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16. Abstract

The characteristics of mineral filler materials have been investigated to determine their potential in upgrading the performance of asphaltic concrete, especially by increasing hot-mix stability and durability to alleviate problems with rutting and shoving.

Three phases of testing were conducted. These included (1) testing of mineral fillers alone, (2) testing asphalt cements, and (3) testing of mastics composed of mineral filler and asphalt cements.

Both the testing of the fillers alone and testing of the asphalt cement-mineral filler mastics revealed significant differences among the different fillers and filler blends. These differences are believed to portend important differences among hot-mixes constructed using the different mineral filler types. Based on previous research and the limited work done in this substudy, the use of certain mineral fillers offers enhanced opportunity for increased stiffness and strength in asphalt concrete.

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Evaluation of Several Mineral Fillers for Use in Item 340 Hot-Mix Asphaltic Concrete

by

Fred C. Benson
and
D. Fred Martinez

Research Report 285-3

May 1984

Cooperative Research Project
2-9-80-285

"Asphalt Concrete Mixture Design
and Specifications"

Sponsored by

State Department of Highways and Public Transportation
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College Station, Texas

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EXECUTIVE SUMMARY

To establish testing schedules, and procedures and to learn about materials for potential use in hot-mix asphalt concrete, the Texas State Department of Highways and Public Transportation (SDHPT) initiated a mineral filler substudy as part of Cooperative Research Project 2-9-80-285 titled "Asphalt Concrete Mixture Design and Specifications." Fourteen mineral fillers submitted by SDHPT districts were tested according to recommended test schedules and procedures in J. O. Izatt's "Orientation Testing Program" taken from his Filler Manual (2).

The 14 filler materials were tested using most of the tests recommended by Izatt in his Orientation Testing Program. Some potentially valuable tests were not conducted because of various substudy constraints, and the inclusion of these tests in future research work is recommended. In spite of the limited scope of in the substudy, valuable experience was gained in running and evaluating tests for mineral fillers, and worthwhile information was also gathered about the nature of the submitted filler materials.

Three of four phases of the Orientation Testing Program were accomplished. These included testing of the mineral fillers and blends of fillers alone, testing asphalt cements and testing of mastics composed of mineral filler and asphalt cement. The fourth

phase that was not reached is that of using mineral fillers in laboratory compacted specimens of hot-mix and subsequent testing of these specimens.

Both the testing of the fillers alone and testing of the asphalt cement-mineral filler mastics revealed significant differences among fillers and filler blends. These differences are believed to portend important differences among hot-mixes constructed using the various mineral filler types. Based on previous research and the work done in this substudy, it is believed that the use of certain mineral fillers will increase the stiffness and strength of asphalt concrete.

INTRODUCTION

As part of Study 2-9-80-285 titled "Asphalt Concrete Mixture Design and Specification", the Texas State Department of Highways and Public Transportation (SDHPT) included an investigation of the characteristics of mineral filler materials. The major purpose was to determine how the use of these materials could upgrade the performance of the SDHPT's Item 340 hot-mix asphaltic concretes, especially in the area of increasing hot-mix stability and durability and thus alleviating problems with rutting and shoving.

Mineral filler for use by the SDHPT is specified in Section 340.2 (d) of the 1982 Standard Specifications (1) as follows:

> ". . .Mineral filler shall consist of thoroughly dried stone dust, slate dust, portland cement, fly ash or other mineral dust approved by the Engineer. The mineral filler shall be free from foreign matter.
>
> Fines collected by baghouse or other air cleaning or dust collecting equipment may be permitted as mineral filler in the asphaltic mixture up to 2 percent, provided that the passing No. 200 master gradation limit is not exceeded. When these fines are permitted in the asphaltic mixture, they shall be introduced in the same manner prescribed for other mineral fillers."

Furthermore, the SDHPT defines the grading characteristics of allowable fillers by specifying in the same section as above that:

"When tested by Test Method Tex-200-F (Part 1 or Part III, as applicable), it shall meet the following grading requirements, unless otherwise shown on the plans:

	Percent by Weight or Volume
Passing No. 30 sieve	95 to 100
Passing No. 80 sieve, not less than.	75
Passing No. 200 sieve, not less than	55"

In his unpublished report on mineral fillers for the SDHPT, Izatt (2) defines a mineral filler as follows: "Filler is defined as a finely divided material all of which passes a No. 200 sieve (0.074). Filler is included in the mineral aggregate gradation specifications for most asphalt paving mixtures. Wide experience teaches that its use can improve the mechanical and durability properties of the pavement. Filler can influence the behavior of the paving mixture during spreading and compacting." Izatt emphasizes that "The primary role of the filler is to stiffen the asphaltic paving mixture under controlled conditions" (2). Definitions of different catagories of fillers as listed by Izatt are given in Appendix A.

Concerning stiffening effects, Izatt states that "In general, the stiffening effects of filler are related not only to the amount but to the type and characteristics of the filler. These characteristics have been described in terms of the following test properties: Specific Gravity, Particle Size Distribution, Geometric Characteristics, Specific Surface, Surface Activity [and] Plasticity Index" (2).

Izatt's Filler Manual (2) summarizes the current usage of mineral fillers by transportation agencies including the following entitites: Texas, Arkansas, Louisiana, Oklahoma, New Mexico; American Society for Testing and Materials (ASTM), American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA). This manual contains six chapters which are titled as follows:

1. "Introduction -
   Definitions and Descriptions
   Conventional Specification Requirements
   Performance Type Specifications
   Special Fillers"
2. "Proposed Laboratory Testing Schedules. . ."
3. "Test Methods and Equipment for
   Characterizing the Filler, Asphalt, Mastic
   and Pavement Mixes"
4. "Filler and Voids in the Asphalt
   Paving Mixture"
5. "Equipment and Handling Methods
   for Filler at the Hot Mix Plant"
6. "An Outline. . ."

The second and third chapters above are especially pertinent because they served as guides for the mineral filler testing work that was accomplished in deriving data for this report on evaluation of mineral fillers for use in hot-mixes. The second chapter "Proposed

Laboratory Testing Schedules. . ." contains the suggested schedules for the 'Orientation Testing Program' to be used for testing mineral fillers. This orientation program was intended to be an initial "shake down" or prototype testing in which (1) mineral fillers would be evaluated (2) test results and test procedures and (3) the adequacy of tests used and the need for additional test methods determined. This initial testing program thus served as a beginning reference to evaluate several mineral fillers for use in hot-mix. It also served to establish the usefulness of the proposed tests and procedures.

OBJECTIVES

The objectives of this substudy on the evaluation of selected mineral fillers for use in SDHPT Item 340 hot-mix asphaltic concrete are summarized as follows:

1. It was desired to test and evaluate several mineral fillers submitted by the SDHPT districts to determine the suitability of the testing program and procedures in the "Orientation Testing Program" as outlined by Izatt (2) for determining the potentially beneficiating effects of fillers.
2. If the program and some test methods as outlined in the Filler Manual (2) were deficient, needed revising or required replacement, the efforts of the substudy would serve to reveal the needs and the corrective measures.
3. Materials properties of the proposed mineral fillers submitted by the districts would be documented and the potential suitabilies of these for use as enhancing mineral fillers in hot-mixes would be indicated. These properties would be determined in three phases: from the mineral fillers only, from filler-asphalt mastics and from fillers used in laboratory molded hot-mix specimens.
4. The direction and scope of future mineral filler testing and research work would be indicated.

Because of constraints in Study 285 time and funding available, the above purposes or objectives were not met as fully as was desired. However, interesting properties and test results were revealed as a result of the work that was accomplished under this mineral filler substudy.

MATERIALS TESTED

Table 1 lists the materials tested in this substudy for potential usage as mineral fillers. Actually, three of the materials submitted by SDHPT District 11 had been tested in their laboratory for potential use as "mineral fillers" or "filler additives" (as defined in Reference 2) in test sections (3), and probably all of the limes in Table 1 have been used as "filler additives" (to preclude stripping). The limestone and iron ore fines are "filler" (by definition in (2)). The fly ashes and silica rock flour can be termed "special fillers" (2).

An interesting item in Table 1 is the calcium carbonate fines material furnished by Texas Lime Company, from their Cleburne, Texas, plant. This material is a natural by-product from the manufacture of lime. Apparently, at the Texas Lime Company plant, this material accumulates in copious quantities and there seems (as of 1983) to be no great demand for the material.

It was the initial intention of this substudy that all of the materials listed in Table 1 be run through all of the pertinent parts of the Orientation Testing Program from Reference 2. However, this complete testing was not accomplished so a good comparison of the properties of all of these materials among themselves was not obtained.

TESTING PLANS - PROPOSED AND ATTAINED

These testing plans are shown in four Tables 2 through 5. The general description of the test type is shown in the left column in each table. The proposed testing is based on Izatt's Orientation Testing Program (2) and constitutes the middle column of each of these tables. The right column contains the actual test method and test method number used.

Table 2.

This table illustrates the proposed and accomplished testing on the individual filler materials. All materials in Table 1 were subjected to the actual testing done as listed in the right column of Table 2. No specific surface or surface activity testing was achieved in this mineral filler substudy although it is believed that the relatively expensive surface activity testing using the microcalorimeter would have yielded some very valuable data.

Table 3.

No testing as proposed in this table was specifically accomplished under this substudy. Instead, data were obtained from that published annually by Division 9 of the SDHPT (17) for the asphalt cements used in this work. Only two sources and grades of asphalt cement, AC-10's from Kerr-McGee and Oklahoma Refining Co., were actually combined with mineral filler materials submitted by District 3 in mastics for subsequent evaluation.

Table 4.

As samples to be prepared and tested as shown in this table, only 10 different mastics were actually prepared and tested. Five mastics involved varying blends of District 3 limestone fines with District 3 fly ash and Kerr-McGee AC-10 asphalt cement, and five consisted of the same blends of District 3 limestone fines and District 3 fly ash with Oklahoma Refining AC-10. Only the first five mastics received all the testing listed in Table 2C; the penetration and softening point tests were obtained for the second five mastics. The squeeze film viscosimeter test for apparent viscosity, η, was accomplished on all of the 10 mastics.

Table 5.

No testing listed in this table was accomplished on laboratory compacted hot-mix specimens containing the mineral fillers.

TEST DESCRIPTIONS

Most of the tests listed as used in Tables 2 through 5 are widely employed by the SDHPT (4), (5), (6), (7), (8), (9), (10). However, several are not widely used and these are discussed further in the following sections.

Voids in Mineral Filler by Kerosene Absorption

This test is listed in Table 2. The test method was developed by Warden, et al. (11) to correlate with the Rigden procedure (12). Its purpose is to determine the ratio of the volume of filler material to that of the bulk volume. The relationship of the volume of filler material to the bulk volume is given as follows:

$$V_{fk} = 0.97\ V_{fr} \quad (1)$$

where

V_{fr} = volume percent of filler by Rigden method and

V_{fr} = volume percent of filler by kerosene method.

In the testing for the voids in mineral filler by kerosene absorption, a dish of approximately hemispherical shape and 5 inches (13 cm) in diameter is used. Twenty grams of dry, cool mineral filler material is placed in the dish, and kerosene is gradually and continuously added to the filler. The filler material and kerosene are vibrated and moved around the dish by shaking with a rotary motion. The mineral filler powder will continue to absorb the kerosene as it is added and the mineral filler-kerosene will form a ball due to the surface tension of the kerosene. The test end point is reached when the capacity of the ball to hold additional kerosene is exceeded and a smear shows on the side of the dish.

The volume of voids in 100 grams of the mineral filler are therefore equal to five times the volume of kerosene used in the 20 grams of material. The percent voids of the bulk mineral filler is then easily calculated using the kerosene voids and the specific gravity of the mineral filler solids.

Figures 1 and 2 show the actual dish used for testing and several of the mineral filler balls achieved in the testing. The dish photographed is an easily obtainable porcelain item commonly used in laboratory testing.

Squeeze Film Viscosimeter

An actual testing apparatus was fitted together by TTI personnel from existing and purchased materials to form a "squeeze film viscosimeter" or "parallel plate transverse flow viscosimeter" based on information contained in research by Dienes et al. (13) and Manning et al. (14). A device of this nature has seen some use in the roofing and mastic industries for measuring the influence of filler types and amounts on the viscosity of mastic systems (2). Its applications for testing mastics involved in highway paving could be promising based on the nature and work done in this mineral filler substudy.

Figures 3 and 4 are photographs showing this device as built by TTI. A brief description of the test procedure is given below.

In preparation for the test, samples of mineral filler and asphalt cement are mixed together at 250°F (121°C) and poured into molds to form approximately 57.1 mm diameter by 3.8 to 4.9 mm-thick coupons. These are allowed to cool to room temperature. Prior to testing, the mastic is brought to 104°F (40°C) for 1 hour; then it is placed between the squeeze film viscosimeter plates which have been brought to 104°F (40°C) also. The top plate, 57.1 mm in diameter, is then loaded to 11.5 lbs (5.216 kgf) and brought to bear on the top of the testing mastic coupon which rests on the bottom plate. An initial average height, h_0, of mastic is taken at time = zero. The load is left to bear for 30 minutes at a temperature of 104°F (40°C), and a final average mastic height, h_f, is taken.

Based on the data obtained from testing, including geometry, pressure and time, a dynamic viscosity, η, can be calculated for the mastic tested as follows:

$$\eta = \frac{4\ g\ M\ t}{3\pi R^4 \left(\frac{1}{h_f^2} - \frac{1}{h_0^2}\right)} \qquad (2)\ (\underline{14})$$

where

η = dynamic viscosity in poises (pascal-seconds),

g = acceleration due to gravity of 980.6cm/sec^2,

m = the mass on the upper plate or M = weight on upper plate divided by g or 5216 grams force divided by 980.6cm/sec^2,

t = the time of test, 1,800 seconds,

R = the radius of the upper plate or 2.855 cm,

h_o = initial thickness of the specimen, cm, and

h_f = final thickness of the specimen after 30 minutes testing at 104^oF (40^oC), cm.

The mastics used in the squeeze film viscosimeter tests were prepared based on the kerosene voids values obtained for the mineral fillers or mineral filler blends tested. Thus, if the kerosene voids were computed to be 40 percent, then the solid volume of the specimen consisted of 40 percent asphalt cement and 60 percent filler. All efforts were made to remove any entrained air from the mastic specimens, thus achieving a voidless system of filler material and mastic.

Penetration Index

The rheological (flow or deformation) properties of paving asphalts for most practical purposes are widely indicated by their penetrations at 77^oF (25^oC) and viscosities at 140^oF (60^oC) before and after the TFOT (Thin Film Oven Test) or RTFOT (Rolling Thin Film Oven Test). Therefore, the Penetration Index, PI, test as called for in Table 3 may be calculated either by equation or by nomograph. To calculate the PI by equation, the following relationship is used.

$$PI = \frac{30}{1 + 90PTS} - 10, \qquad (3)(15)$$

where

$$PTS = \frac{Log_{10}800 - Log_{10}Pen\ @\ 77^{o}F}{R\&B\ Softening\ Pt.,\ ^{o}F,\ -77^{o}F}$$

To obtain the PI value by nomograph, two sources may be consulted. These are works by Pfeiffer et al (15) and Warden et al (11). Items required to determine the PI from the nomographs in the above references are (1) the penetration at 77°F (25°C), 100 grams and 5 seconds and (2) the R&B (ring and ball) softening point in degrees Fahrenheit, °F.

In interpreting the PI results obtained for asphalt cements, it should be noted that a PI range from -2 to +2 takes in essentially all paving grade asphalts. Asphalts with PI's at or near -2 are said to be highly temperature susceptible; whereas, asphalts with PI's at or near +2 are said to have very low temperature susceptibility. Generally, the less temperature susceptible an asphalt cement is, the more desirable is that material.

Stiffness, lbs/in^2

Stiffnesses of asphalt cements and asphalt cement-mineral filler mastic systems may be determined using Van der Poel's "Stiffness Nomograph"(16). Changes in stiffnesses of asphalt that occur after the TFOT or RTFOT and also after the addition of mineral filler within the range of filler concentrations normally used in asphaltic paving mixtures may be readily determined from this nomograph if the original penetration of the asphalt cement and the R&B softening point of either the asphalt cement after TFOT or the filler-mastic system is used. A knowledge of the stiffness of an asphalt or asphalt-filler mastic may be useful in the studies of both mastic stiffnesses and the creep tendencies of asphalt paving mixtures.

