NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT 252

ADDING DUST COLLECTOR FINES TO ASPHALT PAVING MIXTURES

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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ADDING DUST COLLECTOR FINES TO ASPHALT PAVING MIXTURES

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AREAS OF INTEREST:

BITUMINOUS MATERIALS AND MIXES
MINERAL AGGREGATES
(HIGHWAY TRANSPORTATION)
(AIR TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. DECEMBER 1982

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

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FOREWORD

By Staff
Transportation
Research Board

Many asphalt mix plants must now include collection equipment that captures dust particles in the exhaust gases. Rather than wasting these fines, it is often permitted to reintroduce them into the production process as part of the mineral filler fraction. To capture very fine material suitable for reuse, secondary collection equipment called "baghouses" are commonly used. Accordingly, individuals involved in the production, specification, or control of asphalt mixes, and particularly those now using or contemplating the use of collected dust fines, will find the report of special interest. The report contains a state of the art derived from past and present studies and current practices on the effects and handling of mineral fillers and dust fines, conclusions based on actual samples on the characteristics of dust fines, and recommendations pertaining to dust handling procedures. Researchers should also find the report an excellent resource document for future pursuits. The raw test and classification data on dust samples from a variety of asphalt plant configurations and aggregate types are included.

In various parts of the country, environmental regulations require controls on the emission of dust from asphalt mix plants because of ambient air quality standards on particulate matter or as a general requirement to prevent a public nuisance. Therefore, to meet regulations or to avoid being a public nuisance, many plants capture dry dust particles from exhaust gases. To capture very fine materials, secondary collection equipment called baghouses are commonly used where dust is prevented from entering the atmosphere by fabric filters. As a good business practice and when permitted, dust fines are reintroduced as part of the mineral filler fraction in the production of the asphalt mix. However, because difficulties exist in characterizing the dust fines and ensuring a uniform mix, the reuse of dust fines becomes suspect in various field problems associated with the placement of asphalt pavements. The sponsors of the NCHRP recognized this situation, and, as a result, The Pennsylvania State University was selected to conduct NCHRP Project 10-19, "Adding Dust Collector Fines to Asphalt Paving Mixtures."

The report contains a state of the art on the effects and use of mineral fillers in general and collected dust fines in particular. The report also documents the results of study on the characteristics and variability of baghouse dust collected from asphalt mix plants representative of different plant types (drum mix and batch), generic aggregate types, and dust collection systems. The report also contains recommended guidelines for the proper handling of dust and the actual test data on samples of dust.

CONTENTS

ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 10-19 by The Pennsylvania Transportation Institute of The Pennsylvania State University. The work was carried out under the direction of Dr. David A. Anderson, who served as the Principal Investigator.

Joseph P. Tarris acted as the principal research engineer and coordinated the field studies. Mark Goodman, Senior Research Technologist, and Steve Chrismer conducted the testing in the laboratory. Special appreciation is extended to all the plants that graciously participated in the study. Carl Lubold, Jr., of The Asphalt Institute was especially helpful in reviewing plant sampling procedures. The cooperation of Dr. Don Brock, ASTEC Industries, and James Scherocman, Barber-Greene, is also gratefully acknowledged.

ADDING DUST COLLECTOR FINES TO ASPHALT PAVING MIXTURES

SUMMARY

As a result of stricter air pollution codes, many asphalt plant operators have added filter fabric baghouse dust collectors to asphaltic concrete mixture plants. The baghouses have made available large quantities of fine dust that were previously wasted to the atmosphere. Many asphalt plant operators are now adding this dust to asphalt mixtures as a partial or total replacement for mineral filler.

The objectives of the research were (1) to conduct a state-of-the-art review of the effect of mineral fillers and baghouse dust on asphaltic concrete, (2) to survey current practices and procedures for specifying and handling baghouse dust, and (3) to characterize the baghouse fines currently being collected and used in the industry.

Samples were collected from asphalt plants throughout the United States, representing different plant types, dust collection systems, and aggregate types. The samples were tested in the laboratory to determine day-to-day, within-day, and plant-to-plant variability in the characteristics of the dust.

State-of-the-Art Review

Excessive quantities of baghouse dust can affect the compactibility of asphaltic concrete mixtures. Baghouse dust also can act as an extender for asphalt cement. Most field problems related to baghouse fines, such as obtaining compaction or tenderness, are the result of sudden increases in the quantities of dust fed into the plant from the handling system. These variations are due to improper handling procedures rather than to inherent properties of the dust. Problems have also occurred when a baghouse is added to an existing asphalt plant. Proper application of mixture design criteria, such as Marshall (or Hveem) properties and void criteria, as part of plant process control would minimize the effect of changing from one source of dust to another. Insufficient data exist in the literature to determine the effect of dust properties on basic mixture behavior such as creep, fatigue, and resistance to the effects of water and asphalt cement aging.

Dust Properties

Considerable plant-to-plant variation was found in the fineness of baghouse dust. The fineness of the dust is primarily related to the gradation of the cold feed and the efficiency of the primary dust collector. Generic aggregate type is not a determining factor in the fineness of the baghouse dust, nor is all baghouse dust fine.

Variations in the gradation of the baghouse dust, day-to-day or within-day, are related primarily to the type of primary collector. These variations are not sufficient to cause significant variations in mixture behavior. However, more study is needed of dusts that exhibit a high degree of stiffening to determine their effect on fatigue, creep, water resistance, and asphalt extension. Until these effects are defined, the development of specifications for dust collector (primary or baghouse collectors) fines is not warranted. Fineness or gradation of the dust is not an accurate indicator of dust performance. Any specifications

should be related to the entire fine (<75 μm) fraction, not to the baghouse dust alone.

Handling Systems

Handling systems varied considerably, according to plant configuration, gradation of the cold feed, design of the dust collection system at the plant, and requirements of the specifying agency. Close attention in plant operations can minimize sudden variations in the quantity of fines fed into the plant.

Each plant should be considered as a unique system because of variations in manufacturers' designs, plant configuration, and aggregate characteristics. Rigid specifications for dust handling procedures may not be cost effective. In the study reported herein, general guidelines for dust handling procedures were developed for both drum mix and batch plants.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT AND RESEARCH OBJECTIVE

In the past decade, many states have promulgated strict air pollution control codes and standards regarding the emission of particulates into the atmosphere. This has brought about an increase in the use of secondary collection equipment, especially filter fabric baghouse collectors. The addition of baghouses, as shown in Figure 1, has resulted in the collection of fine dust, < 30 µm, that was previously wasted to the atmosphere. To help offset the cost of this equipment and to avoid the accumulation of a waste product, asphalt plants are using the baghouse dust as fines in paving mixtures. A study by The Asphalt Institute (1) indicates that baghouse fines can perform as well as standard filler materials, but it is important that the fines be obtained from good quality parent aggregate and be introduced in a manner that yields a controlled mix. Production operations, however, are often not consistent with this recommendation. In many instances, collected fines are returned to the bottom of the hot elevator of a plant, and, in subsequent production operations, this results in surges of fines when materials are drawn from the hot bins. At plants where baghouse materials are directed to the mineral filler bin, other problems arise. There is little or no mixing of collected material with the standard mineral filler, and yet these two sources of fines frequently have different gradations and specific gravities. The quality of the resulting baghouse material becomes questionable.

The objectives of this project were (1) to conduct a state-of-the-art survey of studies dealing with the effect of dust collector fines on asphaltic concrete and current practices for specifying and handling these fines, and (2) to characterize by generic type those dust collector fines now in use.

SCOPE OF STUDY

To satisfy the objectives of the project, a review of the literature on mineral fillers and baghouse fines was conducted, with an emphasis on recent studies, both published and unpublished. Current agency practices were established by interviewing materials and construction engineers from 45 states. Arrangements were made to obtain random samples of baghouse dust at 33 plants, in 12 states, which represent the generic aggregate types in common use in the United States. Dust samples were collected by plant personnel as directed by a project engineer. Plant conditions at the time of sampling were documented by plant personnel. Each sample was tested in the researchers' laboratory to determine within-day, day-to-day, and plant-to-plant variability of the baghouse dust.

RESEARCH APPROACH

Current Agency Practice

To evaluate the specifications, practices, and procedures regarding the use of dust collector fines, a survey of 45 state agencies was conducted. A bituminous materials or construction engineer from each state was contacted to obtain the following information:

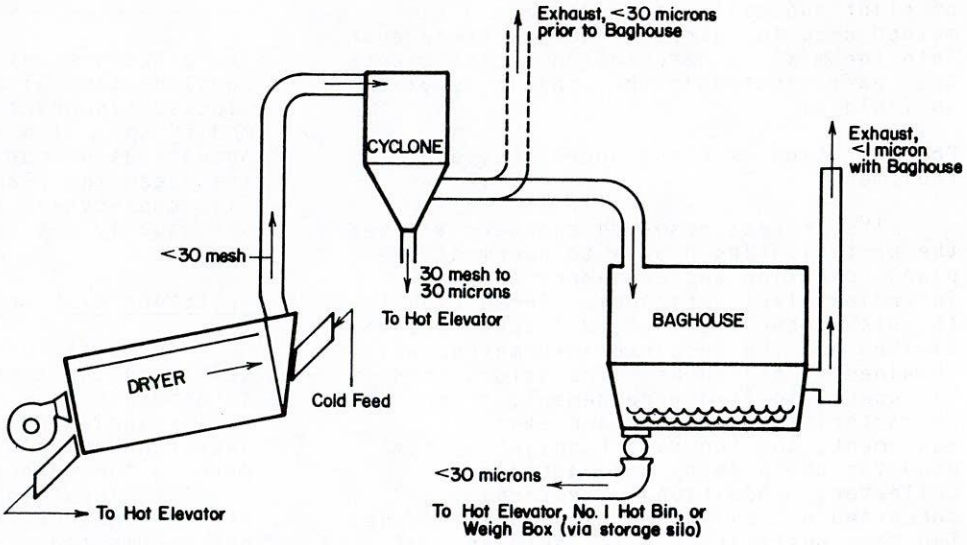


Figure 1. Schematic of baghouse added to batch plant.

1. The percentage of asphaltic concrete plants in the state possessing baghouses.

2. The generic aggregate types used in the state to produce asphaltic concrete.

3. The results of any unpublished studies conducted by the state pertaining to dust collector fines.

4. The current handling requirements for dust collector fines.

5. Pavement problems, past or present, related to the incorporation of baghouse fines into the mix.

A follow-up survey of 26 state agencies was conducted to obtain the following information: the mix design practices within the state, the plant quality control practices, and the specification philosophy of the state (end result versus process control). To gain additional information, the executive directors or technical directors of state pavement associations were contacted. The data collected during these surveys were tabulated and critically reviewed. The surveys also were used as the basis for selecting the plants that participated in the sampling program.

Selection of Sampling Sites

Arrangements to visit plants, to set up a sampling program, and to obtain baghouse dust samples were made at 33 plants located in the following states: Arizona, California, Connecticut, Maryland, New Jersey, New York, North Carolina, Ohio, Oregon, Pennsylvania, Virginia, and West Virginia. Because of insufficient production levels and unanticipated shutdowns, only 27 plants were able to furnish samples.

An attempt was made to include plants that would represent each generic aggregate type. Other criteria used in the selection of sampling sites were the type of plant and collection system and the method used to introduce the baghouse dust into the mix. A description of the plants that participated in the project is given in Table 1.

Documentation of Plant Operations and Equipment

The project research engineer visited the participating plants to document the plant operation and equipment and to interview plant personnel. Three plants (plants numbered 31, 32, 33) could not be visited and the required information was obtained by telephone. The information included cold feed arrangement, dryer characteristics, collection system equipment, and the dust handling system used for the primary and baghouse collectors. Additional questions concerned hot bin characteristics and the fugitive dust tie-in with the plant, if applicable. Plant personnel were asked about plant history, including changes in plant equipment and methods of handling dust.

Sampling Program Methodology

In the course of the plant visit, the researchers furnished the details of the sampling program. These included any plant modifications needed to take the samples, instructions on the physical collection of the samples, determination of the randomized sampling times, and required documentation of plant operations during the collection of the samples. An example of the form used to document the sampling is presented in Figure 2.

Determination of Sampling Times

A sampling program involving five production days was developed. To determine within-day variability, five samples were collected on one day. Four other samples (one on each of the four remaining days) were obtained to evaluate day-to-day variability. In addition, a start-up sample was obtained during one of the single-sample days to permit comparisons of start-up variability. This program specified a total of ten samples to be collected by each participating plant.

The following randomized block design was used to specify a sampling period for the collection of the samples:

Blocked Time Within Day	Day				
	1	2	3	4	5
Start-up			x		
A.M., No. 1		x	x		
A.M., No. 2	x		x		
P.M., No. 1			x		x
P.M., No. 2			x	x	

The procedure was used to select the exact sampling time within each of the five blocks. In practice, it was necessary to modify this plan to accommodate the operations of particular plants. In many instances the plants did not operate for five consecutive days, and the production was usually not continuous throughout the day.

Selection of Sampling Location

Three factors were considered in selecting the sampling location. First, information from the state-of-the-art review indicated that the fineness of the dust can vary along the length of the flow path in the baghouse. Second, the sampling location must be representative of the time when the operating conditions are documented. For example, a sample

Table 1. Characteristics of plants participating in the project.

Plant No.	Plant Type	Aggregate Type	Primary Collector	Baghouse Dust Handling
1	Batch	Limestone	Expansion chamber	Returned to hot elevator via surge bin
2	Batch	Limestone	Single cyclone	Proportioned to weigh box from silo
3	Batch	Traprock	Multiclone	Screw feeder to hot elevator
4	Batch	Traprock	Multiclone	Screw feeder to hot elevator
5	Batch	Traprock	Dual cyclone	Screw feeder to hot elevator
6	Batch	Sand and Gravel	None	Screw feeder to hot elevator
7	Batch	Traprock	Single cyclone	Screw feeder to hot elevator
8	Batch	Limestone/Argillite	None	Screw feeder to hot elevator
9	Batch	Limestone	None	Screw feeder to hot elevator
10	Batch	Sand and Gravel	None	Screw feeder to hot elevator
11*	Batch	Sand and Gravel	Horizontal cyclone	Returned to hot elevator via surge bin
12*	Drum	Limestone/Sand and Gravel	Knockout box	Returned to drum adjacent to A.C. line
13	Batch	Sand and Gravel	Multicone	Screw feeder to hot elevator
14	Drum	Sand and Gravel	Knockout box	Returned to drum adjacent to A.C. line
15	Drum	Limestone	Knockout box and single cyclone	Returned with cyclone dust to drum adjacent to A.C. line from silo
16*	Drum	Limestone	Knockout box	Returned to drum adjacent to A.C. line
17	Batch	Limestone	None	Screw feeder to hot elevator
18*	Batch	Granite	None	Screw feeder to hot elevator
19	Batch	Granite	Horizontal cyclone	Screw feeder to hot elevator
20	Batch	Granite	Single cyclone	Gravity flow to hot elevator
21*	Batch	Limestone	Single cyclone	Screw feeder to hot elevator
22	Batch	Granite	None	Gravity flow to hot elevator
23	Batch	Granite	Multiclone	Weighed separately then added to weigh box
24	Batch	Granite	Single cyclone	Added to weigh box
25	Batch	Granite	Single cyclone	Dust is wasted
26	Batch	Granite	Dual cyclone	Added to weigh box
27*	Batch	Granite	None	Returned to hot elevator via surge bin
28	Batch	Granite	Single cyclone	Added to weigh box
29	Batch	Granite	Single cyclone	Added to weigh box
30	Batch	Traprock	Single cyclone	Screw feeder to hot elevator
31	Drum	Traprock	Knockout box	Returned to drum adjacent to A.C. line
32*	Drum	Sand and Gravel	Knockout box	Returned to drum adjacent to A.C. line
33	Drum	Sand and Gravel	Knockout box	Returned to drum adjacent to A.C. line

*Samples not obtained because of limited production or plant shutdowns, or samples lost in shipment.

taken from a surge bin or storage silo represents a time-averaged sample. Third, the collection of the sample must not interfere with the normal operation of the plant.

