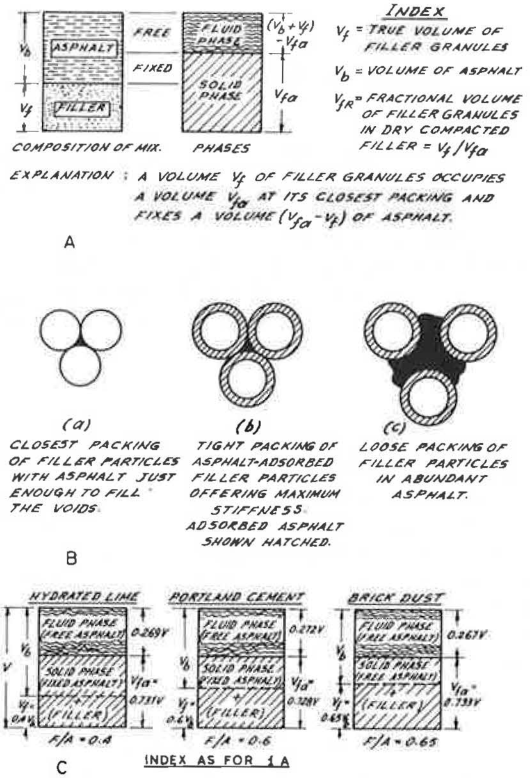


Figure 1. Basic concepts of fractional voids in a filler-asphalt system.

Table 1. Physical properties of mineral fillers.

Filler	Specific Gravity	Specific Surface Area[a] (cm^2/g)	Bulk Density in Benzene (g/cm^3)	Fractional Void Volume in Dry Compacted State[b]	Percent <0.001 cm
Hydrated lime	2.408	3,965	0.267	0.609	42
Portland cement	3.114	2,765	0.625	0.485	22
Brick dust	2.738	1,375	0.833	0.463	6

[a] Determined by using Blaine's air permeability apparatus.
[b] Determined by using Rigden's fractional voids test.

Table 2. Compositional and physical properties of sheet-asphalt mixtures.

Filler	F-A Ratio by Volume	Mix Composition, Percent by Volume of Total Mix[a]: Aggregate	Binder (filler and asphalt)	Air Voids	Bulk Specific Gravity of Compacted Specimens[a]	Functional Volumes, Percent by Volume of Filler and Asphalt: Solid Phase	Fluid Phase	Minimum Rate of Strain Min^{-1} × 10^{-6}, at Applied Stress of: 17.5 psi	35 psi	52.5 psi	70 psi
Hydrated lime	0.2	65.0	30.0	5.0	2.11	42.6	57.4	5.5	23.5	46.9	92.0
	0.3	65.1	30.0	4.9	2.14	59.0	41.0	1.4	8.0	20.0	42.7
	0.4	65.0	30.0	5.0	2.16	73.1	26.9[b]	0.8	5.1	13.3	29.4
	0.45	65.0	30.0	5.0	2.17	79.5	20.5	1.1	6.0	15.7	34.9
	0.5	65.0	30.0	5.0	2.18	85.3	14.7	2.5	10.6	25.1	47.6
	0.55	65.0	30.0	5.0	2.19	90.8	9.2	3.7	15.7	34.7	54.5
Portland cement	0.3	65.1	30.0	4.9	2.19	44.8	55.2	9.1	108.0	364.0	1,040.0
	0.4	65.0	30.0	5.0	2.22	56.5	43.5	5.7	56.0	250.0	670.0
	0.5	65.0	30.0	5.0	2.25	64.8	35.2	4.1	39.6	128.0	400.0
	0.6	65.1	30.0	4.9	2.28	72.8	27.2[b]	2.2	21.3	75.0	202.5
	0.7	65.0	30.0	5.0	2.30	80.0	20.0	2.8	26.5	87.5	262.5
	0.8	64.7	29.8	5.5	2.31	86.4	13.6	3.2	28.7	99.0	310.0
Brick dust	0.4	65.0	30.0	5.0	2.19	53.2	46.8	15.8	208.0	1,040.0	2,470.0
	0.5	64.9	29.9	5.2	2.21	62.0	38.0	9.2	101.6	483.0	1,347.0
	0.6	64.9	29.9	5.2	2.23	69.8	30.2	4.7	52.1	260.0	600.0
	0.65	64.9	29.9	5.2	2.24	73.3	26.7[b]	4.3	37.5	205.0	500.0
	0.7	64.9	29.9	5.2	2.25	76.7	23.3	5.1	55.7	296.0	620.0
	0.8	65.0	30.0	5.0	2.27	82.8	17.2	7.8	87.5	375.0	1,250.0