SUMMARY OF TEST RESULTS

Basic test results are contained in Tables 6 through 11 and in Figures 5 through 18. These are divided into groups according to what testing table, Table 2, 3 or 4, the test results pertain to and are discussed in the sections below.

Characteristics of Fillers and Filler Blends

Tables 6, 7 and 8 and Figures 5 through 18 are results of testing on individual fillers and blends of fillers to determine characteristics. These tables are based on the testing schedule presented in Table 2.

Table 6. This table gives specific gravity, Atterberg limits, gradation and voids information concerning the fourteen mineral filler materials submitted for testing. The gradation information is taken from the particle size distribution curves for the individual filler materials shown in Figures 5 through 18.

Concerning the coefficients of uniformity and curvature C_u and C_v in Table 3, the value for D_{60} represents a particle size at which 60 percent of the material tested is finer, D_{50} indicates the size at which 50 percent by weight of the test sample is finer, etc.

A material may be considered well-graded or not based on values obtained for both the coefficient of uniformity, C_u, and the coefficient of curvature, C_c. In general, if the Cu is less than 2, any soil is considered uniformly or one-sized graded. A soil may also be considered well-graded if the C_c lies between 1 and 3. Finally, it is also generally required that to be well-graded, a soil should meet both of the above criteria.

The test procedure to obtain the voids by kerosene absorption was discussed previously in this report. The total amount of heat released from adsorption testing using a microcalorimeter was not run because of funding constraints previously noted, but it is believed that this is a worthwhile test.

Figures 5 through 18. These figures show the particle size distributions for each of the fourteen mineral filler materials tested. The shapes of these curves can be compared with the C_u and C_c values in Table 6 with respect to grading. It is also obvious from looking at these curves that some of these filler materials fail the SDHPT grading requirements for mineral filler previously shown.

Table 7. Table 7 contains basically some Table 6-type information for blends of certain of the fourteen mineral fillers listed in Tables 1 and 3. For example, District 3 limestone fines are blended with District 3 fly ash, District 18 fly ash and District 18 lime. The TTI laboratory standard limestone fines are blended with District 11 fly ash, District 11 lime, District 11 cement, District 18 fly ash, District 18 lime, District 15 fly ash and District 17 fly ash.

The total volume percentage of the blends in all cases is equal to six percent. The assumption here is that the minus No. 200 (75 μm) sieve contributions of each filler material would combine to equal a total design percent of six percent by volume of aggregate material of the design hot-mix. The design hot-mix chosen for this mineral filler substudy is that designated by the American Society for Testing and Materials (ASTM) (5) as a 9.5-mm maximum size aggregate for a dense graded hot-mix in ASTM Designation: D3515-81 which shows a desired average percent of minus No. 200 (75 μm) sieve material of six percent. This ASTM grading corresponds fairly closely with the SDHPT average grading for Item 340 Type "D" hot-mix asphaltic concrete (1).

As shown in Table 7, Atterberg limits and voids by kerosene absorption are given for the different blends. For the blends with lime, only one-fifth or one-quarter of the total volume of the blend is given to the lime as this would be more representative of the currently accepted practice of using a minimum amount of lime in the field.

Table 8. This table delves further into some of the volume relationships that the six percent by volume of minus No. 200 (75 μm) sieve material would have on the design hot-mix. Although this table only covers values for the individual fillers, all of the items computed herein may be easily computed for the blends.

Included in this table are voids by kerosene absorption, the solid volume of the filler in a packed state V_{fk}, volume of filler and absorbed asphalt, V_{fa}, and an optimum filler-asphalt ratio, F/A. The solid volume of mineral filler in a packed state is equal to 100 minus the kerosene voids.

The total volume of filler and associated absorbed asphalt is equal to six divided by the decimal fraction of V_{fa}. Finally, the optimum F/A value is equal to six divided by V_{fa} minus six.

According to Warden et al. (11), a strong relationship exists between (1) differences in ring and ball temperatures from pure asphalts to asphalt cements with different amounts of mineral fillers and (2) the percentages of mineral filler in the asphalt cement expressed as percentages up to V_{fk}, as shown in Figure 19. Thus taking the District 15 fly ash for example, increasing volume percents of filler to total volume of mastic up to V_{fk} or 64 percent could be plotted (on the x-axis) versus increasing differences in ring and ball temperatures (on the y-axis) above that for the pure asphalt cement. The resulting curve would plot parabolically upward with increasing percentage of mineral filler below V_{fk}, and the slope would approach infinity at the volume percentage of filler equal to V_{fk}, showing the great stiffening effect of increasing the filler up to V_{fk}.

Concerning V_{fa}, Warden et al. (11) also show a strong, positive relationship between differences in ring and ball temperatures and increasing volumes of V_{fa} in pure asphalt cement expressed as a percentage of the volume of pure asphalt cement equal to the optimum volume of filler and absorbed asphalt. Thus at an actual V_{fa} equal zero, the amount of filler in the asphalt would be equal to zero and the difference in the ring and ball temperatures would also be zero. Taking the District 17 fly ash in Table 8 for example, for an actual V_{fa} of 50 percent or 5.7 percent by volume (together with another 5.7 percent by volume of pure asphalt) of the hot-mix for our dense graded design, a significent difference in ring and ball temperature could be confidently expected. This difference would became significantly higher as the actual V_{fa} approached 100 percent or the optimum at 11.3 percent by volume of the mix.

All the above discussion is thus describing what stiffening effects can be expected from increasing the concentration of mineral filler from zero to an amount equal to that shown in the third column in Table 8 for each mineral filler. All of the above emphasis on increasing differences in ring and ball temperatures by increasing the amounts of filler in asphalt cements up to the V_{fk} and V_{fa} levels is therefore intended to indicate that increasing stiffnesses, strengths and stabilities of the asphalt films have been achieved in mastics by these procedures used by the researchers noted. It is believed that these beneficial strength traits are also carried on to actual hot-mixes using the mastic systems.

Characteristics of Asphalt Cements

Table 9 contains test results for the only two asphalt cements used in the mineral filler substudy. The bulk of the test results were obtained from SDHPT Division D-9 data for the year 1984 (17). The tests conducted and reported in this table are in consonance with the recommended testing schedule shown in Table 3. The two asphalt cements shown are those often used in the Wichita Falls district of the SDHPT.

No tests on residue for the thin film oven test, TFOT, and the rolling thin film oven test, RTFOT, are reported here. However, these are obtainable from D-9 upon request if needed. Penetration Index, PI, values as shown for each asphalt are computed based upon equation 3 on Page 12. As footnoted on Table 6, stiffness values for asphalt cements based on the Van der Poel's nomograph (16) are obtainable if certain conditions of the loading of the asphalt cement are known or estimated.

Characteristics of Filler/Asphalt Mastics

Tables 10 and 11 contain test results obtained on the filler/asphalt mastic systems. The tests were generally conducted in accordance with the recommended schedule in Table 4.

As noted earlier, various combinations of constraints reduce the numbers of filler/asphalt combinations and the number of tests for each combination that could be accomplished. Some test results were, however, ultimately obtained for two asphalt cements and two mineral fillers that could be important to District 3's hot-mix design and production efforts.

Table 10. This table contains test results using the TTI fabricated squeeze film viscosimeter device on mastics composed of District 3 limestone fines blended with the District 3 fly ash and using either the Kerr-McGee AC-10 or the Oklahoma Refining Company AC-10 asphalts. It is pointedly noted that the viscosity results are for tests run on the mastics at $104^{o}F$ ($40^{o}C$) and that no comparison tests were run on the pure asphalt cements at the same temperature.

Table 11. This table contains the only penetration and ring and ball test results accomplished on a filler/asphalt mastic in this substudy.

DISCUSSION OF RESULTS

Characteristics of Fillers and Filler Blends

Specific Gravities. Apparent specific gravities as determined by test method Tex-202-F are shown in Table 6. These range from a low of 2.037 for the District 17 fly ash to a high of 3.226 for the District 11 cement. Both the District 18 and District 17 fly ashes have rather low gravities, due most probabality to internal voids of the individual fly ash particles.

Concerning design of hot-mixes using the unusual gravity mineral filler, it is quite probable that the above two fly ashes and the District 11 cement would cause more than the specification limited 0.300 variation in the range of determined gravities (1). Therefore, some care would have to be taken in adding required amounts of these materials to hot-mixes by either weight or volume proportions.

Atterberg Limits. These are shown in Table 6 for the individual fillers and Table 7 for blends of fillers. In general, all of the fillers can be termed "low plasticity" materials, with the two limestone fines and the District 11 fly ash showing the highest plasticity index of 3. The fly ashes for the most part are non-plastic or of very low plasticity. Indices were not run on the two hydrated limes.

Table 7 contains Atterberg limits results for the blends of different mineral fillers and shows three situations in which blending has apparently raised the limits from those of the individual fillers across the board. These three blends are the District 11 lime, District 18 lime and theDistrict 17 fly ash combined with the TTI laboratory standard limestone fines. For the worst case, three parts to one part by volume of the TTI laboratory standard fines and the District 11 lime raised the plasticity index of the blend to 10 as compared to 3 for the limestone fines alone. Of course, it is noted here that no Atterberg limits were obtained on the limes individually as this was not deemed necessary in the proposed testing schedule (2).

The SDHPT 1982 Standard Specification (1) require that the plasticity index of the fine aggregate passing the No. 40 (425 μm) sieve shall not be more than 6 when tested by Tex-106-E. It is conceivable, therefore, with the original minus No. 40 (425 μm) borderline to begin with as far as PI is concerned, that adding a mineral filler which increases plasticity, such as the above three materials with the laboratory standard limestone, would result in a fine material that exceeded specifications.

Grain Size Distributions. In general, coefficients of uniformity and curvature, C_u and C_v, and the shapes of the actual grading curves in Figures 5 through 18 show the limes and the fly ashes to be more uniformly graded and all other materials to be more well or dense graded. Of the fly ashes, the District 17 and District 18 materials show the greatest tendency toward being well graded. Concerning gradation, Izatt (2) notes in his Filler Manual that particle size distribution is not applicable as a basis for predicting the stiffening effects of filler.

Izatt (2) does, however, state that "In general, for a particular type of filler, the stiffening effects on the filler-asphalt mastic and the asphalt mixture increase as the amount and fineness increases." Concerning fineness, the particle sizes at different percents passing for the fillers studied can be seen in Table 6. Taking the D_{50} size, or the size at which 50 percent of the particles are finer and coarser, it is noted how the different materials aggregate according to size. The fly ashes range in D_{50} from 0.027 to 0.044 mm, the limes clump at 0.010 to 0.012 mm as the finest sizes and the rock flour and iron ore group together. Based on D_{50} size, the calcium carbonate fines would fit in with the fly ashes and the limestone fines are seen as two separate materials.

The two limes would seem to offer the greatest potential for stiffening of asphalt films. The fine particle size of fly ashes from District 3 and District 15 offer the best chance for asphalt stiffening, if used in the right quantities.

In relation to meeting SDHPT Item 340 specification requirements for mineral filler (1), most of the materials tested in this substudy do based on the samples submitted. Materials that are too coarse include the District 3 limestone fines, TTI silica rock flour and the District 11 and 12 iron ores. The TTI laboratory standard limestone fines are right on the border as far as meeting specifications.

Voids by Kerosene Absorption. For the substudy as noted in Table 3, the hydrated limes have the highest voids content based upon forming the ball in the 5-inch porcelain dish for the kerosene absorption test. These materials thus have the ability to hold the most volume of kerosene dispersed within by surface tension and to display the greatest expanded volume from containing ab absorbed fluid. Four of the five fly ashes exhibit the lowest capacity for holding the kerosene fluid, with the District 17 fly ash showing considerably different and greater capacity than the other four.

The limestone materials, silica rock flour, calcium carbonate fines and District 11 iron ore all fall together in a group with kerosene voids ranging from 43 to 45 percent. The District 12 iron ore and the cement have voids close to each other. Four of the five fly ashes have kerosene voids that fall into a group ranging from 35 to 38, the exception fly ash being the District 17 fly ash at 47. The remaining materials, the two limes, one cement and District 12 iron ore have voids ranging from 50 to 60.

In considering the kerosene voids for the blended materials in Table 7, it is noted that in most cases, the kerosene voids achieved fell within the range of the voids for the individual materials. Some exceptions to this occurred when the TTI laboratory fines were blended with the following materials: District 11 cement, District 18 fly ash, District 15 fly ash and District 17 fly ash. In these cases, there was a small amount of densification achieved in which the voids obtained for the blends are actually below that for the lower kerosene voids for an individual material.

Concerning voids in mineral fillers, Izatt (2) states that (1) "The measurement of the voids in the dry compacted filler under standardized conditions is rapidly emerging as the most useful method of evaluating the influence of filler type on the asphalt paving mixture." and (2) "The solid volume of filler and the compacted volume of the filler including air voids, variously expressed, are emerging as useful parameters." Warden, et al. (11) (2), in curves relating increases in ring and ball softening point temperatures of mastics over those of pure asphalts to the true and apparent volumes of fillers in the mastics, indicate that the lower the volume of solid filler to achieve the same bulked volume, the more effective the mineral filler is in increasing the difference in ring and all temperature (and thus imparting more strength to the asphalt-filler system). The same trends are illustrated by Puzinauskas (21) in which mineral filler materials that bulk more or allow more voids, thus occupying more volume with less solid volume in comparison with other materials, are shown to have lower penetrations, lower ductility, and higher viscosities at any given temperature than the materials that show less bulking.

The significance of the above previous research in relation to this mineral filler substudy is that the kerosene voids shown in Table 6 indicate the degree to which the different materials tested do bulk and allow volume within voids for fluids such as asphalt cement. The limes, District 12 iron ore and cement bulk and allow the most volume of voids within; whereas, the fly ashes tend to show the least bulking. The limestone fines, silica rock flour, District 17 fly ash, calcium carbonate fines and District 11 iron ore tend to fall in a middle group. It would be expected that the first group of materials would provide the greatest strength in asphalt films in mastics and hot-mixes and that the group of four fly ashes would provide the least strengthening. In fact, Izatt (2) states that "Fly ash, as viewed in photomicrographs, contains a preponderance of spherical, relatively smooth surfaced particles some of which are hollow. There is wide variability in specific gravities and particle distribution. Stiffening effects on the filler/asphalt mastic are, in general, less than for equal F/B [filler/binder] ratios using limestone dusts."

Total Released Heat of Absorption. Although, as shown in Table 6, this particular test was not run because of high cost, it is believed that its use would have been of value to the mineral filler substudy. In brief, in this test procedure, a dilute solution of the particular asphalt cement in a solvent is introduced in contact with the mineral filler sample in a microcalorimeter. The process which then occurs is absorption of the asphalt cement on the mineral filler material surfaces. Since absorption results in chemical reactions which are exothermic, or give off heat, the magnitude of the absorption is determined by measuring the magnitude of the heat generated in the microcalorimeter.

During this test, the rate of heat energy released is observed over a period of about two hours, and the energy rates in terms of millicalories per gram-minute are recorded at intervals for plottings against total time. The area under the plotted line is therefore the total energy released. The better absorbing (and thus the better bonding) mineral fillers tend to have the highest initial energy release rates of absorption and also the greatest area (total energy of absorption) under the plotted curve. According to Ensley (22), "Experience has shown that the magnitude of bonding energy is correlated with highway performance. Stronger asphalt-aggregate bonds mean more durable highways."

Ensley's work (22) shows one lime material to have a high Lottman tensile strength ratio 0.8, a high surface area of 2.3 m^2/g and both a high initial rate of absorption heat energy release together with a high tail rate of energy release. When another lime was added to a Georgia problem feldspar aggregate exposed to an Ac-30 in the microcalorimeter, the peak height of initial energy release was 2.5 times higher for the feldspar with the lime than with the feldspar alone. The tail heights for both feldspar with and without lime were about the same causing Ensley (22) to conclude that the increase in the initial energy with lime"... is probably not so much a function of bonding energy as it is a function of a chemical reaction between asphalt components and lime." Finally, Ensley examined some lime treated aggregate under a microscope and noted that "Microscopic examination of the lime-treated aggregate shows a large portion of the aggregate surface covered with lime particles." He concluded that lime could possibly be responsible for initiating multilayered thicknesses of absorption films on aggregates and that this would show up in an enhanced height of rate of release of heat energy from the exothermic reaction of absorption.