Many plants use a storage silo to meter the dust back into the mix. The baghouse dust is pneumatically transported to this silo. To take samples from the silo was considered inappropriate because the possibility of storage dwell time might result in the dust characteristics not being representative of the operating conditions. It was decided, therefore, that the most desirable sampling location was the point at which the dust exits from the baghouse.

The actual sampling location depended on the equipment and setup of each plant. Many plants have a system where the dust exits from the baghouse, falls through a duct, and enters a screw conveyor or the hot elevator. In such plants this duct was found to be an appropriate sampling location. At other plants, a clean-out plug on the bottom of the screw conveyor was the sampling point; or, if a screw was used to waste part of the dust, the sample was obtained from that point. The sampling locations are shown in Figure 3.

Plants that use a pneumatic conveying system to transport the dust to a storage silo were sampled as follows. The sample was obtained through a hole in the dust-carrying line. This line, under pressure, permits material to escape through the hole. Plants that use a fluidizing system were sampled by allowing the fluidizer to fill up, turning the fluidizer off, opening the clean-out hatch, and collecting the material. A third location was the clean-out plug located beneath the baghouse screw at a point just before the dust exits from the housing. When this plug is removed during plant operation, air rushes into the baghouse, preventing material from exiting. However, it was found, in many instances, that the one-gallon paint can used to collect the samples could be abutted against the open plug. By cutting off the false air, the dust would fall into the can.

One-gallon paint cans with securely fitting lids were used for all samples. These cans prevented the absorption of contaminants from the atmosphere that

SAMPLE FORM

1. Agg. Temp. Setting 316
2. Agg. Temp. Leaving Dryer 295
3. Burner Output at Sampling 60%
4. Dryer Exhaust Temp. 310
5. Stack Exhaust Temp. 285
6. Production Rate @ Sampling (TPH) of Cold Feed 170
7. Describe the Dryer Operation over the past 30 minutes?
   a. continuous c. stopped twice
   b. stopped once d. other _____
8. Type of mix to be produced?
   a. wearing d. commercial
   b. base e. other _____
   c. binder
9. What is the damper setting on the exhaust fan at the time of sampling?
   a. 100% open b. 75% c. 50% d. Other _____
10. Have the dampers on the fugitive system been altered since the inspection or last sample?
    a. Yes - opened more b. Yes - Opened less c. No
11. What percentage of primary dust is being returned to the mix aggregate?
    a. 100% b. 75% c. 50% d. 25% e. Other _____
12. What percentage of baghouse dust is being returned to the mix aggregate?
    a. 100% b. 75% c. 50% d. 25% e. Other _____
13. What is the pressure drop across the baghouse at the time of sampling? 9"

Feed Number	In Operation	Moisture*	% of Total Feed	Feed Dial Setting
1				
2				
3	✓	DAMP	33	43
4				
5				
6	✓	DAMP	33	54
7	✓	DAMP	33	46
8				

*Bone dry (no color), Internal Moisture, Surface Damp (color), Free Water (sheen), or Percentage, if available.

Sample Code 20-2-B
Sample Time 9:10
Sample Date 8-25-81
Weather Fair & mild
Sampled by HZT
Plant Insp. _____

SAMPLE TIME DETERMINATION

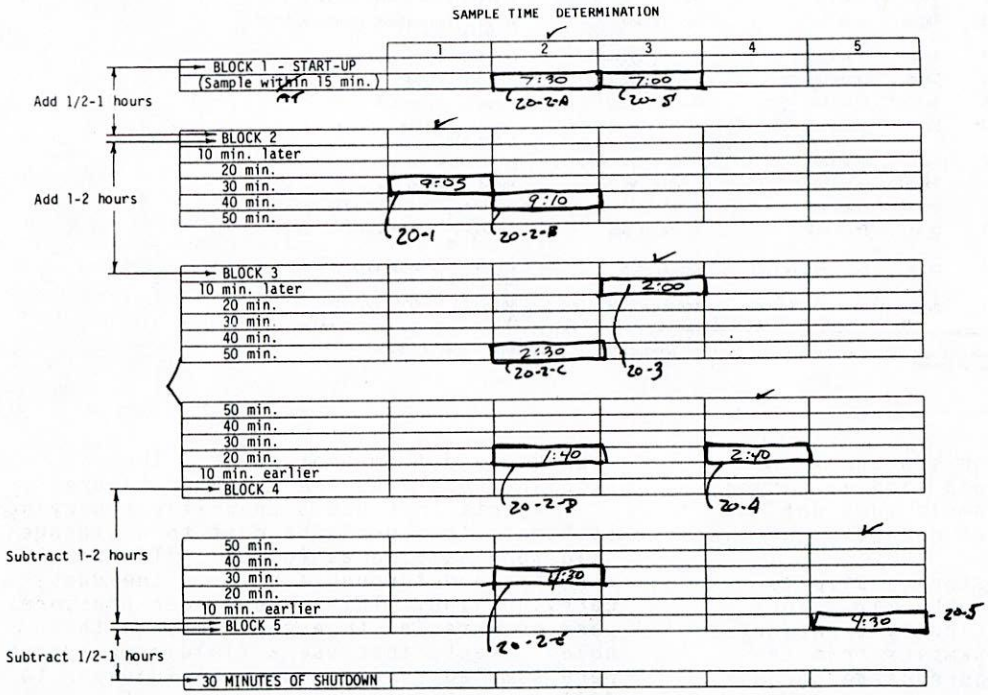


Figure 2. Sample data sheet.

might have occurred had cloth sample bags been used.

Documentation of Plant Operations at the Time of Sampling

Figure 1 incorporates the pertinent operations that can be readily documented at the plant. Because asphalt concrete mix plants do not measure the air flow through the dryer, operations that indicated changes in the dryer air flow were documented, including the exhaust-fan damper setting, the fugitive dust system operation, and the pressure drop through the baghouse. Although not all questions were relevant to both processes, the form was used for both batch and drum mix plant operations.

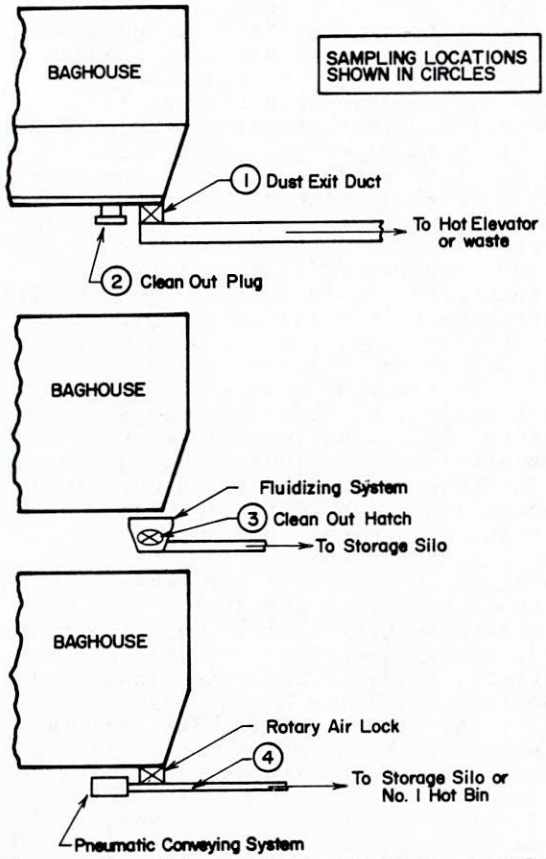


Figure 3. Schematic indicating sampling locations.

Laboratory Characterization of Baghouse Dust

Variability of Dust Properties

The main purpose of the laboratory characterization was to determine the within-day, day-to-day, and plant-to-plant variation in the properties of the dust. Each sample was tested to determine grain-size distribution, Atterberg limits, pH of dust in aqueous suspension, dry bulk (vibrated) density, settled bulk density in toluene and methylethylketone, and hygroscopic moisture. The testing program is presented in Table 2.

Grain-size distribution was determined by wet sieving (ASTM D 242) (2) to determine the percentage passing the No. 30, 50, and 200 sieves. The gradation of the dust passing the No. 200 sieve was determined with a sedigraph manufactured by Micromeritics Instrument Corporation. This device is based on Stokes' law, but a complete grain-size analysis can be completed in 15 to 20 minutes, compared with the 48 hours required for the hydrometer procedure specified in ASTM D 422 (2). The Atterberg limits test (ASTM D 424) (2) was performed to determine if the fines were plastic. Plasticity is caused by the presence of clay minerals. Two liquids, toluene and methylethylketone, were used to determine

Table 2. Characterization tests on baghouse fines.

1. First Series - All Baghouse Fines Samples

   As-received sample
   - Sieve analysis ASTM D242

   Minus No. 40 sieve fraction
   - Atterberg limits ASTM D 424
   - pH of suspension
   - Dry bulk density
   - Bulk density in toluene, methylethylketone
   - Hygroscopic moisture

2. Second Series - Selected Samples

   Minus No. 40 sieve fraction
   - Heat of immersion
   - Air permeability
   - Asphalt mixing
   - Water sensitivity
   - Specific gravity
   - Scanning electron microscope
   - Capillary viscosity
   - Softening Point

bulk density. Methylethylketone is a polar liquid, whereas toluene is nonpolar. Differences in settled density due to the polarity of the settling medium can be attributed to the surface activity of the dust (3). Finally, hygroscopic moisture was determined because a recent report had related hygroscopic moisture content to moisture damage (4).

Range in Properties of the Dust

A series of tests was performed on one of the samples collected from each plant to determine air permeability, asphalt mixing, water sensitivity, and specific gravity. Criteria for the selection of the dust sample were that it be derived from a wearing mixture when possible and that it not be atypical with respect to grain-size distribution.

The air permeability measurement was based on the work of Rigden (5) and Kamack (6), as used by Anderson (7). The test procedure can be used as a measure of the fineness of the dust. The asphalt mixing test is described by Kandhal (4) and is similar to the procedure used in the design of gussasphalt mixtures. This test is a measure of the demand of the dust for asphalt. The water sensitivity test is a standard test procedure for mineral fillers in the state of Michigan (8). Specific gravity, ASTM D 854 (2), was needed for routine calculations in a number of the test procedures. A specific gravity determination was made for a dust sample from each mixture design encountered in each plant.

A series of scanning electron photomicrographs was taken for a typical sample from each plant. The micrograph was used to describe the shape of the dust particles. Finally, heat of immersion data (9) were obtained for five representative dusts, including three different asphalts. Heat of immersion (heat of wetting) is a measure of the bonding energy between the surface of the dust and the asphalt.

Fifteen of the typical dusts selected from each plant were mixed with two different asphalts at two dust-asphalt ratios, and the viscosity at 60 C 140 F and the softening point were determined (ASTM D 2171 and D 36) (10). These tests

were performed to determine the stiffening effect of the dusts.

CHAPTER TWO

FINDINGS OF THE RESEARCH

STATE-OF-THE-ART REVIEW

To comply with air pollution requirements, many hot mix plants have added baghouse dust collector systems. The addition of these baghouse filters has generated fines that were previously wasted to the atmosphere. Many plants are now reintroducing these fines into the plant as mineral fillers. Some engineers have hypothesized that early pavement distress may be a result of this practice because of the quantity and nature of the fines that are being reintroduced (1,4). The literature review is presented in two parts: the first deals with traditional mineral fillers, and the second deals with the dust collected in baghouse collectors.

Mineral Fillers

Mineral filler is finely divided mineral matter, generally passing the No. 200 sieve. It may consist of rock dust, slag dust, portland cement, hydrated lime, ground limestone, and fly ash. Extensive research, much of it from the early part of the century, has been done on the properties of mineral filler and its influence on asphaltic concrete mixtures.

Richardson (11) was one of the first investigators to report on the effects of mineral fillers. He postulated that the function of the filler is more than mere void filling, inferring that some sort of physicochemical interaction occurs when fine mineral dust is added to asphalt cement.

By the late 1930s many studies had been completed on the properties of mineral fillers and mineral filler-asphalt systems. On the basis of an extensive investigation of fillers with respect to their performance in asphaltic concrete, Traxler (12) concluded that the stiffening effect of the fillers could not be reliably predicted from their properties. Traxler considered size and size distribution as fundamental filler properties in that they affect the void content and average void diameter of packed powders. More recent work by Traxler confirms his earlier findings (13).

Mitchell and Lee (3) also attempted to find a single parameter that would adequately predict the ability of a mineral filler to stiffen the asphalt to which it is added. Their data were obtained for mineral filler-asphalt mixtures with relatively small concentrations of solids. Their results indicated that the bulk settled volume of filler in benzene is a good predictor of the performance of the mineral filler.

A very extensive series of experiments on mineral fillers and mineral filler-asphalt systems has been reported by Rigden (5). In particular, he studied the relationship between filler properties and the viscosity of mineral filler-asphalt mixtures. At filler-asphalt ratios similar to those found in typical asphaltic concrete mixtures, the fillers stiffened the asphalt by as much as three orders of magnitude. His data also indicate that fillers affect the temperature susceptibility of the asphalt; however, the stiffening effect did not correlate with any of the fundamental properties of the fillers.

The rheology of mineral filler-asphalt systems has been studied by Winniford (14) using the sliding plate microviscosimeter. Winniford suggested that the role of the filler is more than volume filling, and postulated additional stiffening mechanisms including: (1) a gelation of the asphalt by the mineral surface, which increases the non-newtonian flow characteristics and lowers temperature susceptibility, (2) formation of thick viscous coatings which increase the effective solids concentrations, and (3) surface shielding by absorbed asphaltenes. It was also shown that the stiffening effect of the mineral fillers was more pronounced with smaller sized material.

Tunnicliff has comprehensively reviewed the research on mineral fillers prior to 1967 (15, 16). He concluded that a substantial amount of the mineral filler acts as though it is part of the asphalt film.

Warden et al. (17) presented data on filler-asphalt mixes in conjunction with field observations. This study was motivated by field failures that were attributed to filler type. An easily measured parameter was sought that would predict the performance of the filler in the field. The tests performed on the fillers were empirical tests in use in the late 1950s. A reexamination of the early work by Traxler again demonstrated that no single parameter was sufficient to predict the behavior of different mineral fillers. The softening point of the filler-asphalt mixtures was found to be critical with respect to filler type.

Puzinauskas (18), in reporting on The Asphalt Institute study of mineral fillers, concluded that the mineral filler plays a dual role in asphalt mixtures. He stated that "they are part of the mineral aggregate--they fill the interstices and provide contact points between larger aggregate particles;. . . when mixed with asphalts, mineral fillers form a high-consistency binder or matrix which cements larger aggregate particles together."

Anderson and Goetz (19) used rheological parameters to study the stiffening effect of fine mineral powders on filler-asphalt mixtures. A number of powders were separated into closely sized fractions: 0.63 to 1.25 μm, 2.5 to 5.0 μm, and 10 to 20 μm. Their studies showed that the rheological behavior of the mineral filler-asphalt mixtures depended

on the size and mineral properties of the filler and the source of the asphalt. The stiffening effects of the filler were relatively small at short loading times or low temperatures, but were very large at higher temperatures and long loading times. The temperature susceptibility of the asphalt increased with the addition of mineral filler. The authors concluded that a single test on mineral filler cannot be expected to predict the behavior of the filler in an asphalt mixture.

Craus et al. (20) dealt with the effect of the physicochemical properties of filler on mixture performance. In particular, they examined the geometric characteristics (shape, angularity, and surface texture), adsorption intensity at the filler-asphalt interface, and the selective adsorption of the filler-asphalt system. They concluded that the physicochemical interaction between filler and asphalt increased with the adsorption intensity, geometric irregularity, and selected adsorption of the fillers.