[a] Average test values for three specimens.
[b] Optimum binder content.

EXPERIMENTAL PROCEDURES

Materials

In this study, filler is considered as the fraction of the material passing the No. 200 sieve. The fillers used were hydrated lime, portland cement, and brick dust. The physical properties of the fillers are given in Table 1.

The asphalt cement used was Mexphalte, an 80 to 100 penetration grade asphalt.

The fine aggregate was a locally available river sand. The fraction of the sand passing the No. 200 sieve was removed by sifting; it was not included in the sheet-asphalt mixes. All of the fraction that is finer than the No. 200 sieve was thus contributed by one of the three fillers.

Preparation of Mixtures

Uniform gradation of sand in all the mixtures was achieved by sifting the sand into respective sizes and recombining by weight to get a size distribution that conforms closely to type VIIIa (fine sheet) Asphalt Institute classification.

All the mixtures were designed to contain 30 percent of binder (taken as filler and asphalt), 65 percent of sand, and 5 percent of air voids by total volume of the mix. While maintaining these constant proportions, volumetric F-A ratios were varied within the constant volume of filler-asphalt binder.

The mixtures were formed into cylindrical specimens 2 in. in diameter and 4 in. in height. The specimens were prepared by heating calculated quantities of aggregates and asphalt separately to 325 and 300 F respectively and then combining them in a mixing operation for a period of 2 min. The mixture was placed in a molding cylinder in three layers, each rodded 25 times with a small metal rod. Then, it was compacted in a static load compression machine, and the load was maintained for 1½ min on both faces. The specimens were compacted to a constant height of 4 in., with the help of a mark on the plunger, thus ensuring the stipulated volume percentages of aggregate, binder, and voids. However, small differences in heights of specimens were observed after extrusion from the molds because of variations in specimen rebound. These were responsible for the slight variations in the volume proportions of the mixture components (Table 2). The use of different proportions of filler and asphalt in the different mixes necessitated variations in the compacting pressures (which ranged from 1,000 to 5,000 psi) to achieve constant volumes for the specimens. The specimens, after extrusion from the molds, were allowed to cure in air at a temperature of about 80 F for 2 days before testing. The volumes of the specimens were determined by using the water displacement method, and their weights were obtained for bulk specific gravity calculations and determination of voids.

The compositional and physical properties of the mixtures are given in Table 2.

Creep Tests

Two Soiltest consolidometers were adapted for applying static loads on the specimens. The tests were carried out in an air-conditioned room, and the temperature was held at 85 F during the period of testing.

The deformations were measured at chosen time intervals ranging from 6 sec elapsed time to 12 hours or until the specimens failed, in cases of earlier failure.

The sheet-asphalt specimens were tested for creep under four constant loads corresponding to 17.5, 35, 52.5, and 70 psi. Six different mixtures were formed with each filler corresponding to six different F-A ratios. Because the filler-asphalt volume is kept constant for all the mixes, very low percentages of filler, especially in the cases of portland cement and brick dust, resulted in mixes that were too plastic and yielded too quickly under the applied loads to give accurate results. On the other hand, higher F-A ratios, particularly with hydrated lime, gave mixes that were very dry and unworkable. The F-A ratios with each of the fillers were thus suitably selected so as to include at least two concentrations on either side of that giving the maximum resistance to deformation. The F-A ratios utilized in the study are given in Table 2.

Figure 2. Strain versus time at different concentrations of hydrated lime filler.