Filler Volumes in Mastics. Table 8 delves into computing the parameters of volume of fillers in the packed state V_{fk}, volume of filler and absorbed asphalt V_{fa} and an optimum filler to asphalt ratio, F/A. As discussed earlier, Table 8 is based on the assumption that a solid volume of filler is used which is equal to six percent of the volume of a designed hot-mix aggregate gradation at the mid point of the ASTM nominal 9.5-mm maximum sized aggregate dense gradation given in ASTM D3515 (5). Further, the six percent of material is for minus No. 200 (75µ m) sieve particles.

Table 8 is developed from the results of the kerosene voids testing shown in Table 6. The volume of filler in a packed state V_{fk}, therefore, is equal to 100 percent minus the kerosene voids. Since the solid volume of filler is assumed to equal six percent, the total volume occupied by filler and asphalt cement is then assumed to be equal to six divided by decimal equivalent of V_{fk}. Finally, the optimum F/A ratio, based on results of kerosene voids testing, is equal to the solid volume of filler divided by the volume of asphalt cement assumed taken up in the voids; thus F/A is equal to $6/(V_{fa} - 6)$.

The District 3 fly ash is taken as an example. Kerosene voids test results show this material to have 38 percent voids in a packed state. The volume of the solids would be 100 minus 38 or 62 percent. Assuming six percent by volume of this material is used as minus No. 200 (75 m) sieve material, the total volume of mastic would be six divided by 0.62 or 9.7 percent. The optimum F/A ratio based on kerosene voids would be six divided by 3.7 or 1.62. The amount of asphalt tied up in the filler is therefore assumed to be 3.7 percent by volume of mix.

Concerning the significance of the above parameters, Izatt (2) states that "The solid volume of filler and the compacted volume of the filler including air voids, variously expressed, are emerging as useful parameters.... The optimum asphalt content of the mastic can be defined as that amount necessary to just fill the voids in the compacted filler (maximum density). This is the approximate amount of asphalt where the system is changing from a viscous to a plastic material at the higher road temperatures. (Filler particles are separated somewhat above this amount of asphalt and particle-to-particle contact within the mastic increases below this amount)".

Upon inspection of Table 8 it is seen that six percent by solid volume of the District 18 lime occupies the largest packed volume, V_{fa}, of any filler. The District 11 fly ash occupies the least at 9.2 percent. With the exception of the District 17 fly ash, the fly ashes as a group occupy the smallest V_{fa} volumes, and the limes and cements occupy the largest V_{fa} volumes. This would indicate that on an equal solid volume basis that the limes, cement and District 11 iron ore would have the greatest influence on filler-asphalt mastics and hot-mixes in which they were incorporated, and the fly ashes would have the least influence. Optimum F/A ratios for the apparently most influential fillers range from 1.00 down to 0.67, whereas F/A ratios for the four fly ashes range between 1.62 and 1.88 or nearly double

Characterization of the Asphalt

Table 9 presents results of SDHPT tests on the two asphalt cements used in this mineral filler substudy. Based on the penetration results shown in this table, both asphalts seem to be somewhat on the "soft" side, especially the Oklahoma Refining Company asphalt. Considering viscosity at 140°F, the Oklahoma Refining Co. asphalt still has this soft feature, but the Kerr-McGee asphalt falls on the "hard" side of the specification requirements. Ring and ball temperature results for both asphalts fall into line with the penetration and viscosity results at 140^{o}F e viscosities at 275^{o}F (135^{o}C) for both asphalts indicate that these asphalts should not be tender. Finally, penetration indices of +1.22 and +1.00 provide an indication that neither of the asphalt cements is particularly temperature susceptible.

Characteristics of Filler/Asphalt Mastics

Table 10 and 11 contain the results of testing accomplished on mastics in this mineral filler substudy. Table 10 covers results of the testing with the TTI fabricated squeeze film viscosimeter, and Table 11 documents penetration and ring and ball test results on mastics.

Mastic Dynamic Viscosity,

As shown in Table 10, varying proportions of District 3 limestone fines and District 3 fly ashes were combined and mixed with either the Kerr-McGee or the Oklahoma Refining Co. AC-10's to produce mastics for testing.

After the AC content columns in Table 10, the next two columns contain the heights of mastic test coupon values. The h_0 height was that at the beginning of the test and the h height was that at the end of the test. As noted from these two columns, the differences between these two heights varied within the three tests conducted on each blend or individual filler in the filler-asphalt mastic. The heights from each test were then used in Equation 2 (See page 11) to calculate the mastic dynamic viscosity, η,.

The last column of Table 10 contains the calculated mastic dynamic viscosity values in thousands of poises at $104^{o}F$ ($40^{o}C$). It is important to emphasize here that no testing was done at $140^{o}F$ ($40^{o}C$) and no pure asphalt cements were tested at $104^{o}F$ ($40^{o}C$). Therefore, no direct comparison can be made between the mastic viscosities obtained and pure asphalt cement viscosities. Assuming that the squeeze film viscosimeter results are fairly accurately calculated by Equation 2, the viscosities obtained are generally very high, in the hundreds of thousands or millions of poises area, except for those calculated for the District 3 fly ash alone in a mastic with the Oklahoma AC-10.

Based on the limited results available, for the mastic with the Kerr-McGee AC-10 asphalt cement, the blending of the District 3 limestone fines with the District 3 fly ash appears to produce higher viscosities than those for either of these filler materials used alone. This is especially true if the last viscosity value, which is extremely high, for the District 3 fly ash alone is omitted (in test number 5).

Limited results for using the Oklahoma AC-10 with the same blends of District 3 limestone fines and fly ashes appear to show greatly different results from those using the other AC-10. Firstly, the District 3 limestone fines alone and the blend with the lowest concentration of fly ash produce the highest viscosities, in contrast to the results discussed above. Next, the District 3 fly ash used alone in the mastic produces very low viscosities and the lowest viscosities of any calculated. The trend for the blends is for the viscosity to decrease with increasing concentrations of District 3 fly ash, especially if the two high values of viscosity are discounted in the first two blends. Thus there appears to be a noticeable decline in viscosity going from all District 3 limestone fines to all District 3 fly ash.

Penetration and Ring and Ball Values. As shown in Table 11, limited numbers of test results for penetration and ring and ball temperature tests were obtained. These results are for the District 3 limestone fines and fly ash used with the Kerr-McGee AC-10. In general, these results mirror the trend of the results obtained in Table 10 for the same materials. The limestone fines and fly ash used along with the Kerr-McGee AC-10 produced the higher penetration and lower ring and ball temperatures, and the blends produced the lower penetrations and the higher ring and ball temperatures.

Comparing results in Table 11 with those for the pure asphalt cements shows dramatic increases in ring and ball temperatures and decreases in penetrations for the mastics above the pure Kerr-McGee AC-10. A penetration of 102 dmm characterizes the pure asphalt cement whereas the mastic reduced the penetration dramatically to less than 10 in every case. Ring and ball softening points increase dramatically from 52°C for the pure asphalt cement to from 83°C to 99°C for the single filler mastics to as high as 133°C for the 4:2 blend of limestone fines and fly ash. Thus, ring and ball temperature differences from pure asphalt to filler-asphalt mastics range from 31 to 83°C for the cases listed above. Therefore, from looking at the above changes in penetration and ring and ball temperatures from pure asphalt cement to mastics, the stiffening, strengthening effects of the filler materials are dramatic.

CONCLUSIONS

Although the extent of the testing accomplished in this mineral filler substudy was limited, several conclusions may be drawn. These are listed below.

Characterization of Fillers and Blends

1. The specific gravity, Atterberg limits and grain size distribution curves, although standard tests, contribute to an understanding of the nature of the filler materials, and results of these tests will need to be considered in the design procedure.
2. The voids by kerosene absorption test appears to offer promise as far as characterizing filler materials according to their capacity to occupy effective or bulked volume in the presence of asphalts and their capacity to "tie up" different percentages of asphalt cement.
3. Of the tests not run but shown to be accomplished, the released heat of absorption of mineral fillers with particular asphalt cements as measured in a microcalorimeter apparently holds enough promise of providing good information about the surface activity of mineral fillers in contact with asphalt cements to justify the significant expense and inconvenience to have the test performed, at least as a source qualification test.
4. Although not firmly established in this substudy work, parameters developed from the simple kerosene voids test such

as V_{fk}, V_{fa} and F/A appear to be useful for correlation with penetration, viscosity, change in ring and ball temperature and other tests to indicate strengthening and stiffening effects of mineral fillers in asphalt cements.

5. There appears to be a tendency for lime to significantly increase the plasticity of the blended mineral filler system when combined with certain materials as indicated in this substudy work. This could be a factor that needs to be evaluated further in consideration of designing mineral fillers for hot-mixes.

Characterization of Asphalts

1. The released heat of absorption test previously noted above might be considered for use as a joint mineral filler-asphalt cement characterization test to evaluate its usefulness.

Characterization of Filler/Asphalt Mastics

1. Both the penetration and the ring and ball softening point tests appear to be useful for characterizing filler-asphalt mastics.
2. The squeeze film viscosimeter test with modification and refinement would appear to be useful for evaluating mineral filler-asphalt cement mastics. However, preparation, placement and testing of the mastic pills or coupons was found to be very tedious.

3. Test results comparing penetration, ring and ball and squeeze film viscosimeter test results on mastics with the equivalent or similar tests on the two pure asphalt cements showed considerable stiffening effects from using fillers in the asphalt cement in this substudy.
4. Limited test results on mastics suggest that mastics composed of different combinations of different asphalt cements and mineral fillers can be expected to behave differently.

Properties of Laboratory Compacted Paving Mixtures

1. The tests proposed in Table 5 appear, for the most part, adequate to characterize properties of laboratory compacted specimens using mineral fillers. However, both indirect tensile and resilient modulus testing might be added to this schedule.
2. The research effort should concentrate on and work with materials used in one or two SDHPT districts where there is a definite need to upgrade the existing hot-mixes by providing adequate, well performing fillers.
3. The research effort should concentrate on establishing the adequacy of industrial waste materials such as fly ashes and calcium carbonate fines for utilization as mineral fillers in order to attain more economic end uses of these materials.
4. Background information and proposed testing activities, with modifications, as outliend in Izatt's Filler Manual (2) should be the basis for a new research study evaluating mineral fillers for use in upgrading hot-mixes.

5. The gel permeation chromotography test being employed to characterize asphalts in other research work could also serve as a characterization test for asphalt cement used in mineral filler testing to establish usefulness.

6. No testing was accomplished in the area of laboratory compacted paving mixtures, but this leg of the proposed orientation program is considered as important as any other. In fact, if one area of the characterization had to be eliminated, it is believed that the mastic testing would be better eliminated and replaced with testing in this area.

RECOMMENDATIONS

1. If further research is done in the mineral filler area, the research effort should be a separate, independent study.
2. The research effort should concentrate on and work with materials used in one or two SDHPT districts where there is a definite need to upgrade the existing hot-mixes by providing adequate, well performing minus No. 200 (75 μm) sieve fines.
3. The research effort should concentrate on establishing the adequacy of industrial waste materials such as fly ashes and calcium carbonate fines for utilization as mineral fillers in order to attain more economic end uses of these materials.
4. Background information and proposed testing activities, with modifications, as outlined in Izatt's Filler Manual (2) should be the basis for a new research study evaluating mineral fillers for use in upgrading hot-mixes.

REFERENCES

1. ____________________, Texas State Department of Highways and Public Transportation 1982 Standard Specifications for Construction of Highways, Streets and Bridges, State Department of Highways and Public Transportation, specifications adopted by the Department, September 1, 1982.

2. Izatt, J.O., "Filler Manual - Project 2285 Preliminary 'Mock-up' - Testing", unpublished report prepared for Study 2-9-80-285 for the Texas State Department of Highways and Public Transportation, April 21, 1982.

3. ____________________, Design data furnished by District 11 concerning the placement of mineral fillers in Type "D" hot-mix in SH 94 and/or FM 1271, State Department of Highways and Public Transportation, Lufkin, Texas, January, 1983.

4. ____________________, 1982 Annual Book of ASTM Standards, Part 13, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1982.

5. ____________________, 1982 Annual Book of ASTM Standards, Part 15, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1982.

6. ____________________, 1982 Annual Book of ASTM Standards, Part 19, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1982.

7. ____________________, Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part II, Methods of Sampling and Testing, Adopted by The American Association of State Highway and Transportation Officials, Washington, D.C., July, 1982.

8. ____________________, Manual of Testing Procedures, 100-E Series, Soil Section,Texas State Department of Highways and Public Transportation, revision published by the Department, Austin, Texas, January, 1978.

9. ____________________, Manual of Testing Procedures, 200-F Series, Bituminous Section, Texas State Department of Highways and Public Transportation, revision published by the Department, Austin, Texas, January, 1978.

10. ______________________, Manual of Testing Procedures, 500-C Series _____, Texas State Department of Highways and Public Transportation, revision published by the Department, Austin, Texas, January, 1974.

11. Warden, W.B., Hudson, S.B., and Howell, H.C., "Evaluation of Mineral Fillers in Terms of Practical Pavement Performance", Volume 28 of the Proceedings of the American Association of Pavement Technologists, Denver, Colorado, 1959.

12. Rigden, P.J., "The Use of Filler in Bituminous Road Surfacings. A Study of Filler-Binder Systems in Relation to Filler Characteristics", Journal of the Society of Chemical Industries, No. 66, London, England, 1947.

13. Dienes, G.J., and Klem, H.F., "Theory and Application of the Parallel Plate Plastometer", Volume 17, Journal of Applied Physics, London, England, June, 1946.

14. Manning, R.E. and Lloyd, W.A., copies of three business letters to Vyt Puzinauskas on May 28, 1970, March 2, 1971 and May 11, 1970 and one letter to Fred C. Benson, November 18, 1982 discussing the transverse flow viscometer, Cannon Instruments Company, Boalsburg, Pennsylvania, 1970, 1971 and 1982.

15. Pfeiffer, J.Ph. and Van Doormal, P.M., "Classifying Asphalts by Means of Penetration Index", National Petroleum News, Refining Technology Edition, New York, New York, February, 1938.

16. Van der Poel, C., "A General System Describing the Visco-Elastic Properties of Bitumen and Its Relation to Routine Test Data", Journal of Applied Chemistry No. 4, London, England, 1954.

17. ______________________, "Agenda for Twenty-Eighth Annual District Laboratory and/or Engineering Personnel Meeting", Texas State Department of Highways and Public Transportation, San Antonio, Texas March 21 and 22, 1984.

18. McKerall, W.C., Ledbetter, W.B. and Teague, D.J., "Analysis of Fly Ashes Produced in Texas", Research Report 240-1 produced for the Texas State Department of Highways and Public Transportation by the Texas Transportation Institute, College Station, Texas, January 1981.

19. Lottman, R. P., "Predicting Moisture-Induced Damage to Asphaltic Concrete" NCHRP Report 192, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 1978.

20. DeHilster, E. and Van De Loo, P.J., "The Creep Test: Influence of Test Parameters", Paper presented at the International Colloquium on Plastic Deformability of Bituminous Mixes, Zurich, Switzerland, September, 1977.

21. Puzinauskas, V.P., "Filler in Asphalt Mixtures, Research Report 62-2, The Asphalt Institute, College Park, Maryland, February, 1969.

22. Ensley, K.E., "Progress Report: Bondingnergy Measurements in Asphalt Aggregate Systems Using a Microcalorimeter:, A report to to Federal Highway Administration by the Western Research Institute, Laramie, Wyoming, January, 1983.

SELECTED REFERENCES

1. Anderson, D.A. and Tarris, J.P., "Adding Dust Collector Fines to Asphalt Paving Mixtures", NCHRP Report 252, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., December, 1982.

TABLES

Table 1. Summary of individual mineral fillers tested.

Filler Number	Type of Filler	District Furnishing Sample	Source Description	Comments
1	Portland Cement	11	Not known	
2	Fly Ash	3	Burning of coal from Gillette, Wyoming in Southwest Public Utilities Harrington Power Plant, Amarillo, Potter County, Texas.	Type C Fly Ash
3	Fly Ash	11	Not known	Type C Fly Ash
4	Fly Ash	15	Burning of lignite from Cordero Mine, Wyoming in City Public Service Board J.T. Deely Power Plant, San Antonio, Bexar County, Texas	Type C Fly Ash
5	Fly Ash	17	Burning of lignite from Carlos, Texas in the Texas Municipal Power Agency Gibbons Creek Power Plant, Carlos, Grimes County, Texas	Probably Type C Fly Ash
6	Fly Ash	18	Burning of lignite from Mt. Pleasant, Texas, in Texas Utilities Monticello Power Plant, Mt. Pleasant, Titus County, Texas.	Type C Fly Ash
7	Hydrated Lime	11	Not known	
8	Hydrated Lime	18	Texas Lime Company, Cleburne, Texas Plant, Johnson County.	