The role of mineral fillers in asphalt mixtures was addressed in a comprehensive paper by Heukelom (21). Bitumen number, dry compaction, and the kerosene absorption test were used to determine the void characteristics of mineral filler. The bulk volume (defined as the total filler volume--filler solids plus voids--at condition of densest packing) determined from the kerosene absorption test yielded a bulk volume approximately 17 percent greater than that obtained from the dry compaction procedure.

Assuming that the penetration index (temperature susceptibility) of the asphalt and the filler-asphalt mixtures is the same, Heukelom measured the softening point of the filler-asphalt mixtures and calculated the stiffness of the mixtures. A unique relationship was found between stiffness ratio (ratio of the stiffness of the filler-asphalt mixture to the stiffness of neat asphalt) and percent bulk volume, $\%V_{DB}$ (defined as the bulk volume obtained from compaction divided by the total volume of the filler-asphalt mixture). When this concept was extended to asphaltic concrete mixtures, it was found that stiffness and compactibility are roughly related to the percent bulk volume of the filler.

Other researchers have related the void properties of the filler to the Marshall mixture properties. For example, Hudson and Vokac (22) have related the activity coefficient to Marshall stability. The activity coefficient is defined as the bulk volume of the filler divided by the solid volume of the filler. The bulk volume of the filler was determined from the settled volume of the filler in kerosene. For a given mixture, it was found that the activity coefficient is related to Marshall stability. It was concluded, however, that stability is a function of both filler type and filler concentration.

In summarizing the work that has been reported on mineral fillers, it can be concluded that:

1. Mineral fillers stiffen asphalt, and the degree of stiffening varies significantly between different fillers.

2. For a given filler source, the finer the filler the greater the stiffening effect.

3. Although performance varies for different fillers, there are no tests that can adequately predict their performance.

Baghouse Fines

A number of recent studies have been conducted on baghouse fines. In general, these studies have been initiated because sponsoring agencies have been concerned about the effect of adding baghouse fines to asphalt mixtures. Many of these studies examined the variability of baghouse fines and the effect of variability on mixture behavior. The first study performed on baghouse fines was conducted by the California Department of Transportation (23) in 1976. In the first phase of this study a limited survey of engineers and plant operators was conducted. The results of the survey indicated that 1.5 to 2.0 percent of the aggregate processed through the aggregate dryer is collected as dust in the baghouse. The survey attributed inconsistencies in the mix that resulted in surface flushing and instability to the practice of returning the dust to the hot elevator. In the second phase of this study the effects of six different baghouse fines on Hveem mixture design parameters were studied. It was concluded that a maximum baghouse fines content of 2.0 percent has little effect on the stability of asphalt mixtures and is beneficial with respect to mixture cohesion. The study also noted that, in general, when an extremely fine mineral dust is added to an asphalt mixture to correct a deficiency in aggregate gradation, a reduction in the asphalt content is required to prevent a loss of stability or bleeding. The added dust is so fine that it combines with and acts like the asphalt binder, effectively increasing the volume of the asphalt in the mixture. The report recommended that contractors be permitted to use as much as 2.0 percent baghouse dust, but it recommended also that the dust be placed either in the weigh box or in the pug mill to ensure uniformity of distribution within the mixture. The report further recommends that the baghouse dust to be used in the paving mixture also be used in the mixture design. This requirement may be difficult to achieve with a new aggregate source, but it points out the fact that different mineral fillers may behave differently.

A study conducted in 1978 by The Asphalt Institute (1) had the following objectives:

1. To analyze the properties of several typical baghouse fines, fines/asphalt mixtures, and asphalt/aggregate/fines mixtures.

2. To compare these properties to known properties of commercial mineral fillers and filler-asphalt mixtures.

3. To determine to what extent the reintroduction of baghouse fines affects asphalt mixture properties and asphalt pavement performance.

It was found that significant variations in gradation occurred in the fines sampled from different plants. The report concluded that the quality of baghouse fines is satisfactory for use in asphalt mixtures as long as the quality of the parent aggregate is satisfactory. The report also concluded that the dust should be introduced into the mixture in a manner that will result in a "controlled mix." Furthermore, each aggregate-plant combination is unique and must be considered individually. The findings of the study, however, raised two significant questions that remain unanswered: How uniform is the gradation of the fines being discharged from the baghouse? How do the type and the configuration of the plant and plant equipment affect particle-size distribution?

In a study conducted by the West Virginia Department of Highways (24), baghouse fines from 16 sources with a wide variety of particle-size distribution and chemical and physical properties were studied. From three plants, dusts with varying degrees of fineness were analyzed to determine their influence on the Hveem parameters and the dynamic modulus. The study found that the fine dust, primarily 20 µm and finer, tended to combine with the asphalt and act as an extender. The report concluded that baghouse dust can be successfully reintroduced into the mixture as long as the fines are metered or weighed into the mixture. The report further states that when used in proper quantities the dust is not harmful to the paving mixture. It may even be beneficial and can serve as an inexpensive substitute for part of the asphalt. The West Virginia study recommended that both the amount and the size of the baghouse dust used in a paving mixture be controlled. The results of the study are in disagreement with the work of others (4, 7, 12, 15, 19) in that they concluded that grain size can be used as a single parameter to describe the baghouse dust. A triangular classification procedure based on sand, silt, and clay was adopted for specification purposes. The use of the terms silt and clay should be avoided in describing baghouse fines because silts and clay, as defined in customary engineering usage, are not found in baghouse fines. In the proposed specification, the amount of baghouse dust to be added to a mixture is determined from the grain size of the dust.

The Washington State Department of Transportation (25) recently studied the grain-size distribution of 12 different baghouse fines and added three of these fines to two different asphalt cements. The gradation of the baghouse fines varied considerably from plant to plant. The viscosities of the dust-asphalt mixtures were determined, and the mixtures were aged in the rolling thin-film oven test (ASTM D 28) (10). The viscosity of the different mixtures varied considerably and were affected differently by the aging. Temperature susceptibilities (change in viscosity with temperature) and hardening were different for the different dusts and for the two asphalts. The researchers also found that there is little correlation between particle size and the consistency of the dust-asphalt mixtures.

In a study by Dukatz and Anderson (26) of the influence of baghouse fines and cyclone fines on the properties of Marshall samples, it was found that flow and stability were relatively insensitive to the source of the filler or the asphalt, but that the creep compliance of the samples was affected by the stiffness of the filler-asphalt mixture. Both the fineness of the filler and the source of the asphalt and the filler affected the creep compliance. The researchers also attempted to relate mixture compactibility to the stiffness of the filler-asphalt mixtures and found a limited correlation, indicating that the stiffer filler-asphalt mixtures reduce mixture compactibility.

Kandhal (4), in a comprehensive study of eight baghouse fines and the fines from a primary collector, conducted an extensive characterization program, including the measurement of size distribution, surface area, plasticity index, mineral composition, pH, and void content. Viscosity, penetration, and softening point tests were performed to examine the effects of the dust on the consistency of the dust-asphalt mixtures. A single asphalt was used in the study. No satisfactory relationship was found between the properties of the filler-asphalt mixtures and the size distribution, particle shape, surface area, plasticity index, or mineral composition of the fillers. However, it was found that the bulk volume of the fines correlated with the stiffening of the asphalt. Kandhal defined the "bulk volume of the fines" as the ratio, expressed as a percentage, of the bulk volume of a compacted bed of the fines divided by the solid volume of the asphalt and dust. From the study, Kandhal developed the following specification criteria for baghouse fines: (1) the bulk volume of the fines in a mixture should be less than 50 percent; if the bulk volume is greater than 50 percent, a check on the softening point must be performed; (2) if the bulk volume of the fines is greater than 50 percent, the maximum allowable increase in softening point is less than

11 C (20 F); (3) the percentage of retained tensile strength, based on the Idaho Moisture Sensitivity Test (27), should be greater than 50 percent.

Maupin (28) recently conducted a study on the effect of baghouse fines on mixture voids, stability, and penetration time (used as a measure of mixture tenderness). Two of the mixtures studied contained fine baghouse dust. It was found that increases in dust content produced large changes in mixture behavior and design properties. Two of the mixtures contained relatively coarse dust, and the properties and behavior of these mixtures were not significantly affected by the dust content. The report concluded that the fines should be returned to the hot elevator in a uniform manner. This can be done through the use of time-delay switches to synchronize the dryer and the baghouse return, a surge bin located between the baghouse and the hot elevator, or a silo system. The high cost of the silo system was noted. In this study the triangular classification system developed by West Virginia was referenced. It was recommended that gradation be checked and the percentage of fines reduced if the dust is classified as class 2 or class 3 (as defined by Ref. 24). The assumption made by the study that gradation is a controlling parameter is an oversimplification of the behavior of fine mineral dust (mineral filler or baghouse dust) and can lead to errors in judging the behavior of the dust. Other researchers have shown that gradation alone is not a sufficient parameter to predict either the stiffening effect of a dust or the tendency of a dust to act as a replacement for asphalt (4, 7, 13, 29).

Plant operations and their effects on the properties of dust collected in primary and secondary dust collectors have been reviewed by Anderson and Tarris (29). The maximum size of the particles in the collection system gas depends on the drum gas velocity and can be expected to be in the range of 300 to 500 µm. The gradation of baghouse dust depends in large measure on the existence and effectiveness of the primary collector. Before baghouses were installed, most of the particles less than 30 µm were not captured and were wasted to the atmosphere. Baghouse systems have the potential to collect dust finer than 1 µm.

In another research study (30), different proportions of primary and secondary dusts were added to mixtures and the Marshall properties were measured. The fineness of the dust was not a good predictor of the stiffening effect of the dust, although the finer dusts did produce appreciable stiffening. The dusts that significantly stiffened the mixtures affected the air voids and reduced the compactibility of the mixtures. The finer dusts also acted as asphalt extenders and reduced the air voids.

Anani and Al-Abdul Wahhab (31) examined the effects of baghouse fines on asphalt mixture properties. They found that the addition of baghouse fines increased the optimum asphalt content, increased mixture stability, and decreased the resistance of the mixture to water damage. In their study, the dust that provided the greatest stiffening effect was a primary multicone dust, which was inadvertenently labeled a baghouse dust.

A number of state agencies have performed limited studies that have not been published. Georgia and Vermont found that the grain-size distribution varied considerably between different plants and aggregate sources. However, little variability was observed within the plant.

Kentucky has evaluated the baghouse fines from 25 to 30 plants for grain-size distribution and Atterberg limits. The properties of the baghouse fines were found to be very similar to those of commercial mineral fillers. On the basis of these findings, the state has permitted the contractor to use the same storage silo for baghouse fines and commercial fillers.

Louisiana has evaluated the dust collected from the baghouse of a drum mix plant by emptying the dust into 55-gallon drums. The feed rate from the baghouse into the drums was nonuniform and was attributed to either a nonuniform feed system or irregularities in the baghouse cleaning system. As a consequence of these findings, the State now requires a surge system for the return of baghouse fines.

Prompted by reports of poor compaction and pavement brittleness, Iowa is conducting a study of baghouse fines. Although no conclusions have been reached, plasticity indices as high as 20 were found for dusts collected in plants using natural gravel. On the basis of reports of field performance, a maximum fines/asphalt ratio of 1:3 (volume basis) has been adopted pending the outcome of the study. In summary, the review of the literature on baghouse dust indicates:

1. The size of the dust collected from baghouse collection systems depends on the parent aggregate, the plant configuration, and the operating conditions at the plant.

2. When possible, the mix design should incorporate the same dust that will be used in the actual mixture.

3. The behavior of dust in a mixture cannot be predicted on the basis of fineness alone. Additional testing of the dust is required to predict its behavior.

4. Fine dust can act as an asphalt extender, but it can also interact with the asphalt cement and stiffen the asphalt.

GENERIC AGGREGATE DISTRIBUTION

A generic aggregate is a group of materials of similar mineral composition and method of formation, produced either naturally or artificially. The Bureau of Mines classifies natural stone into nine generic types: granite, limestone,

marble, marl, sandstone, shell, slate, traprock, and miscellaneous (32). Only four of these generic aggregate types contributed significantly to stone production in the United States in 1977: limestone (74%), granite (11%), traprock (8%), and sandstone (3%).

Natural sand and gravel are products of disintegration or decomposition and exist in an unconsolidated or uncemented state. Because of the extreme variety in the distribution, frequency of occurrence, quality, and mineral properties of natural sand and gravel deposits in the United States (33), it is difficult to classify a sand or gravel as a generic aggregate type, although in many cases a single aggregate type may predominate. Consequently, most natural sand-gravel deposits are grouped in a special sixth generic aggregate type--natural sand and gravel.

The distribution of generic aggregate types in common use in the United States was determined from a review of the literature (33,34) and from discussions with state agency personnel. This information is summarized in Figure 4.

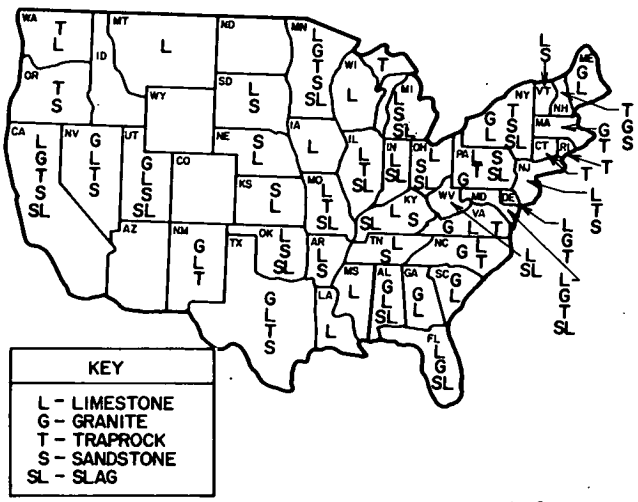


Figure 4. Generic aggregates used for asphalt concrete.

BAGHOUSE DISTRIBUTION

The percentage of plants that contain baghouse dust collection systems is shown on a state-by-state basis in Figure 5. The data in Figure 5 were collected by interviewing state agency personnel or paving association representatives in each state. The distribution of baghouse collectors is concentrated in the northeastern states, especially in New England, and in the Southeast and the western states of Oregon and California. Almost all of the plants in southern California have baghouses.

Several factors have influenced this distribution. First, many states with a high percentage of baghouses are highly

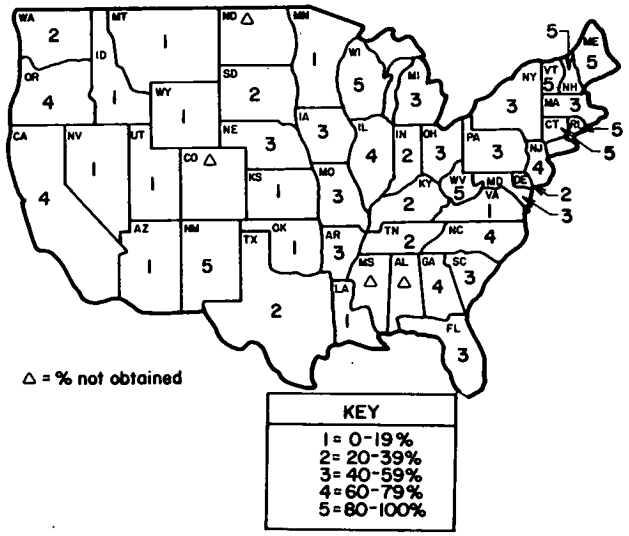


Figure 5. Percentage of plants equipped with baghouses.

urbanized and were governed by local air pollution codes before the federal regulations were promulgated. A second factor is the availability of water. Plants in areas subject to water shortages rely on a baghouse collector instead of a wet collection system. A third consideration is the design philosophy of the manufacturer. In the Northwest, where the Boeing drum mix plant is common, a wet collector or a dry cyclonic collector is used to collect particulate emissions.