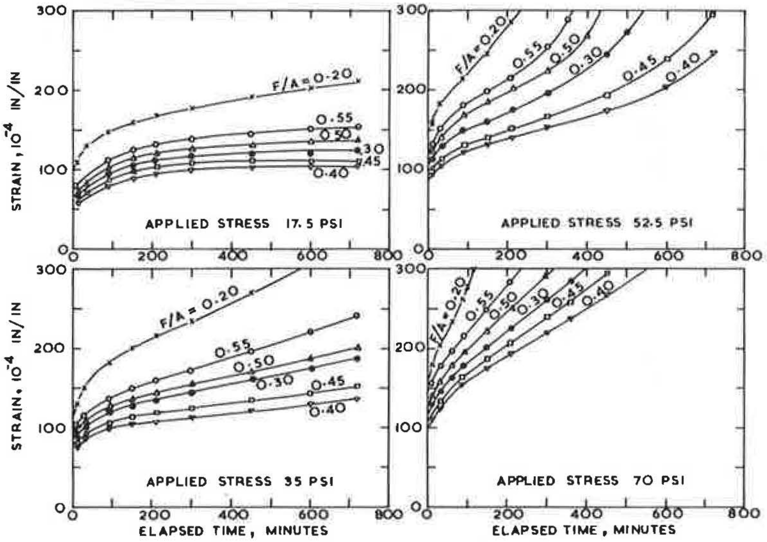


Figure 3. Strain versus time at different concentrations of portland cement filler.

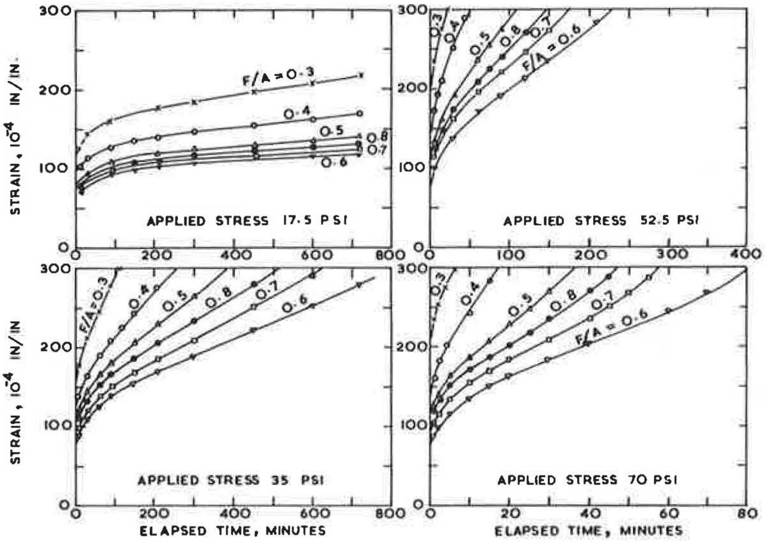


Figure 4. Strain versus time at different concentrations of brick dust filler.