Table 1. (continued).

Filler Number	Type of Filler	District Furnishing Sample	Source Description	Comments
9	Limestone Fines	3	Zack Burkett Company Collier Pit, 3 miles west of Saint Jo in Montague County, Texas.	
10	Limestone Fines	TTI Laboratory Standard	White Mines quarry near Brownwood, in Brown County, Texas.	
11	Silica Rock Flour	TTI Laboratory Standard	From a commercial firm in Brady, McCulloch County, Texas that manufactures frac sands, paint fillers and bar soap and cleanser grit from indigenous natural quartzitic materials.	
12	Calcium Carbonate Fines	N/A (Commercial Source)	Texas Lime Company, Cleburne, Texas, plant, Johnson County.	
13	Iron Ore Fines	12	Thomas McCrorey pit, 7 miles ESE of Willis in Montgomery County, Texas.	
14	Iron Ore Fines	11	Not known.	

*ASTM classification given to so called "high lime" (high CaO contents) fly ashes derived from burning of sub-bituminous or lignitic coal sources (18).

Table 2. CHARACTERISTICS OF FILLERS AND FILLER BLENDS - Summary of proposed and actually used testing schedules and procedures for mineral filler substudy "orientation testing program".

Type of Test	Proposed Test Methods(s)	Test Methods Actually Used
Specific gravity	ASTM D 854 (6) AASHTO T 133 (7)	TEX-202-F (9)
Particle size distribution	ASTM D 422 (6)	TEX-110-E (8)
Geometric Characteristics	British Standard B.S. 812 (Rigden Method) (12)	"Voids in Filler Materials by Kerosene Absorption" See Warden (11)
Specific surface	ASTM C 204 (4) AASHTO T 153 (7)	Test not performed
Surface activity	Released heat of adsorption as measured by microcalorimeter	Test not performed
Plasticity Index	AASHTO T 89 AASHTO T 90 (7)	TEX-104-E, TEX-105-E, TEX-106-E (8)

Table 3. CHARACTERIZATION OF THE ASPHALTS - Summary of proposed and actually used testing schedules and procedures for mineral filler substudy "orientation testing program".

Type of Test	Proposed Test Method	Test Methods Actually Used
Penetration @ 77°F (100 g, 5 seconds) dmm	AASHTO T49 (7) (ASTM D 5) (5)	TEX-502-C (10)
Viscosity @ 140°F, poise	AASHTO T202 (7) (ASTM D 2171) (5)	TEX-528-C (10)
Viscosity @ 275°F, c poise	AASHTO T 201 (7) (ASTM D 2171) (5)	TEX 528-C (10)
Softening point, R&B method, °F	AASHTO T 53 (7), (ASTM D 36) (5)	TEX-505-C (10)
Tests on residue from TFOT or RTFOT	AASHTO T 179 (7) (ASTM D 1754) (5) or AASHTO T 240 (7) (ASTM D 2872) (5)	Not Used
Penetration Index, PI	From nomograph (15)	Calculated by formula
Stiffness, lbs/in^2	From nomograph (16)	Not calculated

Table 4. CHARACTERISTICS OF FILLER/ASPHALT MASTICS - Summary of proposed and actually used testing schedules and procedures for mineral filler substudy "orientation testing program".

Type of Test	Proposed Test Method(s)	Test Methods Actually Used
Composition of mastic	None Available	Used TTI procedure
Preparation of mastic	None Available	Used TTI procedure
Penetration of mastic dmm	AASHTO T 49 (7)	ASTM D5 (5)
Softening point, R&B, °F	AASHTO T 53 (7)	ASTM D 36 (5)
Squeeze film viscometer viscosity, μ, poises	As suggested by references (13) (14)	TTI procedure based upon References (13) (14)

Table 5. PROPERTIES OF LABORATORY COMPACTED PAVING MIXTURES - Summary of proposed and actually used testing schedules and procedures for mineral filler substudy "orientation testing program".

Type of Test	Bulk Specific Gravity	Voids in Mineral Aggregate VMA	Air Voids	Hveem Stability Value	Hveem Cohesimeter Value	Water Immersion	Shell "Creep" Test
Proposed Test Methods	ASTM D 2726 (5)	By Calculation	ASTM D 2726 (5) and D 2041 (5)	Test TEX-208-F (9)	Test Method TEX-214-F (9)	Standard Accelerated Lottman Procedure (19)	Reference 20
Test methods actually used	*No tests performed	*	*	*	*	*	*

Table 6. Characterization of individual mineral fillers: Orientation Testing Program. Project 2-9-80-285

Individual Filler	Specific Gravity	Atterberg Limits			Particle Size Characteristics Size of Percent Passing, mm				Coefficient of Uniformity D_{60}/D_{10}	Coefficient of Curvature $\frac{(D_{30})(D_{30})}{(D_{10})(D_{60})}$	Voids by Kerosene Absorption Percent	Total Amount Released Heat of Adsorption, Calories
		LL	PL	PI	D_{60}	D_{50}	D_{30}	D_{10}				
District 3 Limestone Fines	2.711	19	16	3	0.440	0.220	0.040	0.002	220	1.8	43	---
TTI Laboratory Standard Lime - Stone Fines	2.765	14	11	3	0.110	0.062	0.016	0.003	37	0.8	43	---
District 3 Fly Ash	2.783	12	11	1	0.030	0.029	0.028	0.026	1.2	1.0	38	---
District 18 Fly Ash	2.251		NP		0.058	0.044	0.030	0.015	3.9	1.0	37	---
District 11 Fly Ash	2.554	13	10	3	0.044	0.040	0.038	0.036	1.2	0.9	35	---
District 15 Fly Ash	2.667	15	14	1	0.027	0.027	0.027	0.026	1.0	1.0	36	---
District 17 Fly Ash	2.037		NP		0.049	0.039	0.024	0.010	4.9	1.2	47	---
District 18 Hydrated Lime	2.336		---		0.010	0.010	0.010	0.009	1.1	1.0	60	---
District 11 Hydrated Lime	2.377		---		0.013	0.012	0.011	0.011	1.2	0.8	56	---
District 11 Cement	3.226		NP		---	---	---	---	---	---	50	---
T.T.I. Silica Rock Flour	2.663		NP		0.223	0.163	0.090	0.009	25	4.0	43	---

Table 6. (continued).

Individual Filler	Specific Gravity	Atterberg Limits LL	PL	PI	Particle Size Characteristics Size of Percent Passing, mm D_{60}	D_{50}	D_{30}	D_{10}	Coefficient of Uniformity D_{60}/D_{10}	Coefficient of Curvature $\frac{(D_{30})(D_{30})}{(D_{10})(D_{60})}$	Voids by Kerosene Absorption Percent	Total Amount Released Heat of Adsorption, Calories
Calcium Carbonate Fines	2.687	22	20	2	0.041	0.030	0.027	0.005	8.2	3.6	45	---
District 12 Iron Ore	2.667	16	14	2	0.153	0.117	0.040	0.001	153.0	10.5	51	---
District 11 Iron Ore	2.657	13	12	1	0.182	0.152	0.078	0.008	22.8	4.1	44	---

--- Test not conducted.

Table 7. Characterization of combined mineral fillers: Orientation Testing: Project 2-9-80-285.

Individual Filler No. 1	Individual Filler No. 2	Volume Ratio (Weight Ratio)	Atterberg Limits			Voids by Kerosene Absorption Percent
			LL	PL	PI	
District 3 Limestone Fines (Sp. Gr. = 2.711)	District 3 Fly Ash (Sp. Gr. = 2.783)	4:2 (4:2.05)	14	13	1	40.9
"	"	3:3 (3:3.08)	14	14	0	39.7
"	"	2:4 (2:4.11)	13	13	0	40.1
"	District 18 Fly Ash (Sp. Gr. = 2.251)	4:2 (4:1.66)	19	16	3	41.4
"	"	3:3 (3:2.49)	18	17	1	39.8
"	"	2:4 (2:3.32)	19	19	0	39.9
"	District 18 Lime (Sp. Gr. = 2.336)	5:1 (5:0.86)	25	23	2	49.5
"	"	4.5:1.5 (4.50:1.29)	29	26	3	52.2

Table 7. Characterization of combined mineral fillers: Orientation Testing: Project 2-9-80-285 (Continued).

Individual Filler No. 1	Individual Filler No. 2	Volume Ratio (Weight Ratio)	Atterberg Limits LL	PL	PI	Voids by Kerosene Absorption Percent
TTI Laboratory Standard Limestone Fines (Sp. Gr. = 2.765)	District 11 Fly Ash (Sp. Gr. = 2.554)	4:2 (4:1.84)	15	12	3	35.6
"	"	3:3 (3:2.77)	15	13	2	32.7
"	"	2:4 (2:3.69)	15	13	2	34.8
"	District 11 Lime (SP. Gr. = 2.377)	5:1 (5:0.86)	28	22	6	44.5
"	"	4.5:1.5 (4.5:1.29)	33	23	10	49.9
"	District 11 Cement (Sp. Gr. = 3.226)	4:2 (4:2.33)	17	16	1	39.9
"	"	3:3 (3:3.49)	16	16	0	42.5
"	"	2:4 (2:4.65)	17	17	0	43.3
"	District 18 Fly Ash	4:2 (4:1.63)	15	15	0	34.3

Table 7. Characterization of combined mineral fillers: Orientation Testing: Project 2-9-80-285 (Continued).

Individual Filler No. 1	Individual Filler No. 2	Volume Ratio (Weight Ratio)	Atterberg Limits LL	PL	PI	Voids by Kerosene Absorption Percent
TTI Laboratory Standard Limestone Fines (Sp. Gr. = 2.765)	District 18 Fly Ash	3:3 (3:2.44)	16	15	1	34.0
"	"	2:4 (2:3.26)	18	15	3	37.8
"	District 18 Lime	5:1 (5:0.84)	27	22	5	42.6
"	"	4.5:1.5 (4.5:1.27)	31	25	6	49.3
"	District 15 Fly Ash (Sp. Gr. = 2.667)	4:2 (4:1.93)	16	13	3	35.1
"	"	3:3 (3:2.89)	15	13	2	32.6
"	"	2:4 (2:3.86)	15	13	2	36.0
"	District 17 Fly Ash	4:2 (4:1.47)	21	16	5	42.5
"	"	3:3 (3:2.21)	27	23	4	40.5

Table 7. Characterization of combined mineral fillers: Orientation Testing: Project 2-9-80-285 (Continued).

Individual Filler No. 1	Individual Filler No. 2	Volume Ratio (Weight Ratio)	Atterberg Limits LL	PL	PI	Voids by Kerosene Absorption Percent
TTI Laboratory Standard Limestone Fines (Sp. Gr. = 2.765)	District 17 Fly Ash (Sp. Gr. = 2.037)	2:4 (2:2.95)	32	27	5	42.5

Table 8. Determining optimum F/A ratio for mastics from packing of filler in dish test for 6 percent filler by volume of mix.

Individual Filler	Voids by Kerosene Absorption, Percent	Volume Filler in Packed State, V_{fk} Percent	Volume of Filler and Absorbed Asphalt, V_{fa} Percent of mix	Optimum F/A Ratio, $6/(V_{fa}-6)$
District 3 Limestone Fines	43	57	10.5	1.33
TTI Laboratory Standard Limestone Fines	43	57	10.5	1.33
District 3 Fly Ash	38	62	9.7	1.62
District 18 Fly Ash	37	63	9.5	1.71
District 11 Fly Ash	35	65	9.2	1.88
District 15 Fly Ash	36	64	9.4	1.76
District 17 Fly Ash	47	53	11.3	1.13
District 18 Hydrated Lime	60	40	15.0	0.67
District 11 Hydrated Lime	56	44	13.6	0.79
District 11 Cement	50	50	12.0	1.00
TTI Silica Rock Flour	43	57	10.5	1.33
Calcium Carbonate Fines	45	55	10.9	1.22
District 11 Iron Ore	52	48	12.5	0.92
District 12 Iron Ore	44	56	10.7	1.28

Table 9. SDHPT Division 9 test results for two asphalts used in mineral filler substudy. (17)

Test	Average Asphalt Cement Asphalt Test Results	
	Kerr-McGee AC-10 WynneWood, Oklahoma	Oklahoma Refining Co. Cyril, Oklahoma
Specific Gravity	0.997	0.985
Penetration @ 77°F (100g, 5 seconds), dmm	102	130
Viscosity @ 140°F stokes	1122	882
Viscosity @ 275°F, stokes	3.70	3.30
Softening Point R&B Method, °F (°C)	125 (52)	118 (48)
Tests on Residue from TFOT or RTFOT	None taken	None taken
Penetration Index, PI	+1.22	+1.00
Stiffness lbs/in^2 by nomograph	Not computed*	Not computed*

$$°C = \frac{(°F - 32)}{1.8}$$

*Value depends upon rate of loading of pavement, temperature of loading , PI value and R&B value

Table 10. Test results to determine dynamic viscosities for prepared filler/asphalt mastics tested: Project 2-9-80-285.

Test Number	Mineral Filler No. 1	Mineral Filler No. 2	Volume Proportions of No. 1 to No. 2	Percent Voids by Kerosene Absorption	Source Grade of AC Used	AC Computed Weight Percent of Mastic to Fill Kerosene Voids	Weight Percent of AC Actually Used	Original Test Height h_o, in.	Final Test Height h_f, in.	Mastic Dynamic Viscosity, η, poise x 10^3 at 104°F (40°C), (pascal-seconds)
1	Dist. 3 L.S. Fines	---	6:0	43	Kerr-McGee AC-10	21.8	22.7	-	-	-
								0.177	0.150	301
								0.180	0.143	210
2	Dist. 3 L.S. Fines	Dist. 3 F.A.	4:2	41	Kerr-McGee AC-10	20.2	17.7	0.188	0.177	1050
								0.188	0.184	2800
								0.188	0.174	795
3	Dist. 3 L.S. Fines	Dist. 3 F.A.	3:3	40	Kerr-McGee AC-10	19.5	17.5	0.188	0.184	2100
								0.185	0.170	708
								0.182	0.171	948
4	Dist. 3 L.S. Fines	Dist. 3 F.A.	2:4	40	Kerr-McGee AC-10	19.4	16.3	0.195	0.185	1307
								0.194	0.186	1547
								0.186	0.181	2450
5	---	Dist. 3 F.A.	0:6	38	Kerr-McGee AC-10	18.0	18.8	0.188	0.171	632
								0.188	0.176	948
								0.181	0.178	3675
6	Dist. 3 L.S. Fines	---	6:0	43	Oklahoma Refining AC-10	21.5	23.6	0.189	0.170	550
								0.183	0.157	354
								0.186	0.169	626

(continued)

Table 10. (Continued)

Test Number	Mineral Filler No. 1	Mineral Filler No. 2	Volume Proportions of No. 1 to No. 2	Percent Voids by Kerosene Absorption	Source Grade of AC Used	AC Computed Weight Percent of Mastic to Fill Kerosene Voids	Weight Percent of AC Actually Used	Original Test Height h_o, in.	Final Test Height h, in.	Mastic Dynamic Viscosity, η, poise x 10^3 at 104°F (40°C), (pascal-seconds)
7	Dist. 3 L.S. Fines	Dist. 3 F.A.	4:2	41	Oklahoma Refining AC-10	20.0	18.7	0.191 0.180 0.180	0.165 0.179 0.165	406 5880 646
8	Dist. 3 L.S.	Dist. 3 F.A.	3:3	40	Oklahoma Refining AC-10	19.2	19.9	0.190 0.189 0.185	0.182 0.161 0.161	1589 359 406
9	Dist. 3 L.S. Fines	Dist. 3 F.A.	2:4	40	Oklahoma Refining AC-10	19.2	18.5	0.188 0.185 0.182	0.147 0.160 0.159	209 382 408
10	---	Dist. 3 F.A.	0:6	38	Oklahoma Refining AC-10	17.8	18.9	0.186 0.178 0.184	0.105 0.107 0.075	62 68 26

[--- material not used]
1 inch = 2.54 cm.

Table 11. Test results for (1) penetration and (2) ring and ball temperature of prepared mastics.