Economic considerations also have made the baghouse attractive to many operators. The baghouse permits dust to be recovered in a usable form, replacing material which previously had to be purchased, handled, and heated. Because the baghouse does not require a sludge pond for operation as does the wet system, the costs and disposal problems associated with this pond are obviated. Often, these ponds require regular cleaning, the frequency depending on the pond's capacity and the plant's production. Cleaning the pond and hauling the sludge away involves labor and equipment costs.

CURRENT AGENCY PRACTICES

A description of state agency practices for 45 states is presented in Appendix A. Information was obtained on dust handling, mix design, plant control, and specification philosophy.

Handling Requirements

Of the 45 state agencies surveyed, the current handling requirements for the baghouse dust collected in batch plants can be broken down as follows:

1. Twenty-four states do not specify the method of handling dust. Contractors are permitted to choose a method.

2. Three states (New York, New Jersey, and Maryland) specify that the dust must be returned uniformly to the system.

3. Six states (Michigan, Minnesota, Missouri, New Mexico, Ohio, and Wisconsin) specify uniform return to the hot elevator.

4. Four states (Indiana, Louisiana, Tennessee, and Washington) specify the use of a surge system to return the dust to the hot elevator.

5. Four states (California, Rhode Island, Illinois, and Kentucky) require the dust to be returned to the weigh box.

6. One state (Arizona) is in the process of rewriting its specification.

7. Three states were not considered because they have no plants with baghouses.

It is difficult to generalize about agency practice because of the many variations in handling procedures that result from special conditions within the state or at a particular plant. Of the six states that specify the hot elevator return, only Michigan prohibits a contractor from using a system to return the dust to the weigh box. Michigan requires the hot elevator return in order to avoid the possibility that dust collected during the production of a nonspecification mix will be cycled through the filler silo and added to a specification mix.

Illinois currently permits one contractor to return the baghouse dust to the hot elevator. The aggregate at this plant is deficient in fines, and a commercial mineral filler must be added at the weigh box. Furthermore, this plant, unlike other plants in the state, does not have a primary collector. Consequently, the baghouse dust is coarser than the commercial mineral filler. To return the baghouse dust to the same silo used to store the filler may result in a variation in the gradation of the combined dust and filler. The contractor, therefore, is being allowed to return the baghouse dust to the hot elevator on a trial basis. One plant in Illinois now uses a dual silo concept: one for filler and one for the baghouse dust. As mentioned, most plants have a primary collector; the particles of collected baghouse dust are similar in size to those of many commercial fillers, many of which may also be collected by a baghouse.

Kentucky's specification is unique in that if 40 percent or more of the fine aggregate for a mixture is a natural, conglomerate, or crushed sandstone sand, return to the hot aggregate at any point is permitted. If less than 40 percent of the fine aggregate is natural, the dust must be returned to the weigh box. The 40 percent breakpoint represents the percentage of sandstone sand required to provide adequate skid resistance in wearing courses.

Tennessee requires a surge system if return of the dust to the hot elevator is to be attempted. Most plants, however, have elected to return the dust to the weigh box, utilizing the filler silos that previously were used to handle the commercial fillers.

With respect to the dust collected in the primary collector of a batch plant, only three states--California, Illinois, and Kentucky--have specific handling requirements. The other states either indicate that the handling method is to be left to the contractor or do not distinguish between the dust collected in the baghouse and that collected in the primary collector.

California permits the dust from the primary collector to be returned uniformly to the hot elevator. Illinois' requirements are similar except that a small surge bin must be used to ensure uniformity. Kentucky permits return to the hot elevator provided that the dust from the primary collector does not contain an appreciable amount of material (about 10 percent) passing the No. 200 sieve.

For drum mix plants, only three states--Illinois, Indiana, and Louisiana--specify a handling method for baghouse dust. These states have similar specifications. The dust is to be returned at a uniform rate at the point where the asphalt cement is added to the dryer. The remaining states either do not address drum mix plants, leave the handling method to the contractor, or require only that the dust be returned uniformly.

Mixture Design

Mixture design practices were found to vary considerably. Of the 26 states surveyed, 19 use the Marshall method and 7 use the Hveem method of mixture design. Only four states (California, Rhode Island, New York, and Connecticut) indicated that the mixture design was performed with material obtained from the hot bins. All the others reported that stockpile material was used. The question of whether a washed or a dry sieve analysis was used for the mix design produced an almost even response. Only one state, Illinois, reported substituting a standard filler for the natural dust found in the stockpile aggregate. Many states perform stripping susceptibility tests on the mixture, specifically, the immersion-compression, Lottman, and boiling tests.

Plant Control Practices

The most common plant control practice is to perform extractions. Extractions may be made on a tonnage basis (1 per 500 tons to 1 per 1,000 tons) or a given number of extractions may be carried out per day. Whether the extractions are performed by the contractor or by state

personnel depends on the state, and the required method of performing the extractions varies. Many states specify the vacuum method while others prefer the centrifuge or the reflux method.

An additional consideration is the application of an ash correction to the extraction results. The ash correction accounts for the fine dust that is carried into the solvent/asphalt cement solution during the extraction process. The means of accounting for this dust varies. Many states apply no correction factor. Some apply a set factor based on previous experience with the plant. Still others perform the ash correction either by centrifuging, vacuum, or by burning the solution from the fines.

A second common method of plant control, used in eight states, is to test Marshall samples, compacted at the plant, for stability, flow, and density. A third method is to check the gradation of each hot bin. As extractions become more widely performed, the practice of checking gradation has decreased. However, many plant operators continue to do this as a means of monitoring the formation of holes in the hot screens.

Specification Philosophy

To account for the varied approaches to the handling of baghouse dust, a follow-up survey was conducted in 27 states to determine the specification philosophy of the state. In particular, the question was asked whether the state employs an end result or a process control philosophy. Eleven states reported an end result philosophy, 12 used process control, and 4 reported a philosophy based on a combination of the two. However, five of the states using process control reported that they were converting to end result specifications.

The criteria for end result specifications vary considerably. Vermont bases payment on the ride quality. Indiana's payment is governed by a committee. Many states base the payment on variations in asphalt cement content, field density, and particular control sieves (although other states, like South Carolina, base the gradation payment over the entire band of sieves). Often the No. 200 sieve is a control sieve; Ohio, however, uses No. 100 as the smallest control sieve.

PLANT EQUIPMENT AND OPERATIONS

A detailed description of plant equipment and operation is presented in Appendix B. Three types of hot mix asphalt plants are in use in the United States: batch, drum mix, and continuous. The drum plant is gaining in popularity, but batch plants still predominate. Figures were not available for the total tonnage produced in each plant type. The batch plant probably accounts for the largest number of plants; however, many of these are small and used to a limited degree, whereas many of the drum mix plants are very large. Continuous plants were once popular because of their portability, but, since the advent of the drum mix plants, they are little used and therefore are not discussed separately in this report. The following discussion of batch plants is, for the most part, applicable to continuous plants.

The asphalt mix plant must be considered as a processing system with a series of interrelated steps. Flow diagrams illustrating the process steps for a drum mix and batch plant are given in Figures 6 and 7, respectively. Each of these steps can affect the properties of the dust collected in the plant. Factors that must be considered in determining the properties of the collected dust include the characteristics of the cold aggregate, entrainment of dust in the system gas, the dust collection system, the dust handling system, and the dust generated during plant processing (degradation).

Characteristics of the Feed Material

The characteristics of the cold feed material play an important role in the quantity and grain-size distribution of the material that becomes entrained in the system gas and is removed by the collection system. With respect to the quantity of material entrained, the percentage of material in the cold feed that passes the No. 30 sieve (595 μm) is important. Aggregate as coarse as the No. 30 sieve (595 μm) can be entrained in the system gas (35). Other characteristics that determine the quantity and grain-size distribution of the collected dust include the moisture content of the cold feed aggregate (36), the tendency of the fine material to agglomerate and adhere to the coarse aggregate (37), and the resistance of the aggregate to degradation.

Another significant factor is the size distribution of the fines in the cold feed. As discussed later and substantiated in the literature (38), this distribution varies from source to source. Dust suppressants are sometimes used to control dust during quarrying and plant operations. These suppressants may also influence the quantity and size distribution of the material that becomes airborne in the dryer.

Entrainment of Dust in the System Gas

Batch Plants

For the direct-fired, counterflow dryer typically used in the batch plant, the amount of dust entrained in the system gas is a complex function of the aggregate that is being dried, the drum gas velocity, the number of flights in the drum, the rate of rotation of the drum, and the construction of the breeching at the feed end of the dryer (39). Other factors influencing the amount of dust entrained are the moisture content of the aggregate (40), the feed rate (41), and the flight arrangement (42).

The most significant factor that determines the amount of dust entrained and the maximum size of the dust is the drum gas velocity (43). Drum gas velocity is defined as the volume flow rate of the gas through the dryer divided by the cross-sectional area of the dryer (44). Studies by Barber-Greene showed that the dust entrained in the system gas increases in direct proportion to the square of the exhaust gas velocity (45). Typical drum gas velocities in the batch plant dryer vary from 600 to 1,000 ft/min (38). At these velocities, particles between 500 and 700 μm have the potential to become airborne. Increasing the drum gas velocity from 600 to 1,000 ft/min will increase the dust carryout by approximately 25 percent (36).

Variability in the drum gas velocity may be caused by changes in the position of the damper (46), changes in the pressure drop through the baghouse (43), and leaks in the ductwork or the primary collector. Combined leaks equivalent to 1 ft^2 in the ductwork may result in a loss of 10,000 cfm through the dryer (47) for a 96-in. dryer. This corresponds approximately to a 200-ft/min reduction in drum velocity.

The fugitive dust system on the batch plant collects dust from the hot elevator, hot screens, hot bins, weigh box, and pug mill (48). The size distribution of this dust has been found to be much finer than the dust entrained in the rotary dryer (41). The magnitude of the proportion of the fugitive dust to the total dust collected is not well documented. It has been reported that if the fugitive dust system is operating properly, the fugitive dust should not significantly affect

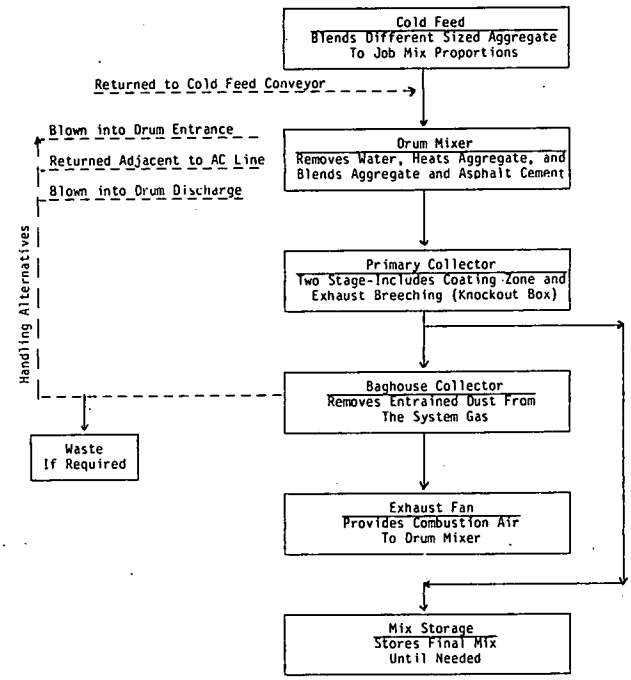


Figure 6. Dust flow through the drum mix plant.

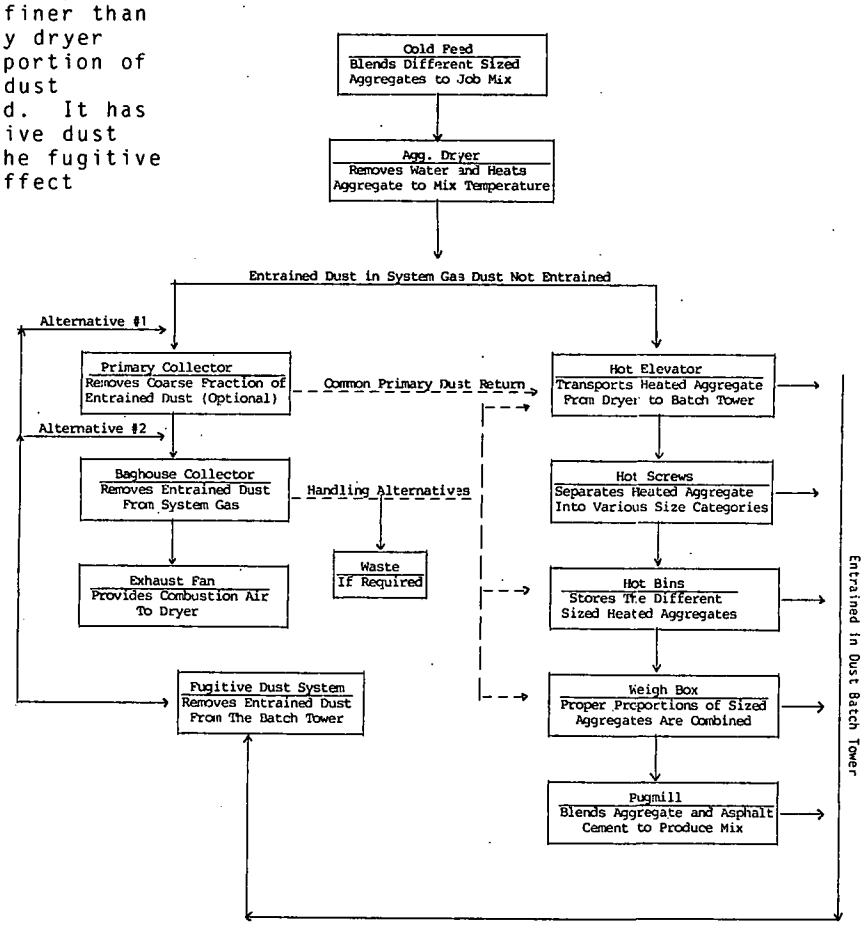


Figure 7. Dust flow through the batch plant.

either overall grain-size distribution or collector efficiency (49). In another report, however, the fugitive dust system is said to contribute up to 20 to 30 percent of the total entrained dust collected in the system (43). If the plant is well maintained and leaks are kept to a minimum, the amount of dust contributed by the fugitive dust system may not be significant.

Although the factors discussed above contribute to the quantity and grain-size distribution of the fines in the system gas, the plant-to-plant variability is largely a reflection of the fines in the cold feed. Entrainment in the system gas of 1.5 to 4.5 percent of the feed material has been reported (50). A loading of up to 10 percent of the feed material was observed in one case (49). Danielson (41), in a report on the dust loading in the system gas at eight installations, found the typical loading to be from 40 to 70 grains per standard cubic foot, with a range extending from 20 to 200 grains. Others have placed the average loading from 20 to 30 grains per standard cubic foot (51). Danielson further reports that only 50 percent of the minus No. 200 sieve material becomes airborne in the dryer.

Drum Mix Plants

In the rotary dryer of a drum mix plant, the flow of material and the system gas move in the same direction. Although many of the preceding comments on batch plants also pertain to drum mix plants, the addition of asphalt cement to the drum complicates the entrainment of dust in the system gas. Another difference between the two types of plants is that the drum mix plant has no fugitive dust system.

Three drum mix plant designs are in current use: Shearer, early entry, and dual zone. In the Shearer process the asphalt cement and the aggregate are combined just prior to the point where the aggregate enters the drum (52). This process ties up the fine dust before it can be entrained in the system gas. At the present time, the Shearer process is not being used in the design of new plants.

In the early entry process, the asphalt cement is added at a point when moisture is still being driven from the aggregate. This moisture limits the amount of dust that becomes entrained in the system gas. Entrained dust must pass through the veil of hot asphaltic concrete. The effect of this coating zone is to scrub the dust from the gas system.

In the dual-zone process, the aggregate is dried and heated in the radiation zone. The asphalt cement is then added in the coating zone (53). The entrained dust must pass through the coating zone which scrubs significant quantities of dust from the system gas.