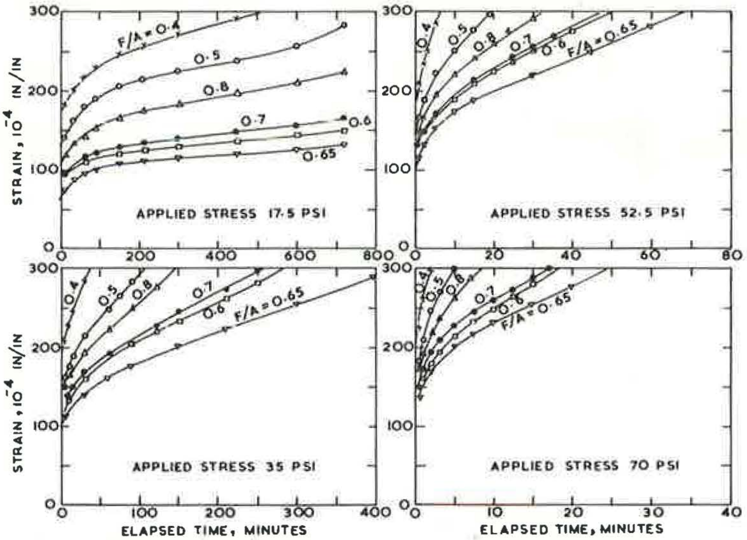
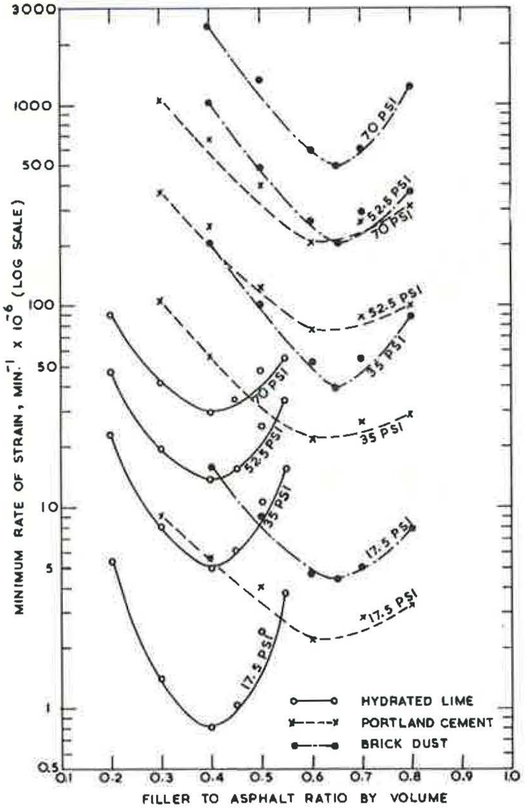


Figure 5. Relation between minimum rate of strain and F-A ratio under different stresses.



Voids in Dry Compacted Filler

Void content in each of the fillers in the dry compacted state was determined according to BS 812 with an apparatus fabricated to the specifications laid therein. Values of the fractional void content in unit bulk volume of the compacted filler are given in Table 1 for the different fillers.

Other Physical Properties of Fillers

The particle size distributions of the fillers, which were determined by a hydrometer, are not shown here, but the percentages of fillers finer than 10 microns are given in Table 1.

The surface areas of the fillers were determined by Blaine's air permeability apparatus according to ASTM C 204-51.

The bulk densities of the fillers in benzene were determined according to BS 812.

These physical properties of the fillers are given in Table 1.

ANALYSES OF TEST RESULTS

The time-versus-strain data obtained from the creep tests on the different mixes under the four different loads are shown in Figures 2 through 4. The minimum rate of strain for each of the mixes under the different loads is given in Table 2. Figure 5 shows the minimum rate of strain and the F-A ratio for the three fillers under the different loads.

It is observed that, under any of the loads, the maximum resistance to deformation has occurred at a particular F-A ratio with each of the fillers. This ratio, which may be called the optimum F-A ratio, is 0.4 for hydrated lime, 0.6 for portland cement, and 0.65 for brick dust.

The fluid phase or excess asphalt calculated for the filler and asphalt binder volume for each of the mixes is given in Table 2. It is observed that the fluid phase at the optimum F-A ratio is 26.9, 27.2, and 26.7 percent for hydrated lime, portland cement, and brick dust respectively. The functional volumes (the solid and fluid phases) at the optimum F-A ratio for the three fillers are shown in Figure 1C.

It suggests that, with the chosen fine aggregate and type of asphalt, any of the fillers gives the maximum resistance to deformation when the filler and asphalt are proportioned so as to yield nearly 27 percent of excess asphalt. However, it may be noted that the minimum rate of strain (corresponding to maximum strength) at the optimum F-A ratio is different for the different fillers. These differences among the fillers could be due to other properties such as chemical composition. What then is the use of Rigden's test? The use of Rigden's test lies in interpreting the optimum F-A ratio for maximum resistance of a sheet-asphalt mixture with any filler, in terms of the optimum F-A ratio with a known filler, by comparing dry compaction characteristics alone, without resorting to strength tests. Regardless of the absolute strengths that result by using different fillers, the optimum F-A ratio with any of the fillers is dependent on an optimum proportion of the excess asphalt necessary for the chosen aggregate fraction and can be ascertained by Rigden's fractional volume voids test.

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