Test Number	Mineral Filler No. 1	Mineral Filler No. 2	Volume Proportions of No. 1 to No. 2	Asphalt Source Grade	Voids by Kerosene Absorption Percent	Volume of Filler and Absorbed Asphalt, V_{fa}, Percent of Mix	Optimum F/A Ratio $6/(V_{fa} - 6)$	Penetration at 77°F (25°C), 100g, 5 sec, dmm	Ring and Ball Softening Point, °C
1	Dist. 3 L.S. Fines	None	6:0	Kerr-McGee AC-10	43	10.5	1.33	10	99
2	Dist. 3 L.S. Fines	Dist. 3 F.A.	4:2	Kerr-McGee AC-10	40.9	10.2	1.43	5	133
3	Dist. 3 L.S. Fines	Dist. 3 F.A.	3:3	Kerr-McGee AC-10	39.7	10.0	1.50	6	124
4	Dist. 3 L.S. Fines	Dist. 3 F.A.	2:4	Kerr-McGee AC-10	40.1	10.0	1.50	1	131
5	None	Dist. 3 F.A.	0:6	Kerr-McGee AC-10	38	9.7	1.62	9	83

FIGURES

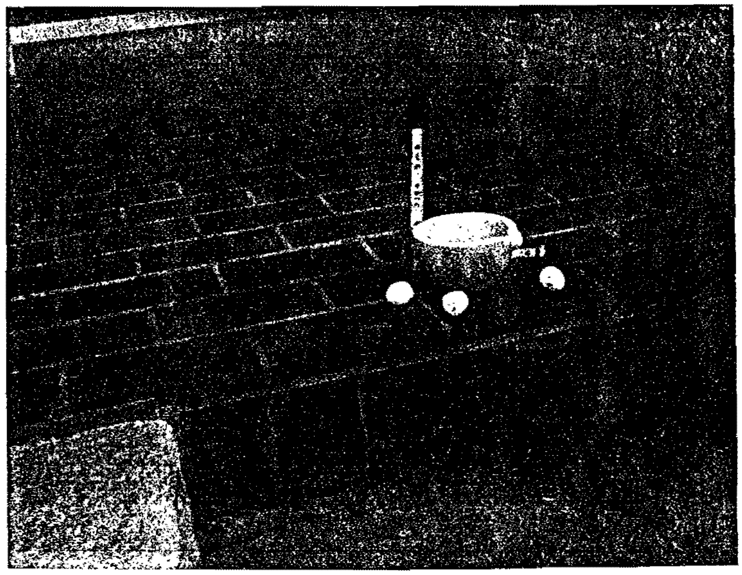

Figure 1. View of 5-inch porcelain evaporating dish and actual completed mineral filler test specimens for kerosene absorption test.

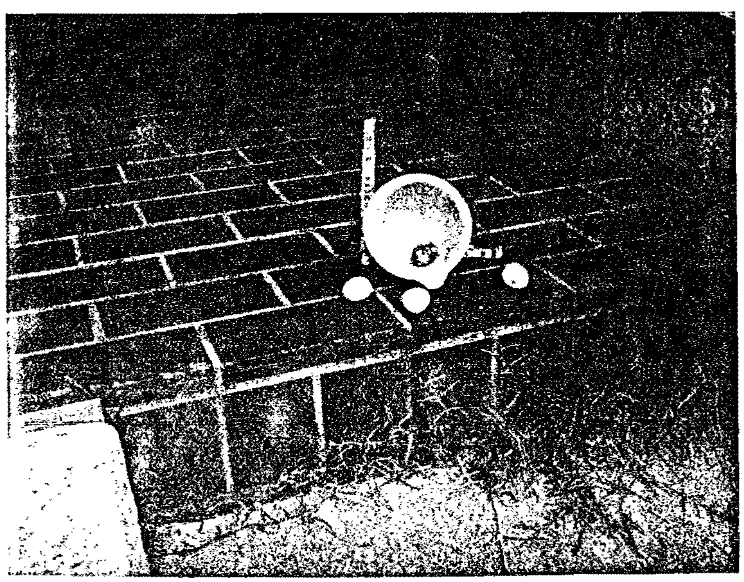

Figure 2. Another view of 5-inch porcelain evaporating dish with completed kerosene absorption mineral filler test specimens.

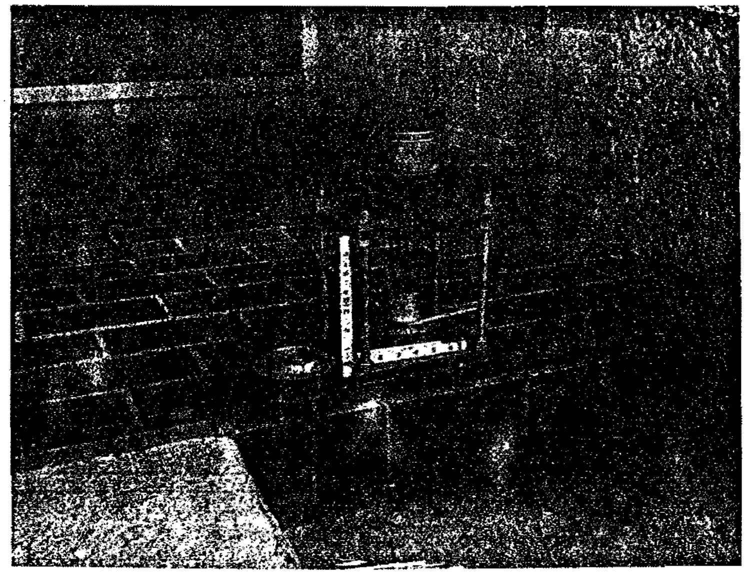

Figure 3. Front view of fabricated squeeze film viscosimeter with mastic specimen molding device on left.

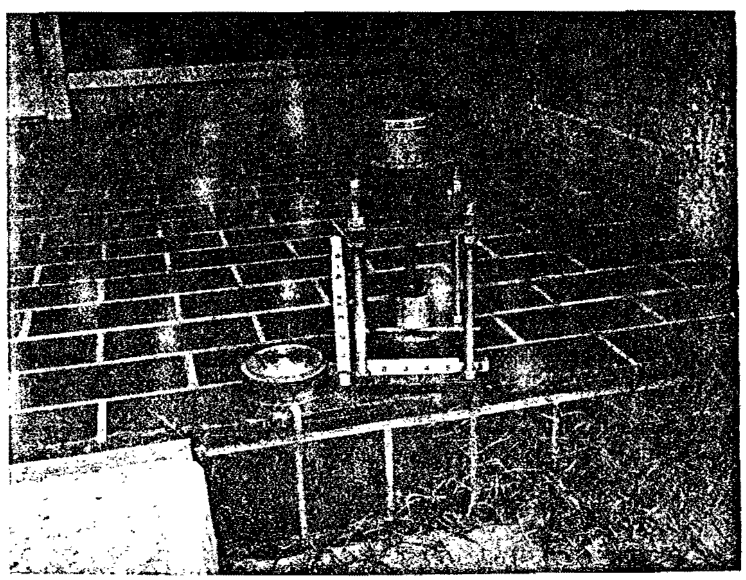

Figure 4. Side view of fabricated squeeze film viscosimeter and molding device.

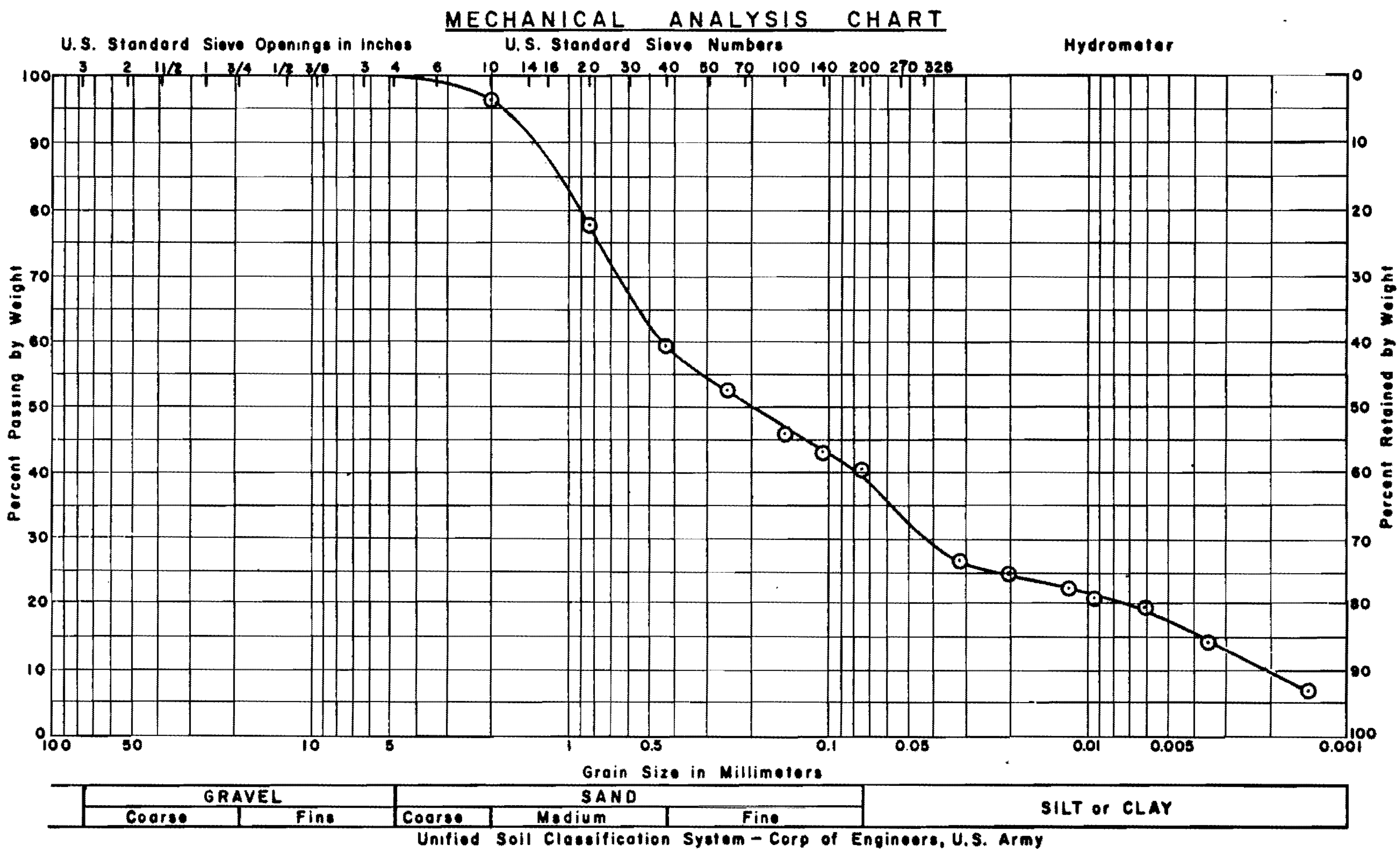

Figure 5. Particle size distribution curve for the District 3 limestone fines.

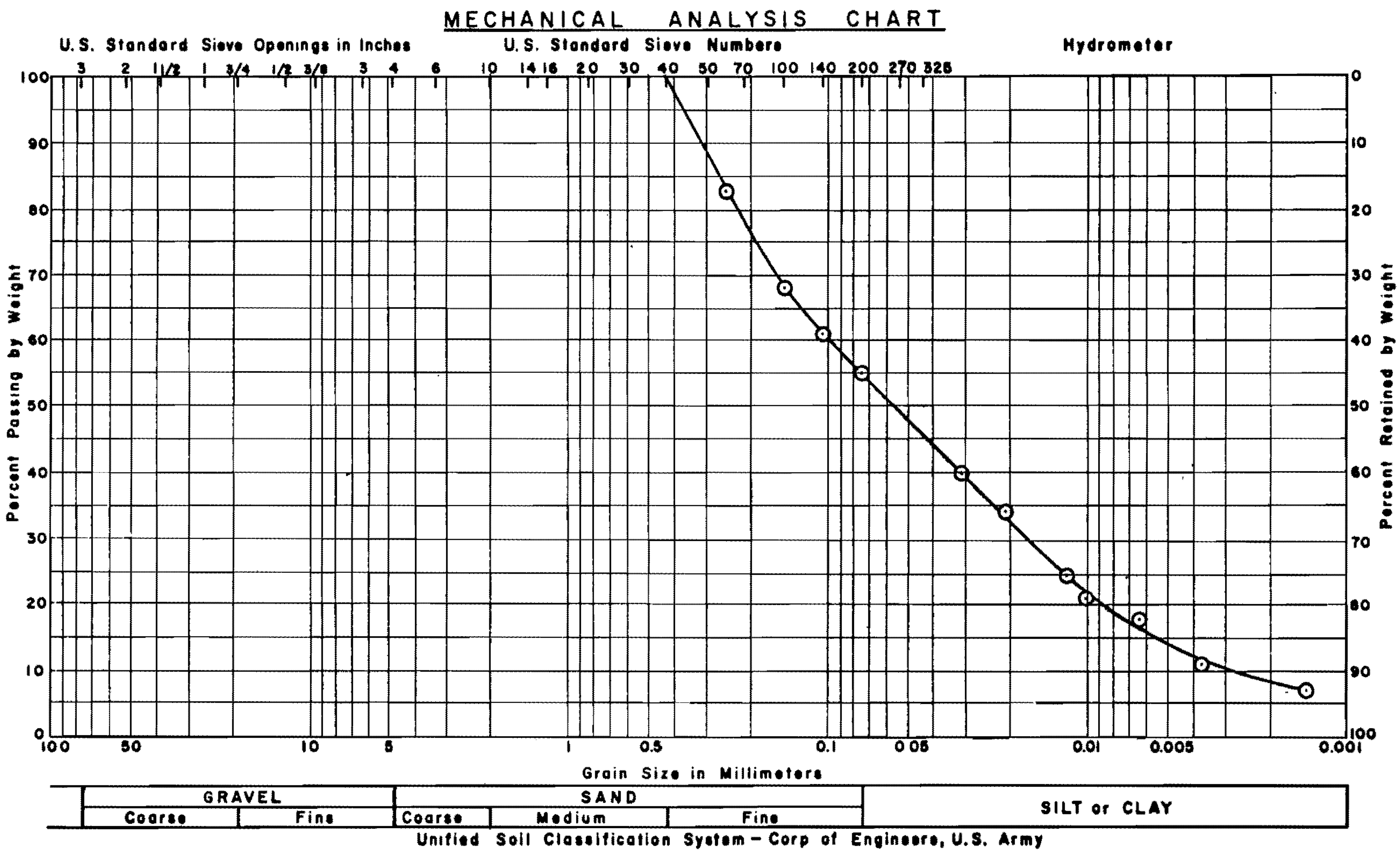

Figure 6. Particle size distribution curve for the TTI laboratory standard limestone fines.