A unique type of drum mix plant is represented by Plant 15. This plant incorporates a center-outlet dryer design that removes the entrained dust from the dryer before it reaches the coating zone. The emissions from this dryer design are obviously much higher than from a typical drum mix plant.

In summary, the drum mix dryer is an efficient dust collector system. Significant quantities of dust are entrapped in the mixture during the coating process. The coating zone is essentially a primary collector and can significantly reduce the dust in the system gas. An EPA study lists emissions factors for drum and batch plants (18). For drum plants, 4.1 pounds of dust per ton of aggregate were reported, whereas for batch plants 45 pounds of dust per ton of mixture were reported. Care must be exercised in applying these figures to specific plants because they are average values.

Collection Systems

A well-designed and properly operated baghouse has a collective mass efficiency of +99.5 percent (54). Under most conditions, this is sufficient to meet the federal pollution limits of 0.4 grains per standard cubic foot of exhaust gas. Many plants also use primary collectors in advance of the baghouse. The primary collector will affect the quantity and size distribution of the baghouse dust.

Primary collectors include the knockout box, single vertical cyclone (Figure 8), horizontal cyclone (Figure 9), dual cyclone (Figure 10) and multicone (Figure 11). A knockout box is simply a box that contains a baffle plate. As the exhaust gas is forced around the baffle plate, the direction of the gas stream changes abruptly and the coarser particles are removed. Design details vary considerably between manufacturers, and the efficiency of knockout boxes can vary considerably. The knockout box is integral to all drum mix plants because the knockout box forms the exhaust breeching. Knockout boxes may also be used in batch plants although this is not common.

The various types of cyclone collectors are all designed to accelerate the exhaust gas stream so that the dust particles are removed by centrifugal force. A schematic representing this group of collectors is presented in Figure 12. On batch plants, the single vertical cyclone is the most common primary collector, although other types may be found. The efficiency of these collectors is determined by the design of the collector, the operating conditions, and the characteristics of the particulates to be collected (55). Although care must be exercised in evaluating the efficiency of any plant collection system, the efficiency with respect to particle classification increases in the following order: no primary collector, the knockout box, horizontal cyclone, single vertical cyclone, dual cyclone, multicone.

The baghouse, as shown in Figure 13, may be the only collector or it may be used in conjunction with a primary collector. A well-designed, properly operating baghouse, free of holes in the bags, will collect material finer than 1

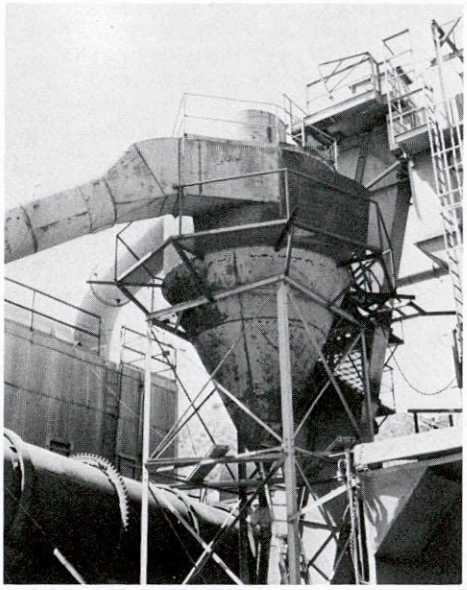


Figure 8. Photograph of vertical cyclone, primary collector.

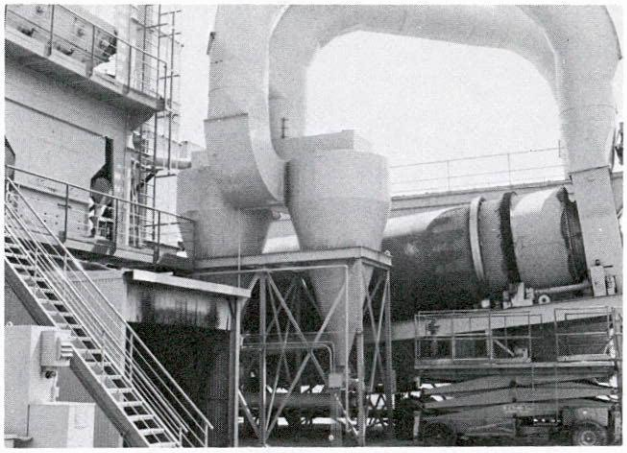


Figure 10. Photograph of dual cyclone, primary collector.

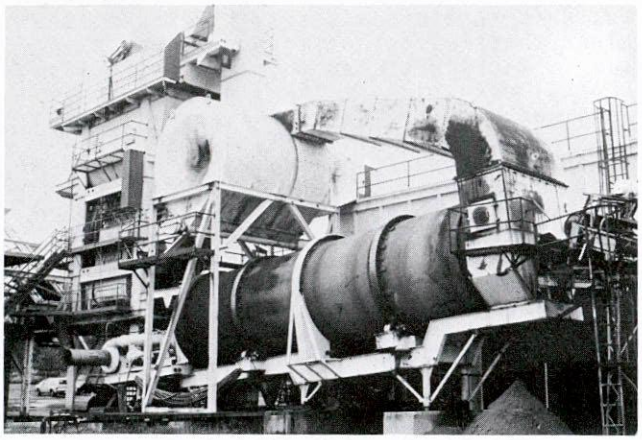


Figure 9. Photograph of horizontal cyclone, primary collector.

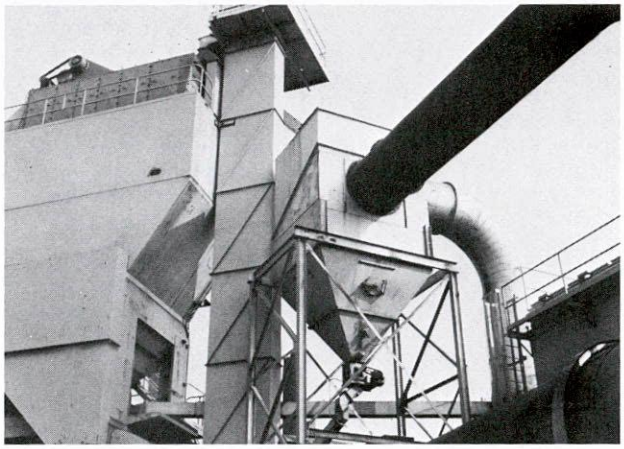


Figure 11. Photograph of multicone primary collector.

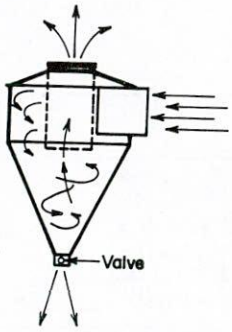


Figure 12. Schematic of operation of cyclone collector.

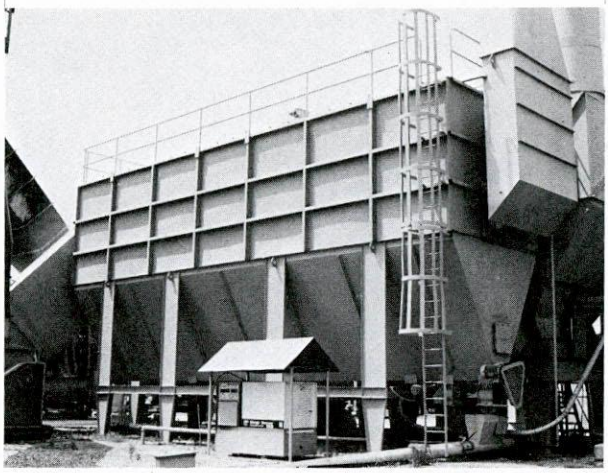


Figure 13. Photograph of baghouse.

μm (44). In contrast, the multicone, the most efficient of the primary collectors, has an effective collection range only down to 10 μm (30). The electrostatic precipitator also is a high-efficiency, dry collector, but it has been used only on one asphalt concrete mix plant (38).

A schematic showing of a baghouse is given in Figure 14. Baghouses are classified as either low-energy or high-energy collectors (44). Low-energy collectors are characterized by a woven fabric, mechanical shaker or reverse air-cleaning system, and low air-to-cloth ratios, typically ranging from 1:1 to 4:1. The air-to-cloth ratio is the number of cubic feet of exhaust gas divided by the number of square feet of filter cloth area. Although the low-energy baghouse was the earliest type developed, only a few units are still in use today. The high-energy units commonly have a felted fabric, air-to-cloth ratios of 4:1 to 7:1, and a pressure jet or centrifugal fan cleaning system (44). The effect of the higher air-to-cloth ratio is to reduce the size of the baghouse housing.

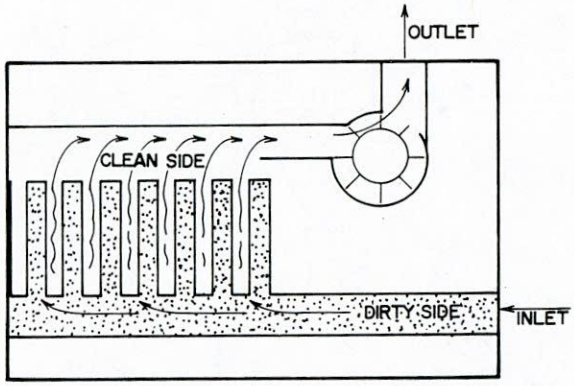


Figure 14. Schematic of filter fabric baghouse.

There are five basic designs for the baghouse collector, characterized by the exhaust inlet and exit location. These are the center plenum; the low air inlet; top entry position at the center of the baghouse length; top entry positioned at the center of the baghouse width; and the knockout design. The fineness of the dust distributed throughout the baghouse may vary according to its design. A well-designed exhaust entry will function as a knockout box to remove the coarser particulates from the system gas (48). This action is designed to extend the life of the bag by reducing the dust load that the bags must handle. Its purpose also is to protect the bags from the high-velocity incoming air. The extent of this knockout action, however, depends on the existence of a primary collector. If a primary collector has already removed the coarser particulates from the system gas, the knockout function of the exhaust entry should be minimal. If the material removed by the knockout action falls into the same collection hopper as the dust removed from the bags, the exhaust entry should be considered as a functional part of the baghouse collector and not a separate primary collector.

Handling Systems

Methods of handling collected dust in asphaltic concrete mix plants may be classified as either closed or open systems. A closed system is defined as a plant that returns all dust recovered in the collection system to the plant. Tight control over the cold feed aggregates is required. An open system is defined as a plant that must waste all or a portion of the collected dust if the final product is to satisfy the mixture design requirements. This situation occurs when the plant cannot blend the aggregates at the cold feed to meet the job mix gradation. If the screenings or sand or both contain excess minus No. 200 material, the dryer will effectively act to wash a portion of that material out of the aggregate.

A plant may perform the following actions to waste the dust: store it on site, return it to the quarry, sell it, or install a settling pond to store the material. The first two options may present difficulties with respect to pollution codes. The most marketable dust is a limestone that can be sold to the farmers as fertilizer. Installing a sludge pond results in the same difficulties and costs associated with the wet collection systems.

Alternatives for the Batch Plant

Dust collected in batch plants may be handled in a number of ways. Dust collected in the primary collector is generally returned to the boot of the hot elevator. This may be accomplished by allowing the dust to fall by gravity through a duct directly from the collector to the hot elevator, Figure 15, or through

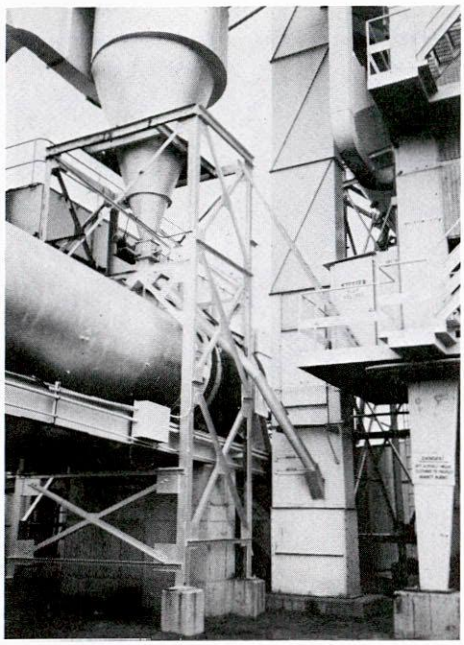


Figure 15. Vertical cyclone with gravity feed system.

a screw conveyor as shown in Figure 16. The dust exits the primary collector through a flop gate, trickle valve, or rotary air lock (48). Baghouse dust is removed from the baghouse hopper by a screw conveyor. A flop valve, Figure 17, or rotary air valve, Figure 18, is used at the end of the screw conveyor to prevent "false air" from entering the baghouse. The dust may be returned to the boot of the hot elevator, the No. 1 hot bin, or the weigh box. The return of material to the boot of the hot elevator may be accomplished by gravity flow from a duct between the baghouse and elevator, as shown in Figure 17, or a screw conveyor, Figure 19, may be used to return the dust directly to the hot elevator. An alternative method of returning the dust to the hot elevator is to use a small surge bin as shown in Figure 20. The surge bin may be fed directly from the baghouse by gravity, screw conveyor, or pheumatic blower system (Figure 21). The surge bin may have low and high bin indicators for monitoring the level of the dust. The dust is removed from the surge bin by a rotary air lock and fed by gravity or a screw conveyor to the hot elevator.

Baghouse dust can be returned to the No. 1 hot bin by transporting it via a pneumatic blower system. The dust exits from the baghouse through a rotary air lock and is blown directly to the No. 1 hot bin.

Dust added to the weigh box is routed through a storage silo. Three methods of adding the dust were found. The dust may be added as a separate material to the weigh box and is listed as such on the batch ticket. The dust may also be weighed on a separate scale and then added to the weigh box. In both cases the dust would be listed separately on the batch ticket. A third alternative is to add the baghouse dust in conjunction with the material from the No. 1 hot bin. This is accomplished by a screw running from the silo to the weigh box. The screw turns in proportion to the weight of material in the No. 1 hot bin. In this method, the dust is part of the No. 1 hot bin weight on the batch ticket.

The pulsing sequence that is used to clean the filter bags can affect the uniformity of the gradation and quantity (with respect to the time) of the dust exiting the baghouse. If there is an appreciable variation in the gradation of the dust that is collected in different parts of the baghouse, the overall gradation of the collected dust can be reflected by the pulsing sequence. Three pulsing sequences are used. The bags can be pulsed in blocks, pulsed sequentially from the front to the back of the baghouse (one or two rows at a time), or pulsed sequentially every fifth row at a time. A random pulsing sequence is preferable with respect to ensuring uniformity and therefore the latter procedure is preferable.

If there is an appreciable variation in the quantity of the dust that is collected in different parts of the baghouse, the pulsing sequence can also affect the uniformity in the quantity (with respect to time) of fines exiting the baghouse. Again, a random pulsing sequence is preferred.

Miscellaneous Comments-Dust Handling Systems

In the foregoing discussion general schemes for handling dust were presented. It should be emphasized that in practice the details of the systems may vary greatly from plant to plant. For example, in one plant that was wasting part of its primary dust (plant 2, App. B) the excess primary dust was diverted into the baghouse hopper. The primary dust was combined with the baghouse dust and routed to the storage silo for disposal or future use as needed. The net effect of this scheme is to increase the size distribution and variability of the dust existing in the baghouse.

Another scheme for removing excess baghouse dust is presented in Figure 22. An adjustable gate valve is used to split the dust into two streams, one that is wasted and one that is returned to the plant. A two-screw system may also be used to split the dust stream into two parts.

Appendix B presents details on the dust handling system of each plant including the historical development of each system. This appendix should be consulted to gain an appreciation of the uniqueness and variety of the dust handling systems that are being used in the plants.