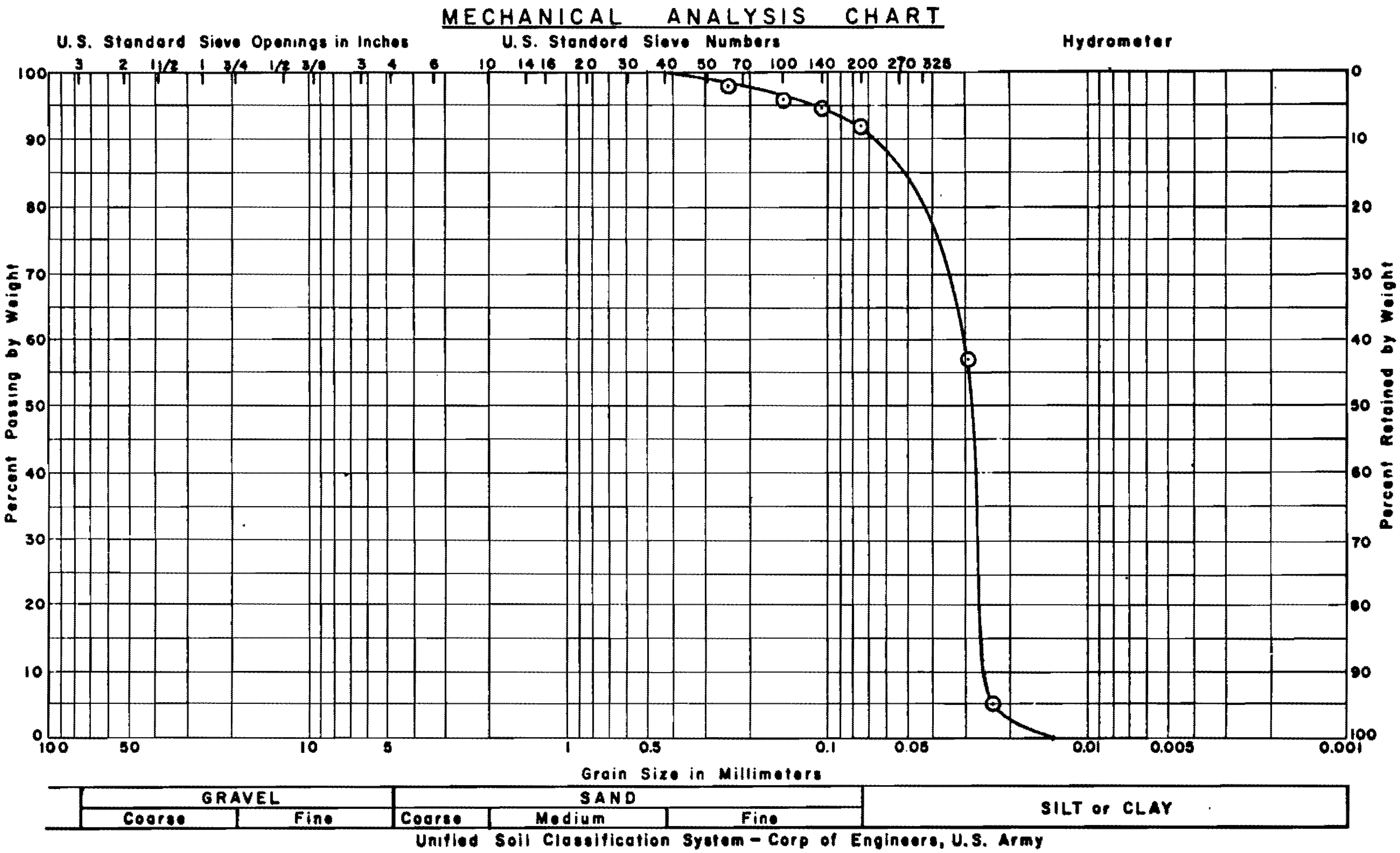

Figure 7. Particle size distribution curve for the District 3 fly ash.

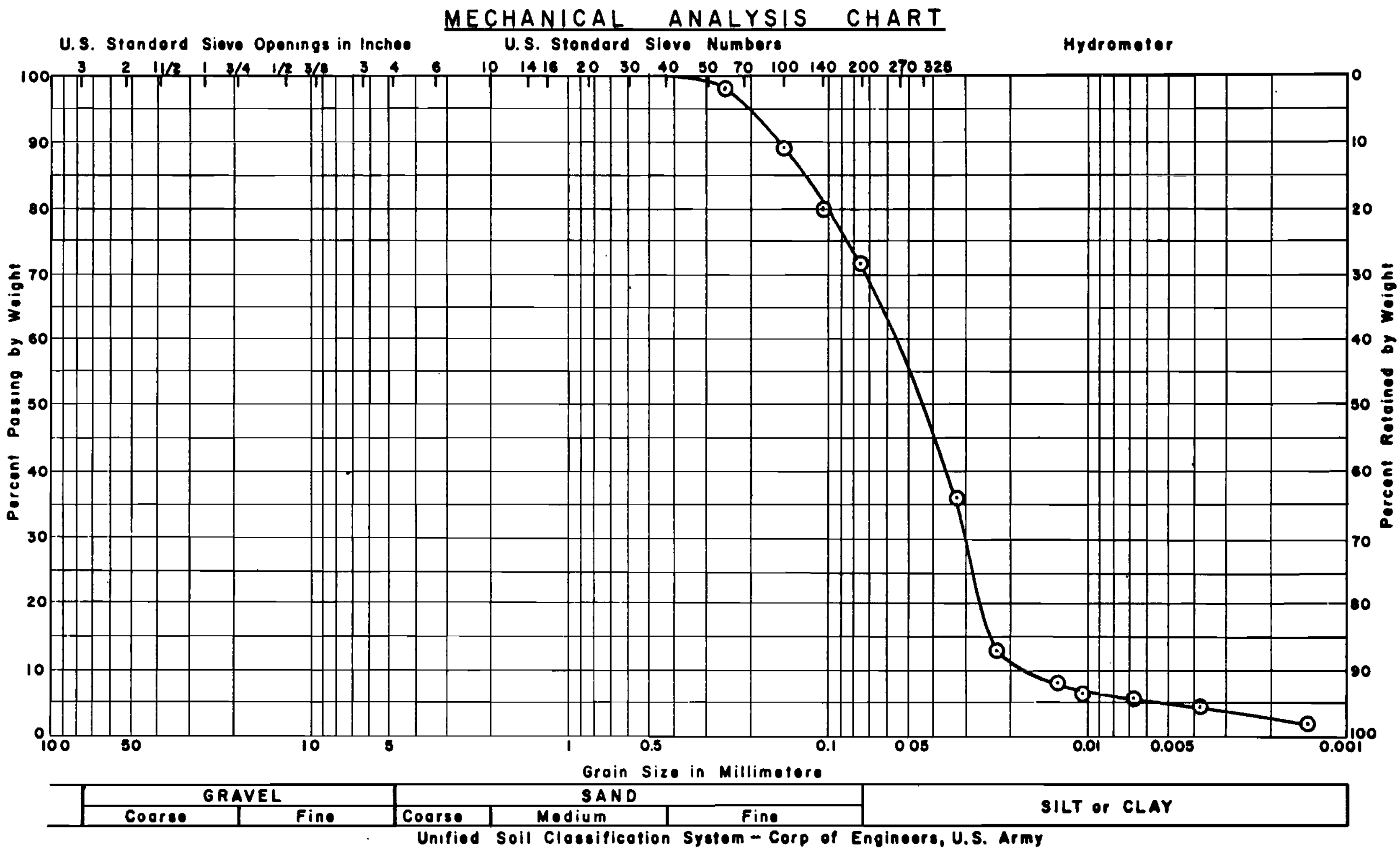

Figure 8. Particle size distribution curve for the District 18 fly ash.

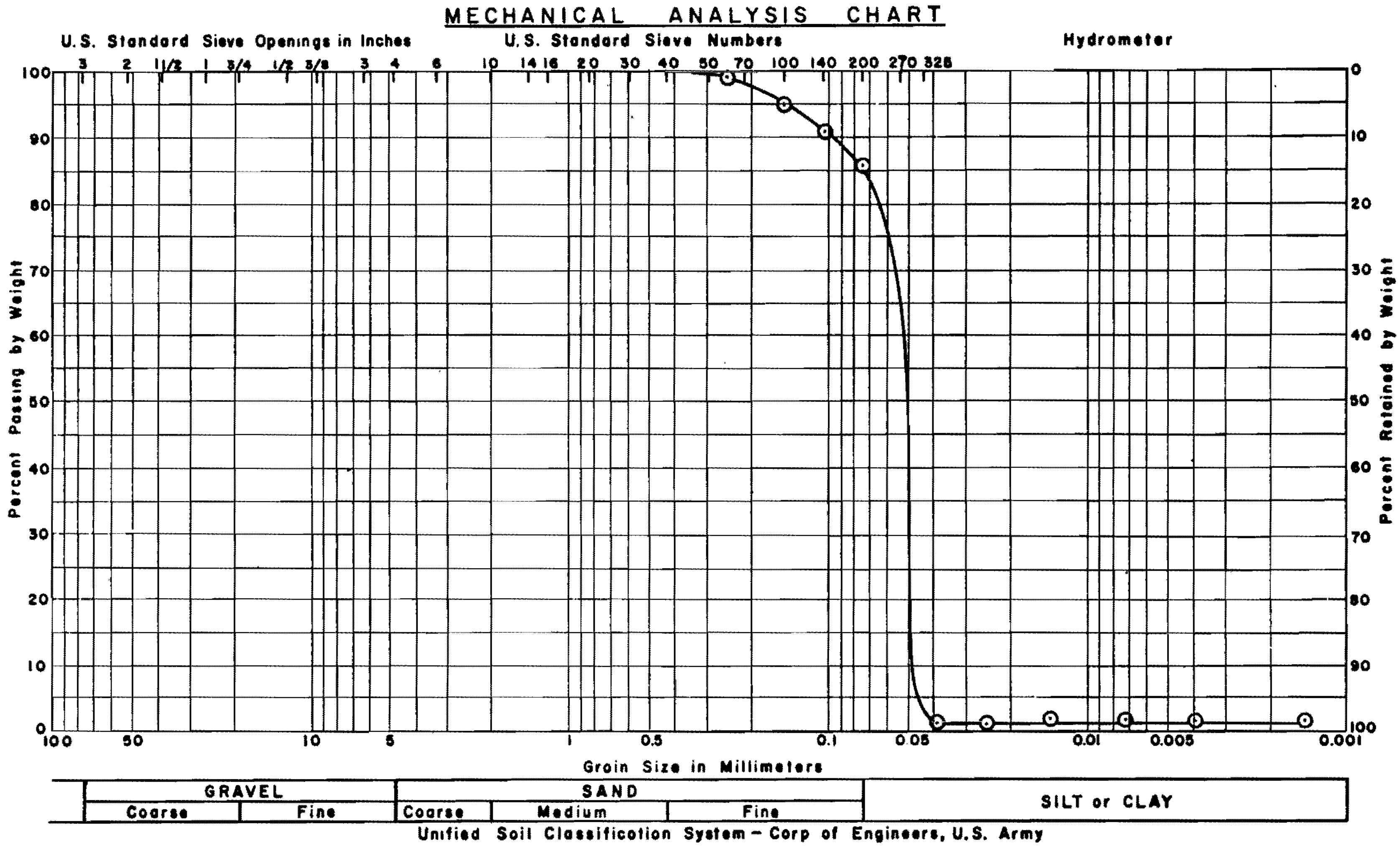

Figure 9. Particle size distribution curve for the District 11 fly ash.

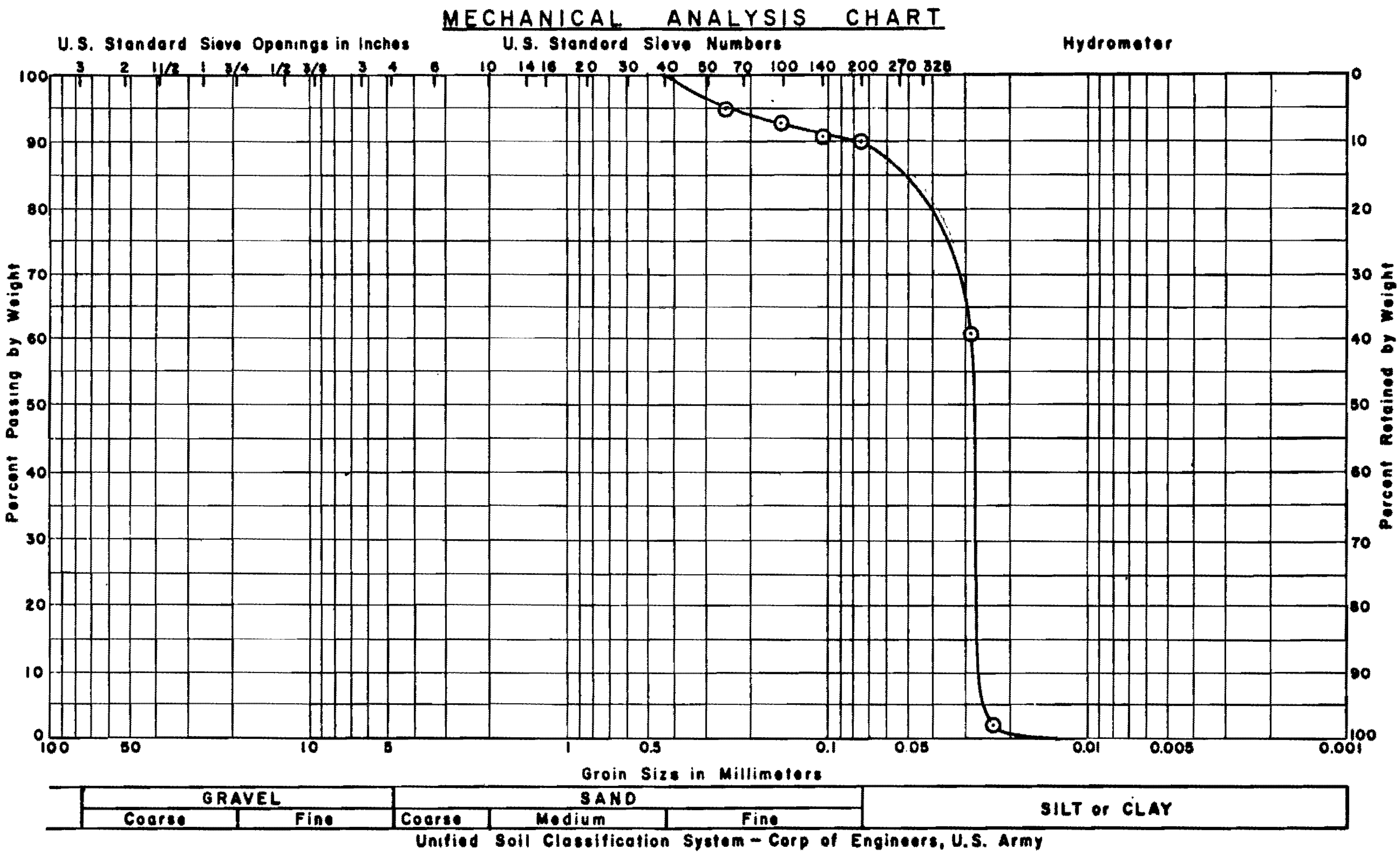

Figure 10. Particle size distribution curve for the District 15 fly ash.

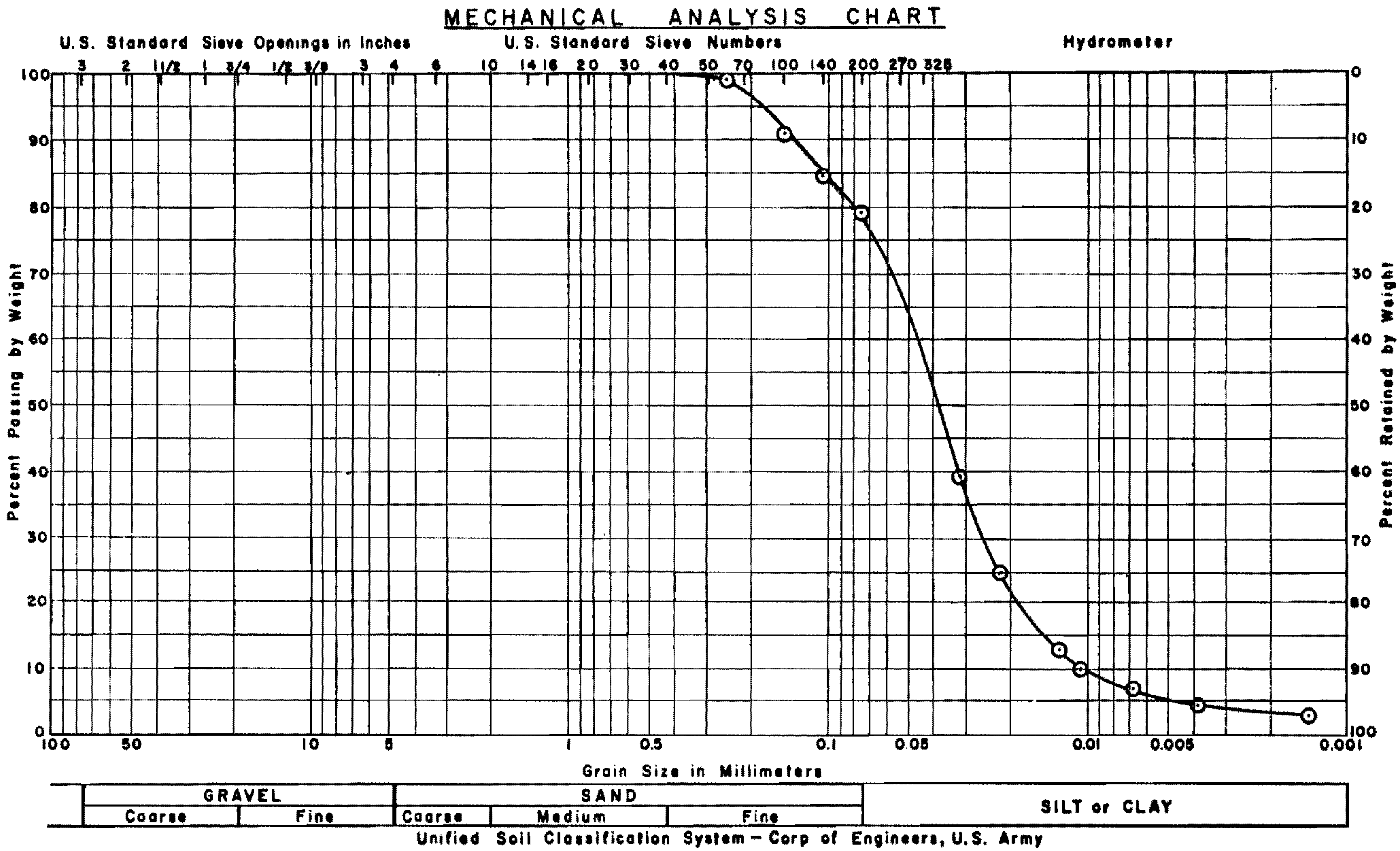

Figure 11. Particle size distribution curve for the District 17 fly ash.

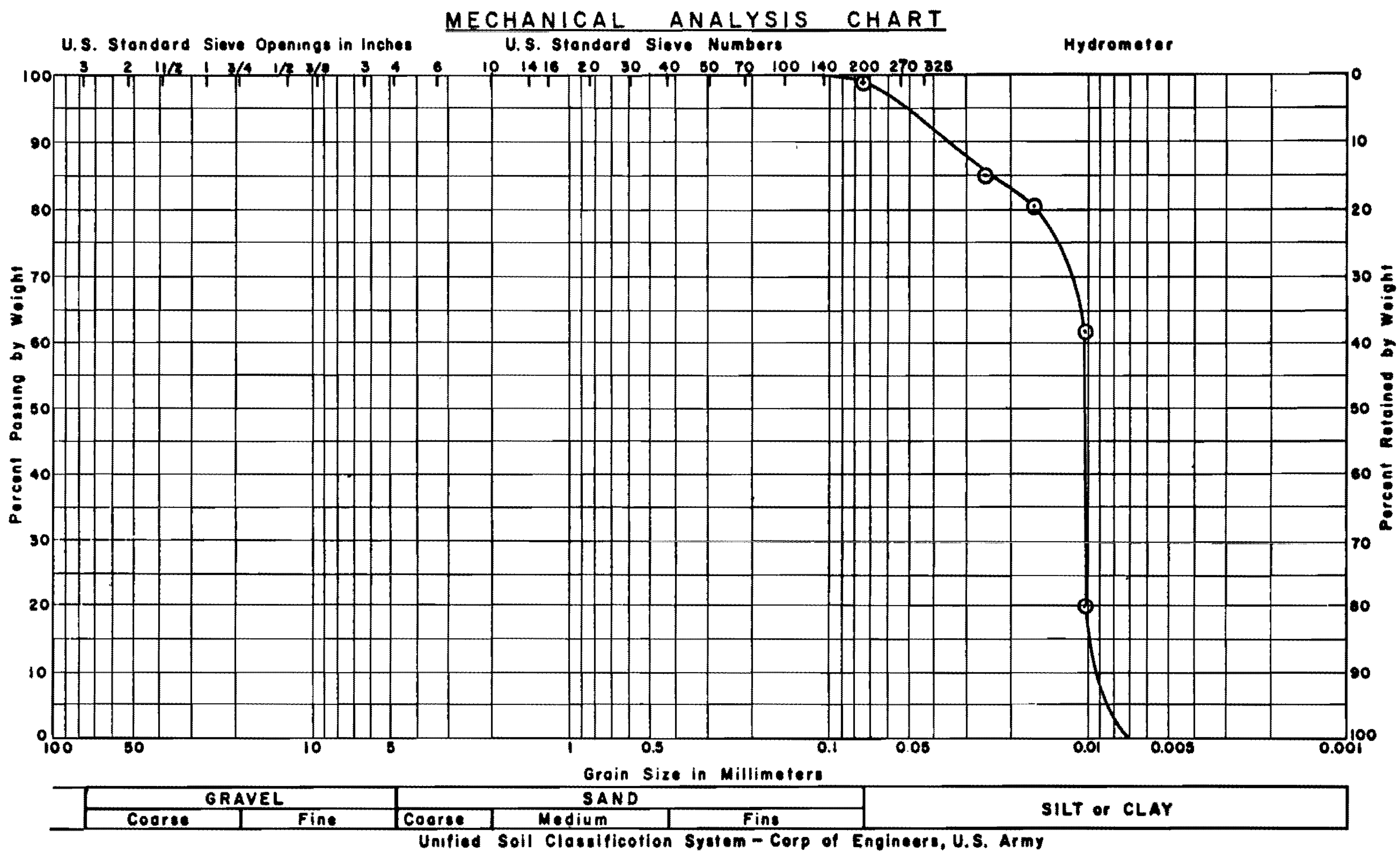

Figure 12. Particle size distribution curve for the District 18 hydrated lime.

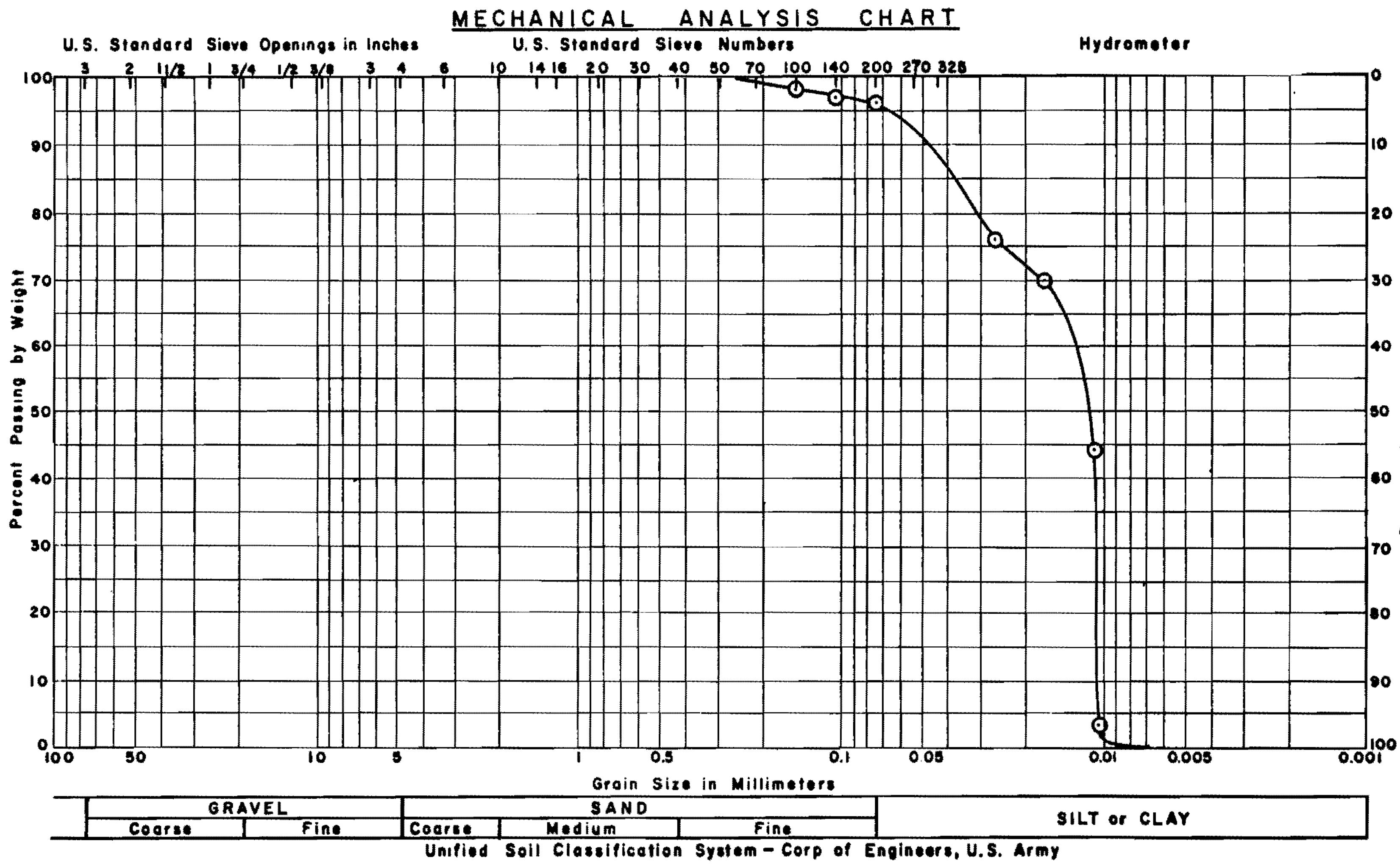

Figure 13. Particle size distribution curve for the District 11 hydrated lime.

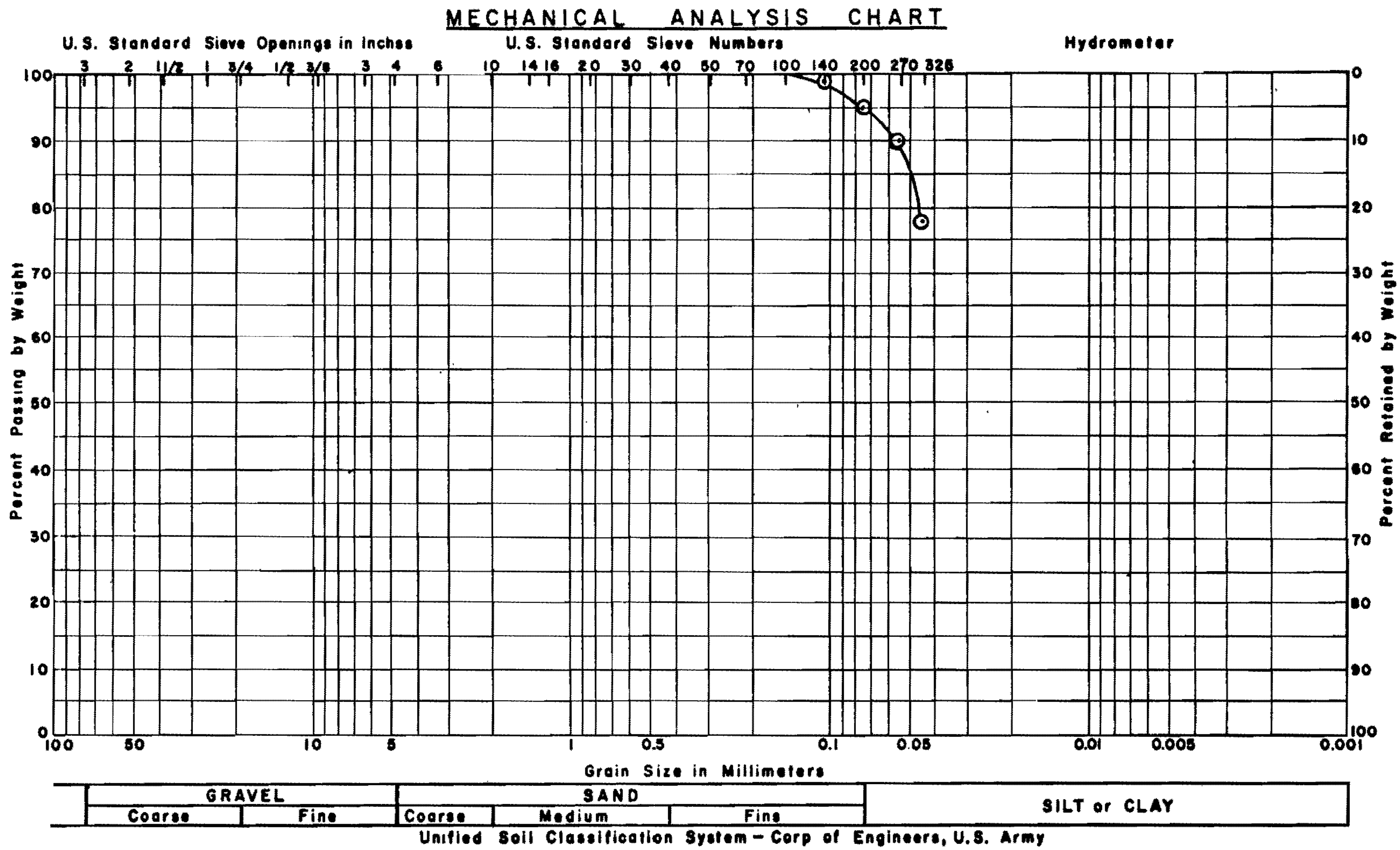

Figure 14. Particle size distribution curve for the District 11 cement.

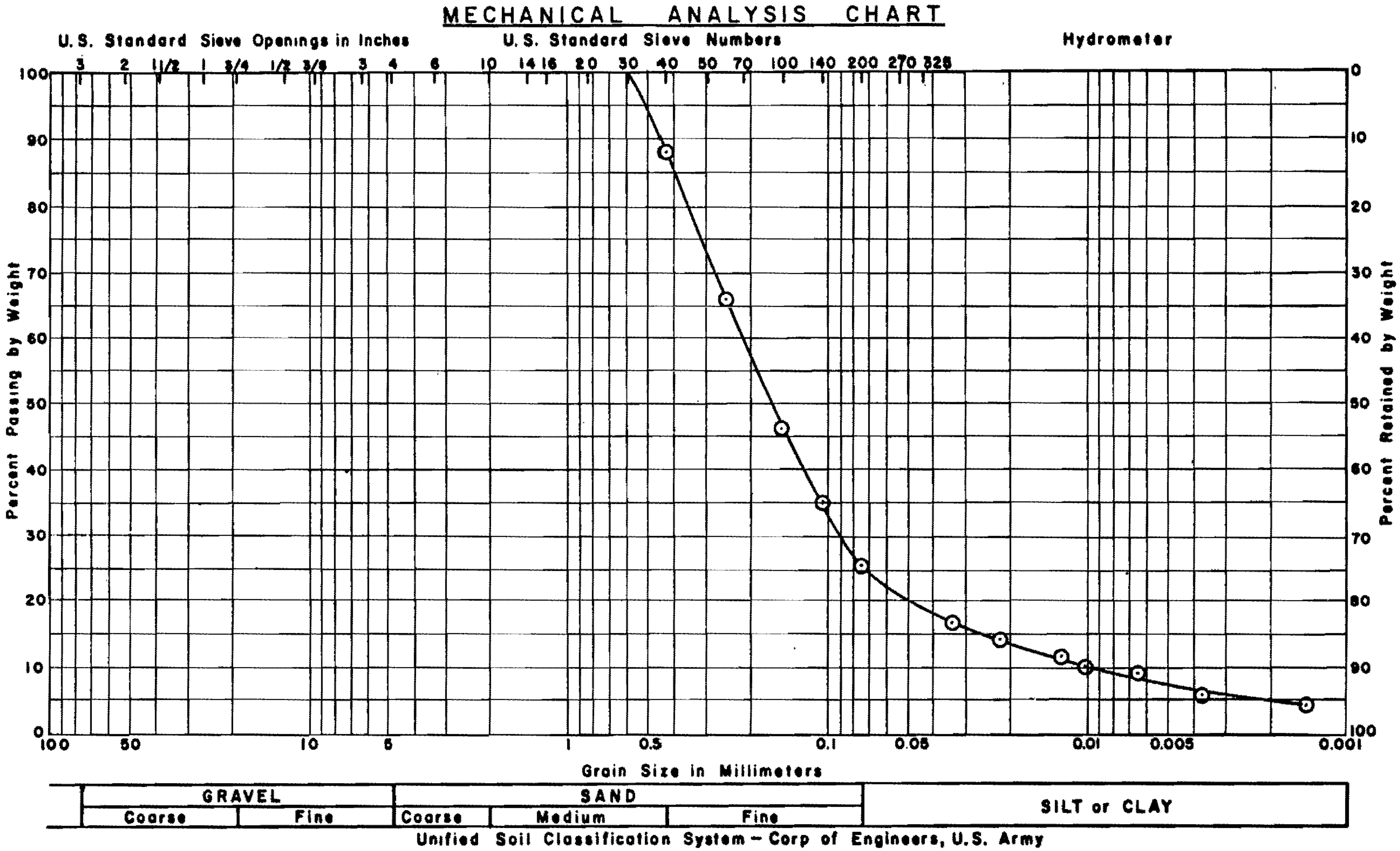

Figure 15. Particle size distribution curve for the TTI silica rock flour.