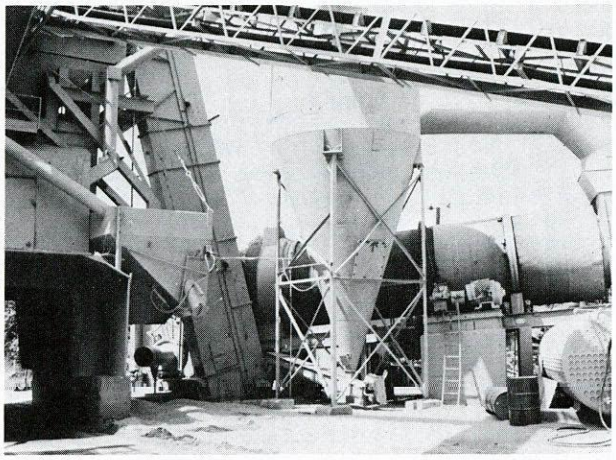


Figure 16. Vertical cyclone with screw conveyor feed system.

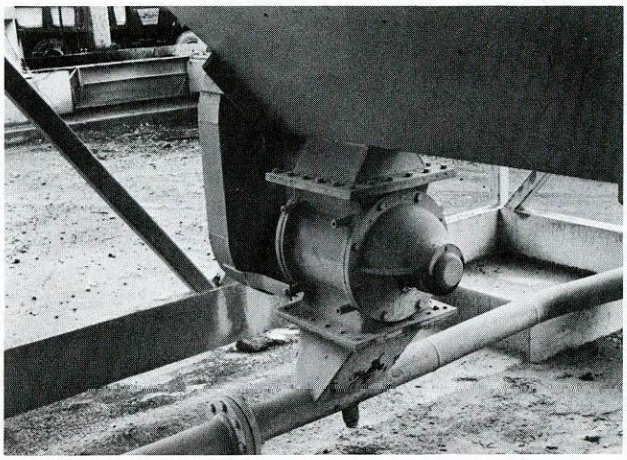


Figure 18. Rotary air-lock.

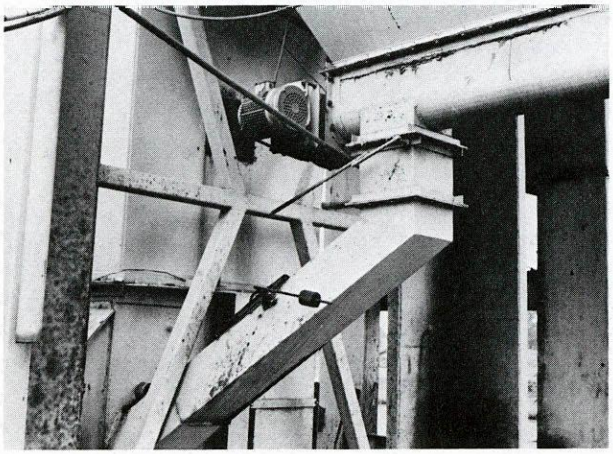


Figure 17. Gravity return of baghouse dust to hot elevator through flop gate.

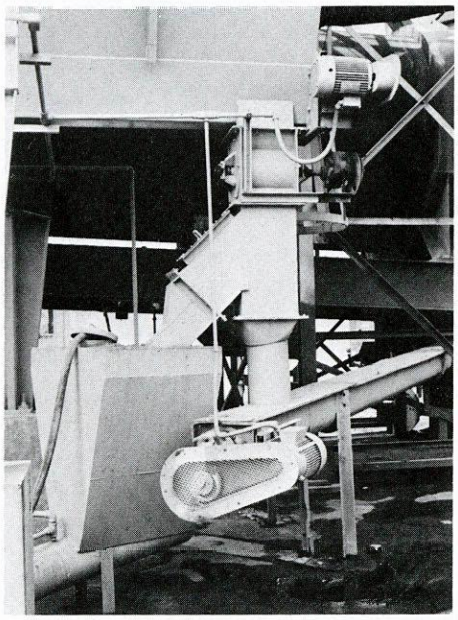


Figure 19. Return of baghouse dust.

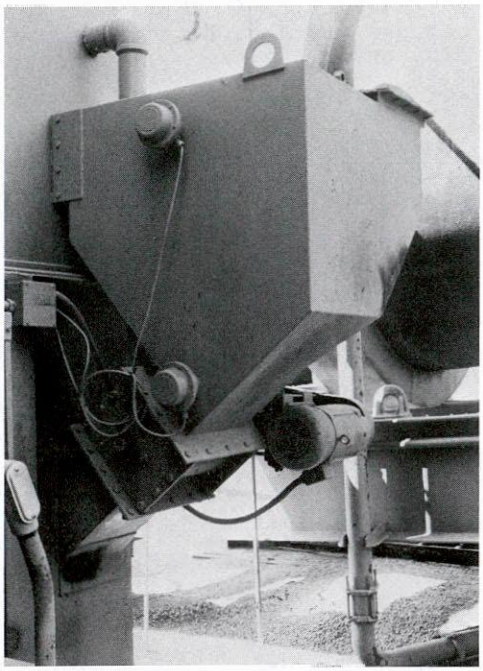


Figure 20. Surge bin used in return of baghouse dust.

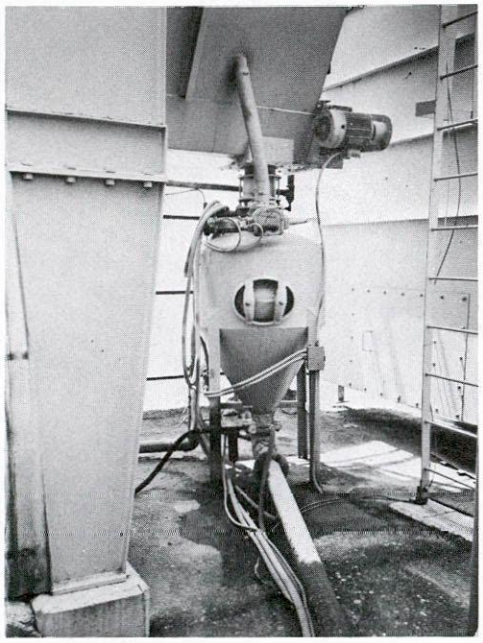


Figure 21. Typical fluidizing pod.

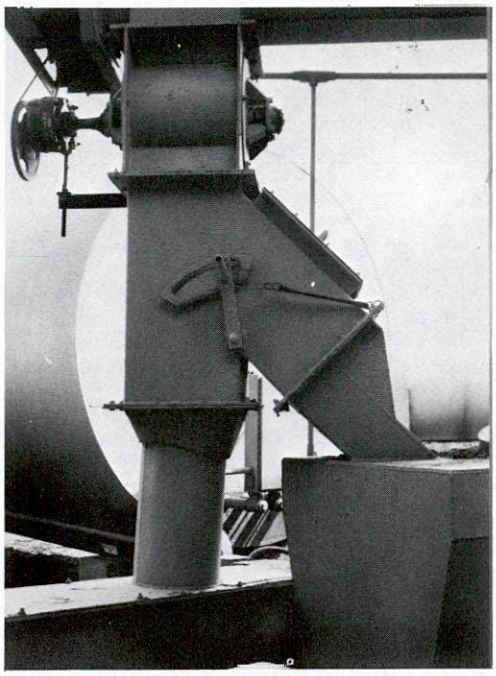


Figure 22. Adjustable gate to regulate quantity of dust returned to the plant.

Alternatives for the Drum Mix Plant

Several alternative handling methods are in use in drum mix plants. The baghouse dust may be returned to the cold feed conveyor, blown into the feed end of the drum, injected adjacent to the point at which the asphalt cement is introduced into the drum, or blown in at the point at which the mixture is discharged from the drum. In two-stage primary collection systems--coating zone and knockout box--dust handling is an inherent part of the process.

For the cold feed conveyor return, the baghouse dust is deposited directly from a screw conveyor from the baghouse. The other three methods involve pneumatically transporting the dust directly from the baghouse dust discharge or from a filler silo system. A rotary air lock ensures a uniform return of material, but it is susceptible to wear through the action of the abrasive dust.

Of the four return methods, the one most widely accepted by state agencies and manufacturers is the return to a point adjacent to the asphalt cement injection. The advantage of this method is that the dust is embedded in the asphalt before it is reentrained and transverses the coating zone, thus ensuring dispersion through the mix.

Changes Induced in the Material by Plant Processes

Two changes are considered here: degradation of the feed material by the plant's processes and contamination of the fine material. It might be expected that

degradation of the feed material would occur through the abrasive action of the dryer screens, pug mill, etc. The effect of such degradation is an increase in the quantity of fine material. Information about the extent of this degradation was not found in the literature. The applicability of the Los Angeles Abrasion Test as a relative indicator of the extent of degradation must be questioned because this test parameter was found not to correlate with degradation in an earlier study, NCHRP Project 10-3 (56).

The plant operators participating in the sampling program were asked about aggregate degradation. Although there was general agreement that dust production is inevitable, the operators reported that the quantity is not significant and is ignored when the cold feeds are set up. Reports of degradation in the dryer are often based on comparisons of extraction data and gradation measurements from the cold feed. This is not a valid comparison unless the cold feed gradation is based on a washed sieve analysis, which is often not the case. The researchers do not believe that degradation in the plant is a serious problem with most aggregates that meet typical state specification criteria.

Contamination of the cold feed aggregate is caused primarily by improper burner operation or by too great a pressure drop in the baghouse, reducing the air available to the dryer for fuel combustion (54). These conditions can result in a coating of unburned fuel on the aggregate. Soot (unburned carbon particles) may also be found in the baghouse dust (38), especially in plants that burn oil rather than natural gas (41). The total quantity of soot, however, is probably not significant as long as the plant is operating properly.

Condensation of the water vapor in the system gas in the baghouse will result in moisture in the baghouse dust. This condition will occur if the exhaust temperature through the baghouse falls below the dew point (82-100 C [180-212 F]) during production or if the baghouse has not been preheated above the dew point during start-up (44). The presence of moisture may clog the bags, which, in turn, increases the pressure drop through the baghouse and reduces the air available for combustion.

Other Operations

During the course of the agency survey, occasional bleeding associated with excess fine material was cited as a potential problem. Two different plant operations may account for this problem. First, the problem may occur if the return of the baghouse dust to the hot elevator or to the No. 1 hot bin is not synchronized with the cold feed and the dryer operation. To minimize this potential problem, Schenk (59) recommends that the start-up and shutdown of the dryer and baghouse be synchronized. A drawback to this procedure is that dust may remain in the baghouse screw conveyor, and may result in plugging of the hopper (60). Another difficulty is that it is difficult to purge the bags during shutdown. A second plant operation that may be involved in a sudden surge of fines is the operation of the No. 1 hot bin when the level of the bin is low. This permits fine material that has accumulated along the bin wall to break free and fall into the weigh hopper. This condition is referred to as a "dust slide." A cap or baffle plate installed in the No. 1 hot bin will help distribute the fine material throughout the bin and minimize the chance of dust slides (58). The use and proper maintenance of low bin indicators will help to avoid operation when the No. 1 hot bin is low, and therefore reduce the chance of dust slides.

LABORATORY TEST PROGRAM

In the first series of tests, four dust properties--grain-size distribution, Atterberg limits, pH, and bulk density--were examined to determine plant-to-plant, day-to-day, and within-day variability of the baghouse dust. A second series of tests was conducted on limited samples of dust in order to study the nature of the dust and the consistency of the asphalt-dust mixtures.

Grain-Size Distribution

The grain-size distribution of the dust was determined with a sedigraph 5000D analyzer (61), which produces a plot of percentage of fines versus the logarithm of grain size. The sedigraph cannot accommodate powders with grain sizes coarser than 75 μm, and therefore the dust was wet washed through the No. 200 mesh sieve prior to testing. The grain-size distribution of the coarse fraction (plus No. 200) was determined by wet sieving (ASTM D 546) (2). Both the grain-size distribution of the minus No. 200 fraction and the composite grain-size distribution (combined sedigraph and wet sieve) were incorporated in the analysis. The average grain-size distribution obtained for each plant is given in Table 3.

Considerable care was taken in performing the grain-size analyses. Four different dispersants, sodium hexametaphosphate, sodium pyrophosphate, sodium oxalate, and sodium silicate, were used in concentrations of 0.4 percent. Dispersions of each dust were prepared and were allowed to settle in a graduated test tube. The bulk density of the settled powder was calculated, and the results are shown in Figure 23. In each case, except for Plants 13 and 31, sodium hexametaphosphate was the most effective dispersant. This conclusion is based on the bulk density; a higher bulk density or smaller settled volume, indicating less flocculation of the settled powder. In addition to the measurement of settled volume, the appearance of the settling column was also observed for the appearance of flocs. The dust from Plants

Table 3. Average grain-size distribution by plant.

Plant No.	Percent Passing							
	No. 30 (600 μm)	No. 50 (300 μm)	No. 200 (75 μm)	50 μm	20 μm	10 μm	5 μm	1 μm
1	99	96	60	54	18	7	2	1
2	99	89	64	61	43	27	14	3
3	100	100	91	89	71	47	26	7
4	100	100	93	92	77	55	28	6
5	100	100	100	99	95	73	41	7
6	99	94	43	40	23	12	4	0
7	100	100	100	99	91	63	35	7
8	100	96	61	59	42	25	11	1
9	100	94	47	44	27	17	9	3
9S*	100	95	57	51	32	21	12	3
10	95	88	35	34	22	15	9	3
13	100	100	96	94	80	61	40	12
14	100	99	83	81	72	61	47	12
15	100	100	98	97	92	73	44	8
17	99	94	26	24	11	6	2	1
19	100	99	96	95	77	46	23	6
20	100	100	93	92	75	52	27	4
22	99	94	50	47	28	14	6	1
23	100	99	89	83	70	48	28	8
23P**	92	81	21	19	8	5	3	1
24	100	100	99	97	83	52	29	7
24P**	90	75	19	17	3	1	0	0
25	100	100	99	99	86	47	18	4
26	100	100	100	100	95	78	49	12
28	100	100	94	92	72	46	26	10
29	100	99	91	89	72	46	24	7
30	100	99	94	92	71	45	23	5
31	98	92	57	53	35	27	15	3
33	100	99	73	69	47	35	25	7

*9S was sampled from the end of the baghouse.
**23P, 24P were collected from the primary collector.

13 and 31 was very difficult to disperse; a 1 percent solution of sodium hexametaphosphate was required to disperse these materials.

The sedigraph affords a rapid means of determining a gradation analysis. On the assumption that this instrument would not be available to most mix plants or state materials laboratories, a series of hydrometer analyses was performed on the limited studies sample from each plant. Typical curves of grain-size distribution obtained by hydrometer and sedigraph analyses are shown in Figure 24. The grain-size distribution curves from the hydrometer analysis were consistently coarser than the curves from the sedigraph analysis. The variations typically ranged from 2 to 10 percent, the maximum difference occurring in the midrange of the grain-size curve. At the tail of the gradation curve, in the range of the D_{10} to D_{20} sizes (corresponding to 10 percent 10 percent and 20 percent passing), the variation was not more than 2 to 3 percent. These differences are not considered significant; however, they indicate the need for proper procedures in grain-size measurements.

Five parameters were used to analyze the large data set resulting from the gradation analysis: (1) percentage of composite sample passing 75 μm; (2) size corresponding to 50 percent passing, composite sample; (3) percentage of composite sample passing 10 μm; (4) size corresponding to 50 percent passing, sedigraph sample (<75 μm); and (5) percentage of sedigraph sample passing 10 μm (<75 μm). Other parameters for describing the shape of the grain-size distribution curves, such as coefficient of curvature and uniformity coefficient, were explored, but were not considered useful because of the wide range dust size.

Average grain-size curves for five of the plants are shown in Figure 25. These curves are typical of five different dust collection systems. In general, the order of increasing fineness of the baghouse dust occurs in plants that have (1) no primary collector, (2) a knockout box, (3) vertical cyclone, (4) multicone, and (5) dust cyclone. Although theoretically the multicone should remove finer particles than the dual cyclone does, the converse is usually true because of poor maintenance practices or difficulties in obtaining an equal distribution of gas through each cone.