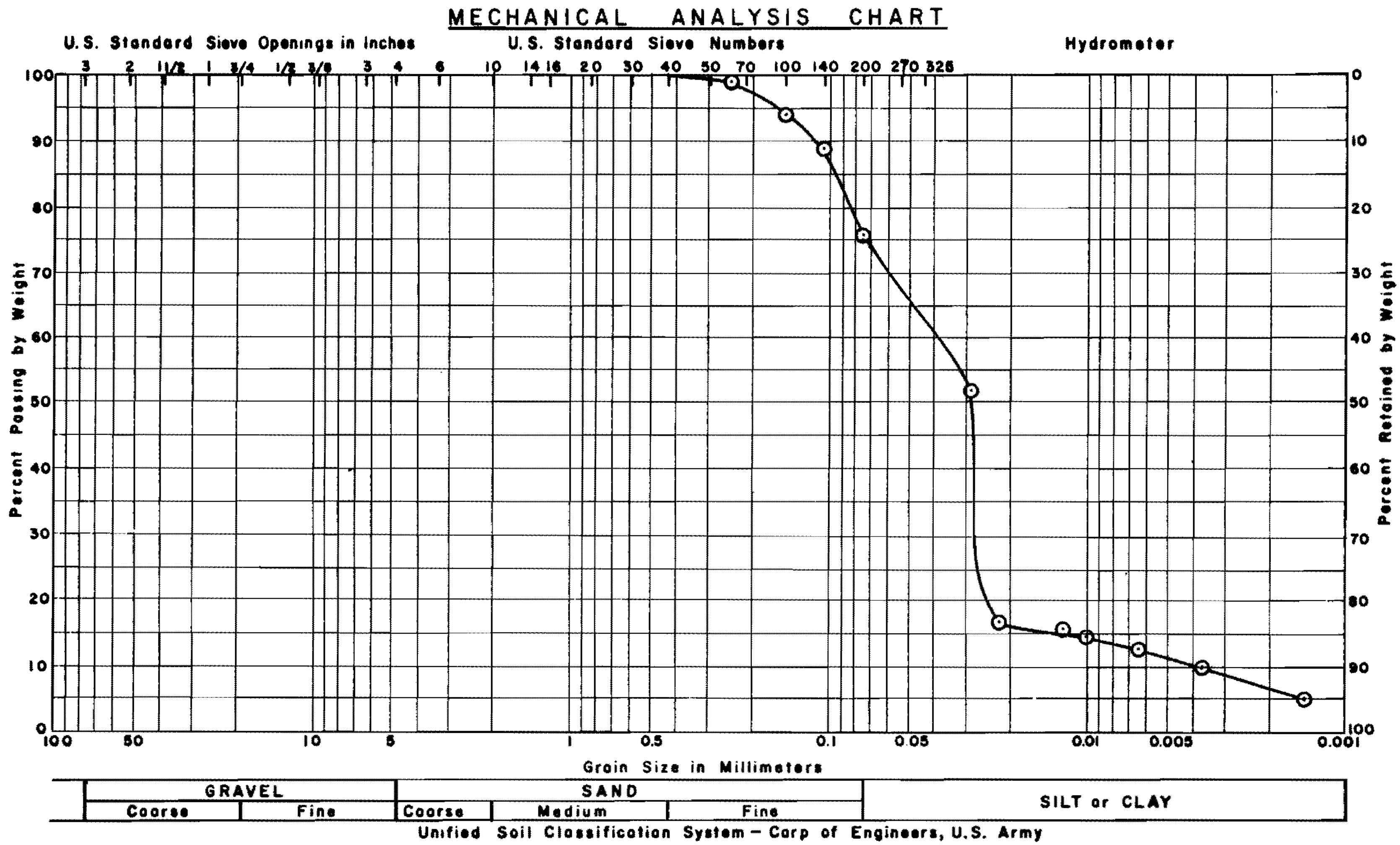

Figure 16. Particle size distribution curve for the calcium carbonate fines.

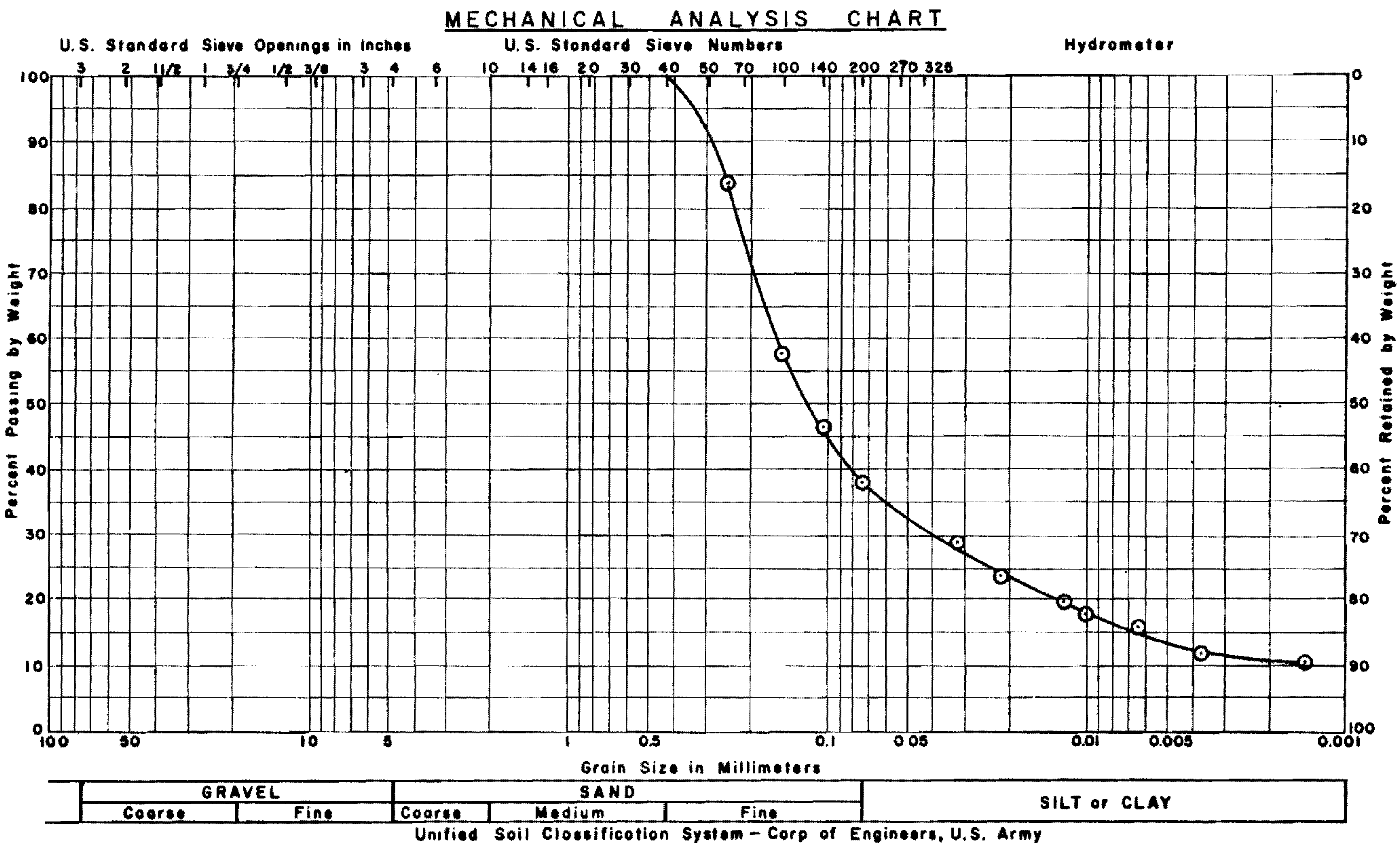

Figure 17. Particle size distribution curve for the District 12 iron ore.

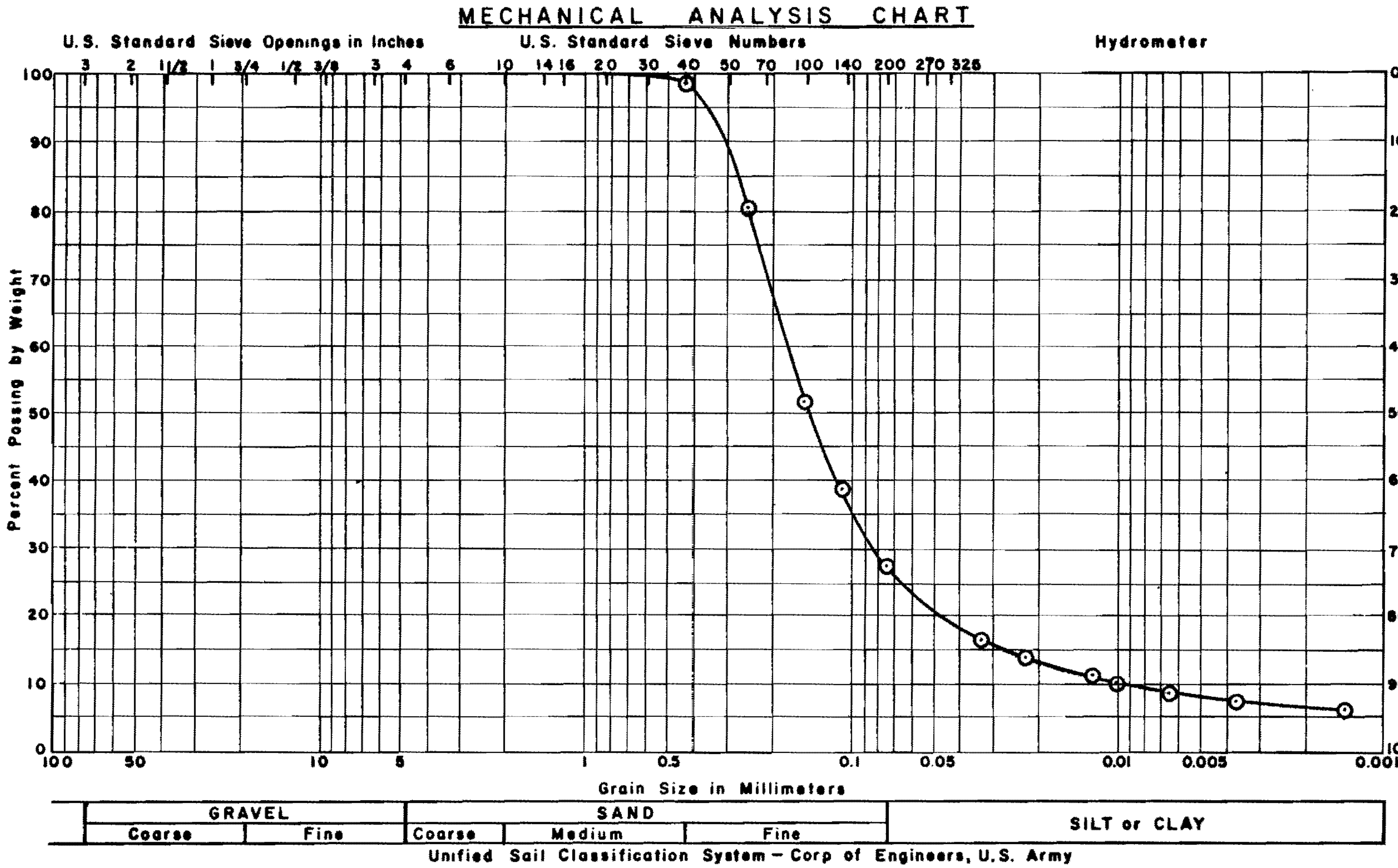

Figure 18. Particle size distribution curve for the District 11 iron ore.

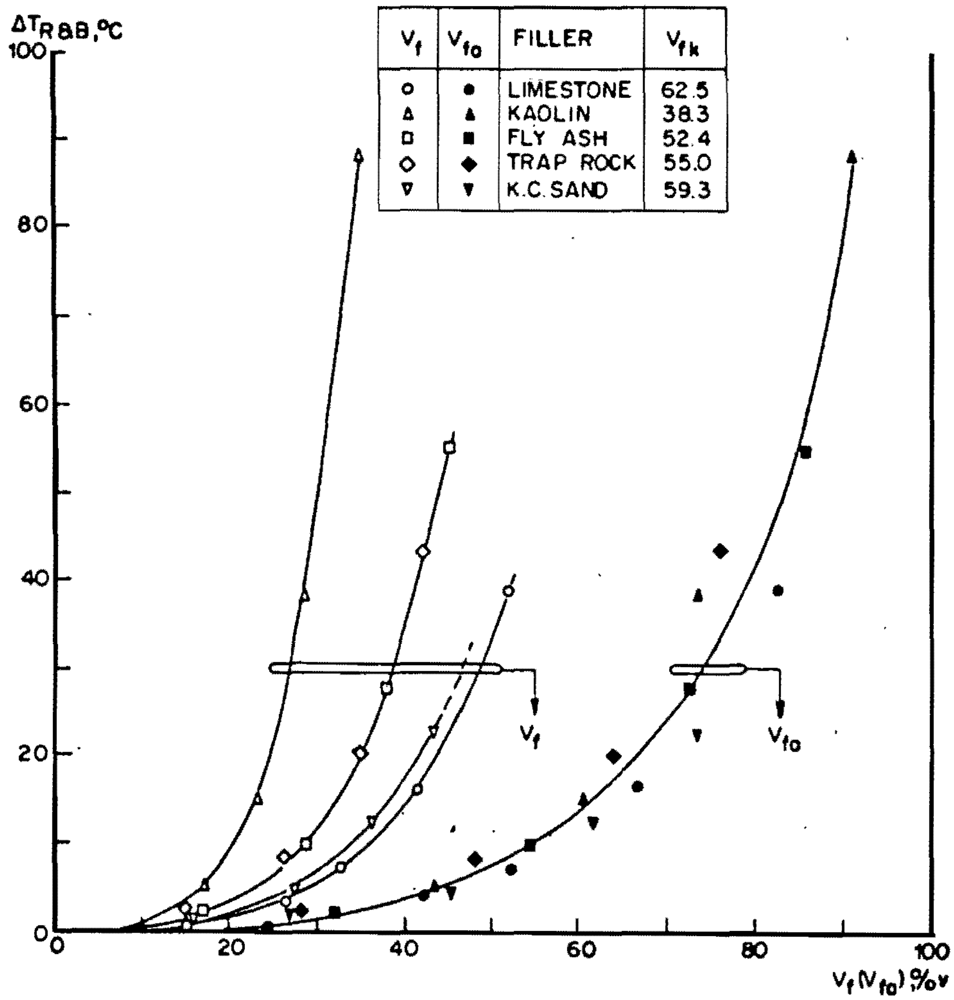

Figure 19. Increase in softening point R&B of mastics according to Warden, et al. of mastics as a function of true and apparent percentage by volume of filler. (2)

APPENDIX A

Definitions of Different Categories of Mineral Fillers (2)

1. Filler

The general category of filler for asphalt paving mixtures includes finely divided mineral particles which are either naturally present in the mineral aggregate or which are added to the mineral aggregate. Filler particles are considered those passing the No. 200 (75 μm) sieve. (One μm is one-millionth of a meter.)

2. Mineral Filler (Added Filler)

This material is that part of the finely divided portion of a hot-mix aggregate gradation which is not present naturally and has to be added to beef the gradation up. Particles sizes of htis material are smaller than the No. 200 (75 μm) sieve. If this material contains particles larger, these are considered as "Fine Aggregate" in the preparation and testing of asphalt paving materials.

3. Special Fillers

These materials are finely divided mineral matter water passing the No. 200 (75 μm) sieve which are usually by-products from the processing and production of products other than mineral aggregates and which normally require special handling methods and equipment. Included in this category are bag house fines, fly ashes, flue dusts and others.

4. Filler Additives

These are finely divided materials whose particle sizes are normally smaller than the No. 200 (75μm) sieve and have unusual or unique properties such as being rod-like particles (fibers), polymers (including rubber) or asphalt extenders such as carbon black and sulphur. Hydrated lime is included in the group of filler additives since it is highly surface active and its use is normally restricted to two percent or less by weight of a hot-mix.