As represented in Figure 25, all of the dusts tested were well graded; however, the range in sizes varied from

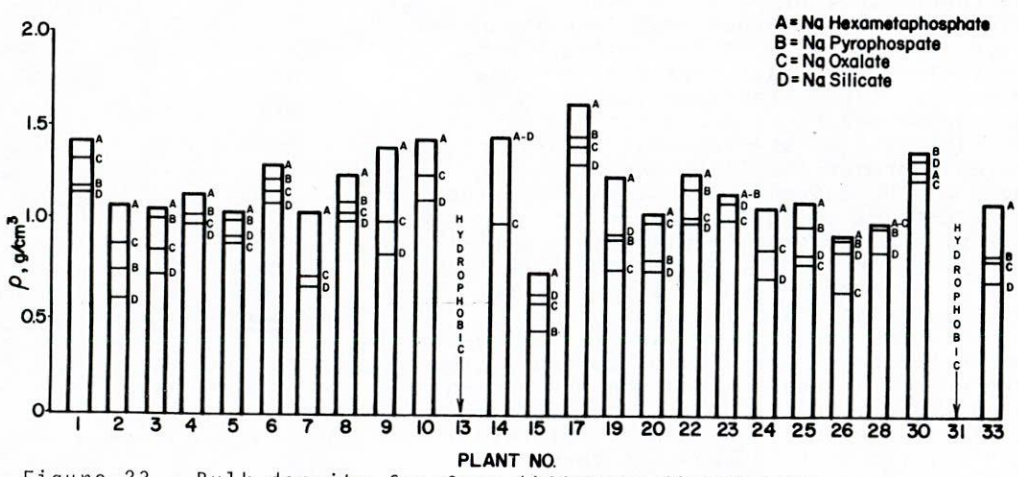


Figure 23. Bulk density for four different dispersants.

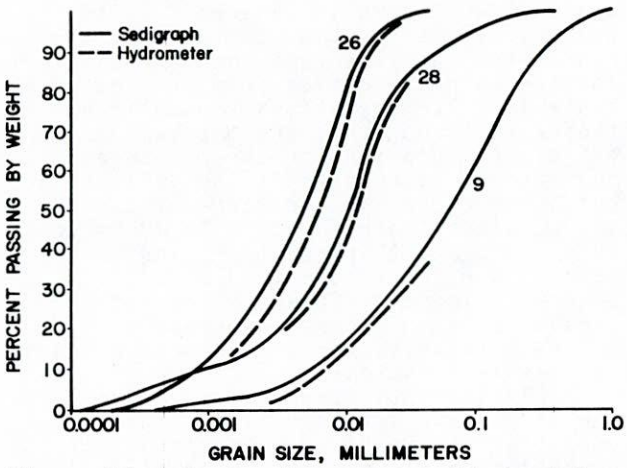


Figure 24. Grain-size curves obtained from sedigraph and hydrometer measurements.

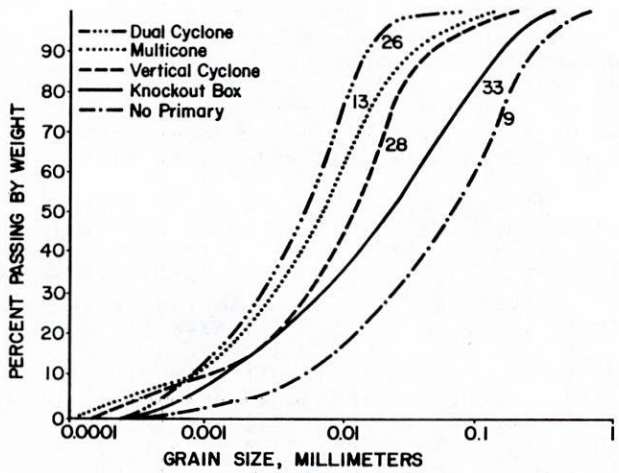


Figure 25. Typical grain-size distribution curves for plants with different collection systems.

plant to plant. Plants with an efficient primary collector tended to give a narrower range of particle sizes. The upper size limit depended primarily on the type of primary collector at the plant. Dusts that contained 5 percent or more particles finer than 1 μm (based on sedigraph analysis) are described in Table 4. The results are somewhat surprising: in only one of the limestone plants and none of the dolomite plants was more than 5 percent of the dust finer than 1 μm. In six of the ten granite plants, four of the six traprock plants, and three of the four gravel plants, more than 5 percent of the dust was finer than 1 μm.

Baghouse dusts are usually regarded as very fine. This may not be true; the degree of fineness depends on the presence of a primary collector and its efficiency. In fact, baghouse dust can be relatively coarse; for example, only 24 percent of the dust from Plant 17 passed the No. 200 sieve. Therefore, baghouse dust cannot always be assumed to act as a mineral filler in the mixture; a portion of it may act as fine sand.

Plants without a primary collector are of special interest because the dust collected in the baghouse represents the dust entrained in the dryer and the fugitive system. Table 5 represents the maximum size of the material in the baghouse dust from the six plants that do not have a primary collector. Generally, the maximum size was reached at the No. 30 sieve (600 μm). From the state-of-the-art review of plant equipment and operations, this was about the expected maximum size. Plant 8 produced a smaller maximum-sized particle, slightly greater than the No. 50 sieve (300 μm). However, the dust at this plant had been contaminated by fuel, which indicates an improper air flow through the dryer. Reduced drum gas velocity would result in a smaller particle size than is normally encountered.

The grain-size distribution of the dust passing the No. 200 sieve for the six plants without a primary collector is shown in Figure 26. There is a considerable difference in the curves (20 to 40 percent for 10 μm, 0 to 10 percent for 1 μm). The samples with the finest gradation came from plants using limestone (Plants 9 and 10). However, there is not sufficient information to conclude that limestone plants produce finer dust. Other processing operations also may influence the fineness of the dust.

Table 4. Plants with more than 5 percent dust finer than 1 μm.

Plant No.	Percent Finer than 1 μm	Primary Collector	Aggregate Type
3	5	Multicone	Traprock
4	6	Multicone	Traprock
5	7	Dual Cyclone	Traprock
13	12	Multicone	Gravel
14	12	Knockout Box	Gravel
15	8	Vertical Cyclone	Limestone
19	6	Horizontal Cyclone	Granite
23	5	Multicone	Granite
26	12	Dual Cyclone	Granite
25	4	Vertical Cyclone	Granite
28	10	Vertical Cyclone	Granite
29	7	Vertical Cyclone	Granite
30	5	Vertical Cyclone	Traprock
33	7	Knockout Box	Gravel

Table 5. Largest particle size entrained in the system gas in plants without a primary collector.

Plant No.	Average Retained Within-Day		Average Retained Day-to-Day	
	%	Sieve Size	%	Sieve Size
6	2.0	30	1.0	30
8	1.8	50	6.6	50
9	0.6	30	0.6	30
10	3.8	30	5.8	30
17	0.4	30	1.2	30
22	1.0	30	0.8	30

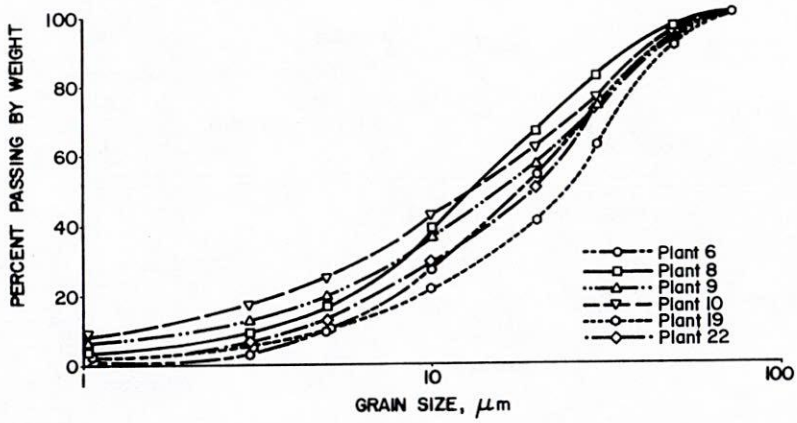


Figure 26. Grain-size distribution of minus 75 μm fraction in plants with no primary collector.

Day-to-Day and Within-Day Variations

The day-to-day and within-day variations of the grain-size distribution of the dust sampled at each plant are shown in Figures 27 through 31. The solid line represents the day-to-day variation and the open bar represents the within-day variation. Each line is centered about the mean, and the line is two standard deviations in length. Also shown is the type of primary collector at each plant.

The extreme sizes in the gradation analyses for the samples from Plants 9 and 28 are shown in Figure 32. The maximum and minimum points represent the extreme data points for all of the samples from each plant. These curves are typical of the range in gradation for the majority of the plants, except for those plants without a primary collector or those plants equipped with a knockout box. Except for plants without a primary collector or plants with a knockout box the gradation of the dust, both within-day and day-to-day, is very uniform.

As shown in Figure 28, plants with a centrifugal primary collector show very little variability, whereas plants without a primary collector or a knockout box show the greatest variability. The percentage of the dust finer than 10 μm in the composite sample is shown in Figure 29. This figure illustrates the wide plant-to-plant variability in the fineness of the dust. Samples from some plants (1, 6, 10, and 22) contained very little material finer than 10 μm, whereas the dust from others (especially plants 5, 15, and 26) contained large quantities of material (>60 percent) finer than 10 μm. On the basis of the data obtained during the research, the fineness of the dust can be related to the parent aggregate, but there is no simple relationship between fineness and generic aggregate type or dust collection system.

Plants 8 and 15 show dramatic differences between the within-day variation and the day-to-day variation. The variation of Plant 8 is probably due to improper burner operation, of improper baghouse or exhaust fan operation, excessive moisture, or any combination of those factors. All samples from the baghouse were visibly contaminated by uncombusted fuel. Plant 15 shows very little within-day variance, but considerable day-to-day variance. A review of the data revealed that one of the samples from Plant 15 was much coarser than the others. The researchers concluded that, because of improper operation of the rotary air lock, the material did not exit from the collector. This failure would allow the coarse material to pass through the cyclone and into the baghouse.

Average within-day and day-to-day standard deviations for the five gradation parameters are given in Table 6 according to type of primary dust collector. Also, average standard deviations for all the plants are shown. The "all-plant" average standard deviations indicate that the day-to-day variation in grain-size distribution is slightly greater than the within-day variation. The differences are small, except for the D_{50} size (grain size corresponding to 50 percent passing) for the composite sample.

Further examination of the data in Table 6 indicates that both the day-to-day variability and the within-day variability are affected by the type of primary collector in the system. In general, the more effective the primary collector, the smaller the variability in both the day-to-day and within-day parameters. The large variability in the D_{50} size was the result of samples from plants without a primary collector or with a knockout box.

Special Studies Relating to Plant Operations

Primary collector samples were submitted by Plants 23 and 24 in conjunction with the five within-day baghouse samples. In addition, five samples were submitted by Plant 23 from the storage silo used to store and feed the baghouse dust to the weigh box. The results of the grain-size analyses from these samples are given in Table 7. As expected, the primary collector samples

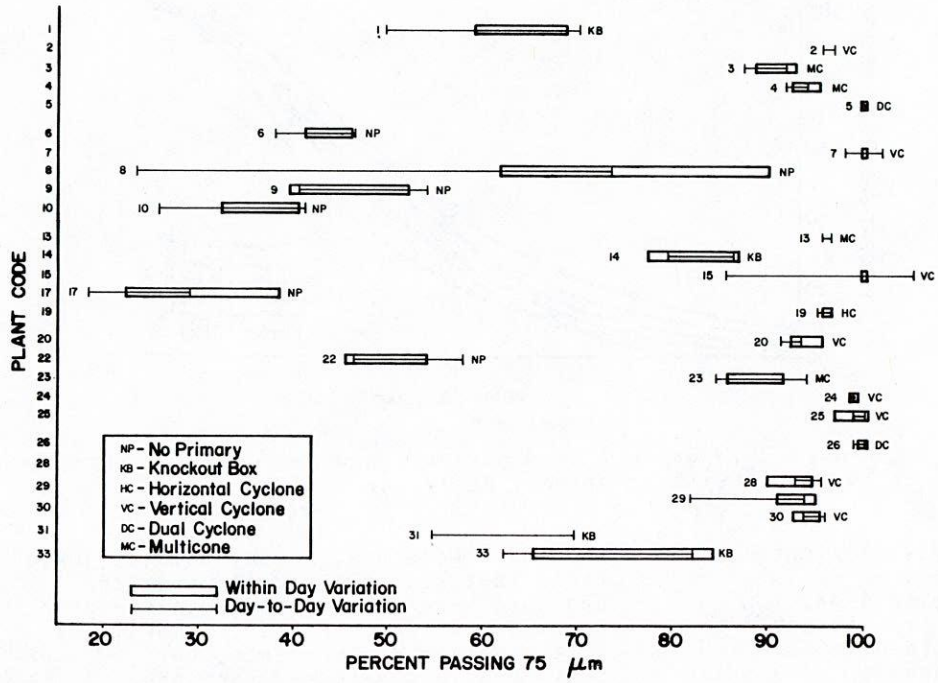


Figure 27. Percentage of dust passing 75 μm, composite sample.

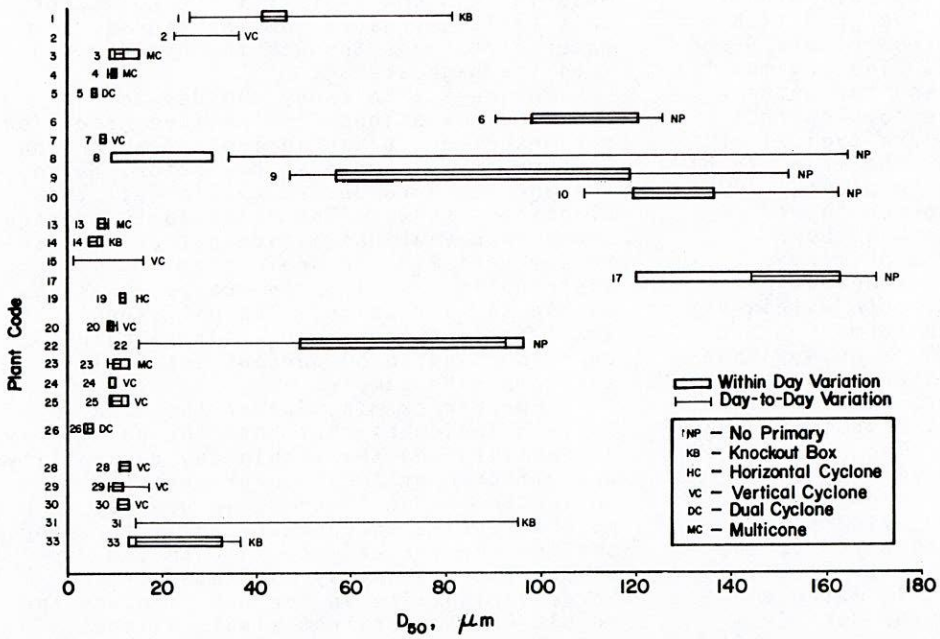


Figure 28. Dust size corresponding to 50 percent passing, D_{50}, composite sample.

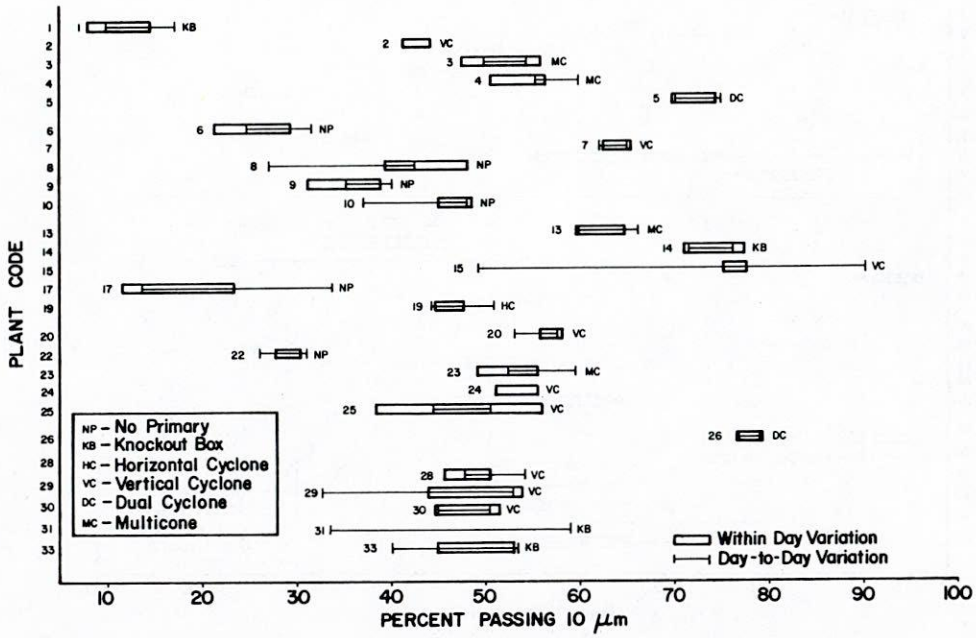


Figure 29. Percentage of dust passing 10 μm, composite sample.

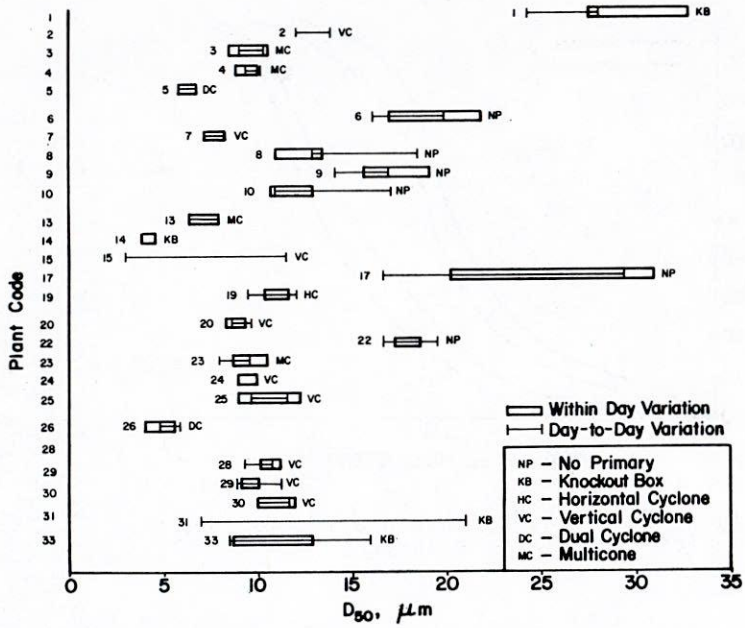


Figure 30. Dust size corresponding to 50 percent passing, D_{50}, minus 75 μm sample.

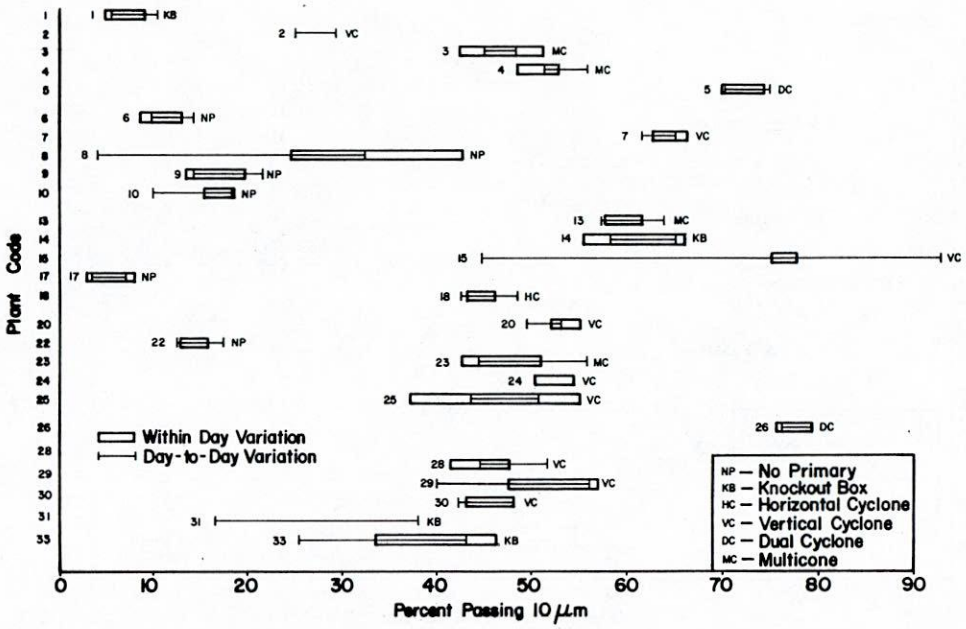


Figure 31. Percentage passing 10 μm, minus 75 μm sample.

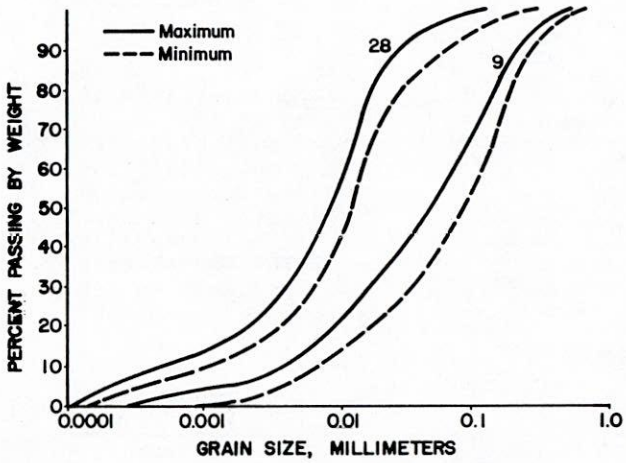


Figure 32. Range of grain sizes for all samples from Plants 9 and 28.

Table 6. Typical variations in five gradation parameters of baghouse dust by primary collector type.

	Average Standard Deviation	
	Within-Day	Day-to-Day
	% Finer than 75 μm, Composite Sample	
No Primary	6.7	9.1
Knockout Box	6.4	9.0
Vertical Cyclone	1.0	2.2
Dual Cyclone	0.2	0.8
Multicone	1.6	2.2
Average, all plants	4.0	4.8
	% Finer than 10 μm, Composite Sample	
No Primary	3.2	4.7
Knockout Box	4.6	6.4
Vertical Cyclone	3.1	5.7
Dual Cyclone	2.0	2.1
Multicone	3.2	3.1
Average, all plants	3.2	4.7
	D_{50}, μm, Composite Sample	
No Primary	18.0	32.2
Knockout Box	5.6	19.8
Vertical Cyclone	0.9	2.7
Dual Cyclone	0.6	0.4
Multicone	1.6	1.0
Average, all plants	6.6	12.6
	% Finer than 10 μm, <75 μm Sample	
No Primary	3.5	5.3
Knockout Box	3.3	6.3
Vertical Cyclone	3.3	5.0
Dual Cyclone	1.8	1.9
Multicone	3.1	2.8
Average, all plants	3.0	4.6
	D_{50}, μm, <75 μm Sample	
No Primary	2.1	2.8
Knockout Box	1.7	3.2
Vertical Cyclone	0.6	1.2
Dual Cyclone	0.6	0.4
Multicone	0.8	0.6
Average, all plants	1.2	1.8

Table 7. Within-day variation of primary collector and baghouse samples, Plants 23 and 24.

	% < 75 µm		D_{50}		% < 10 µm	
	$\bar{X}$ (%)	s (%)	$\bar{X}$ (µm)	s (µm)	$\bar{X}$ (%)	s (%)
Plant 23						
Multicone	20.8	8.2	183.4	26.9	4.8	3.3
Baghouse	88.8	2.9	11.6	1.8	46.8	4.2
Filler Silo	91.6	0.6	10.0	0.0	51.8	0.4
Plant 24						
Vertical Cyclone	19.0	2.8	199.0	9.7	1.4	0.6
Baghouse	99.0	0.0	10.0	0.0	52.4	2.3

were much coarser than the baghouse samples. The data in Table 7 also indicate that the variability of the primary dust is greater than the variability of the baghouse dust. This agrees with the finding concerning variability in the plants that contain a primary collector versus the plants that contain no primary collector or have only a knockout box. In particular, there was considerable variation in the median, D_{50}, size of the multicone material sampled from Plant 23. The dust from the filler silo was slightly finer than the dust sampled from the baghouse. In addition, the standard deviation for the percent passing 75 µm, D_{50}, and percent passing 10 µm, was less for the dust from the filler silo than the dust sampled directly from the sampled directly from the baghouse. Apparently, the filler silo evens out variations in the grain-size distribution of the dust. This effect may not be significant, however, because the variability of the dust from the baghouse is already small.

Samples were collected from Plant 23 at the entrance and the exhaust end of the baghouse. The average gradations of the dust from the entrance and the exhaust end are plotted in Figure 33. The difference between the two curves is small, approximately 6 percent passing over most of the curve. Plant 23 is equipped with a multicone primary collector which removed the coarser fraction (>30 µm) of the dust. This primary collector accounts for the relative uniformity of the dust at the entrance and the exhaust end of the baghouse.

Ten additional samples were collected at Plant 9 at the rear of the baghouse, in conjunction with the usual ten samples. Because of the unique handling system (see App. B), the dust return to the plant represents the dust collected in the first 60 percent of the baghouse. The remaining 40 percent is wasted. The within-day and day-to-day variations in the dust collected from the baghouse at the front and rear of the plant are given in Table 8. Plant 9 is not equipped with a primary collector, and therefore considerable variation in grain-size distribution should be expected across the baghouse, which can act as an expansion chamber. This variability is evidenced in the D_{50} size; 87.8 µm in the first 60 percent as compared with 45.6 µm for the last 40 percent. The standard deviation also is greater in the first 60 percent than in the last 40 percent (31.2 µm versus 9.3 µm). An examination of the minus 75-µm fraction of the samples from Plant 9 (Table 8) shows little variation between the sample from the first 60 percent and those from the last 40 percent. This confirms that the coarse dust, if not removed in the primary collector, is removed by the knockout action of the baghouse.

The data were analyzed carefully to determine if the day-to-day or within-day variations in grain-size distribution could be correlated with different mixture designs. No influence was determined except for Plant 9. Plant 9 produced two different mixtures during the course of the project, a wearing course and a base course mixture. The wearing course utilized a blend of natural and crushed stone sand, while the base course mixture used only the crushed stone sand. The range of sizes for the two mixtures is shown in Figure 34. Most of the variation is in the 30 to 60 µm range. In this range the percent passing was approximately 10 percent greater for the dust collected from the base course mixtures. The gradation of the coarse fraction and the finer sizes, less than 15 µm, did not vary with changes in mixture design. In the opinion of the researchers, the changes in gradation that did occur are probably not significant in terms of mixture behavior, and can be neglected. This conclusion is supported by the average bulk specific gravities (based on dry compaction), which were 1.71 and 1.77 for the base and wearing course mixtures respectively.

pH of Aqueous Suspension

The average pH measurement for each plant is given in Table 9, and the mean and standard deviations for day-to-day and within-day variation are shown in Figure 35. All of the suspensions were alkaline (pH >7.0) except for the dust from Plants 6 and 30, which use a siliceous river gravel and a traprock, respectively. There was very little variability in the pH data except for Plants 14, 20, 24, and 33 (day-to-day variation). Nothing in the aggregate characteristics or plant operations accounts for the variability, which is greater than the experimental error associated with the test. The fact that Plants 14 and 33 are gravel plants and Plants 20 and 24 are granite plants is not sufficient to explain this variability. The pH measurements did not correlate with any other parameters of the dust. Day-to-day and within-day standard deviations were typically 0.4 or less, although a few values were as high as 0.6 to 0.9. The ranges in pH were as expected: 11.2 to 12.4 for dolomite, 6.4 to 11.2 for traprock, 10.9 to 12.5 for

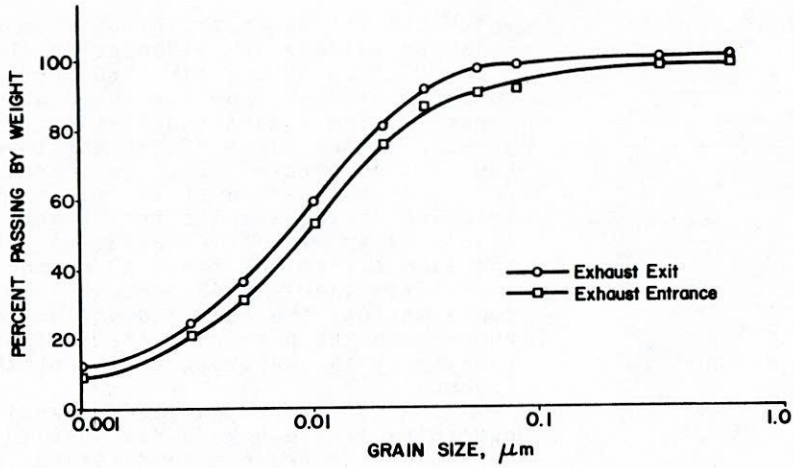


Figure 33. Average Gradation of dust at exhaust exit and entrance of baghouse, Plant 23.

Table 8. Variation of material in the baghouse--Plant 9.

(a) Composite Sample

	Percent passing 75μm				Percent passing 10μm				D_{50}, μm			
	$\bar{X}$wd	swd	$\bar{X}$dd	sdd	$\bar{X}$wd	swd	$\bar{X}$dd	sdd	$\bar{X}$wd	swd	$\bar{X}$dd	sdd
First 60%	45.8	6.3	47.4	6.7	16.2	3.6	18.0	3.5	87.8	31.2	79.2	32.6
Remaining 40%	61.0	5.6	56.4	6.3	21.6	3.2	22.2	3.5	45.6	9.3	54.2	18.5

(b) <75-μm Sample

	Percent passing 10μm				D_{50}, μm			
	$\bar{X}$wd	swd	$\bar{X}$dd	sdd	$\bar{X}$wd	swd	$\bar{X}$dd	sdd
First 60%	35.0	3.8	37.8	2.5	17.4	1.8	15.6	1.3
Remaining 40%	35.6	3.4	39.2	3.6	17.6	1.8	15.6	1.5

Note: $\bar{X}$wd = average, within day
$\bar{X}$dd = average, day-to-day
swd = standard deviation, within day
sdd = standard deviation, day-to-day

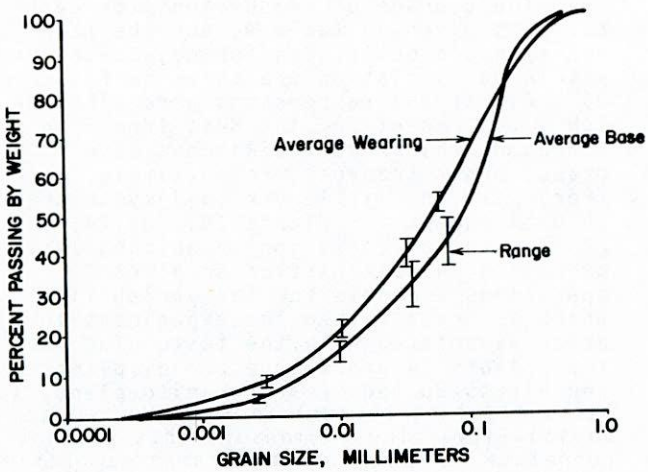


Figure 34. Average grain-size distribution for dust from wearing and base course mixtures, Plant 9.

Table 9. Average pH and Atterberg limits for samples from each plant.

Plant No.	pH	Hygroscopic Moisture	Liquid Limit	Plastic Limit	Plasticity Index	Aggregate Type
1	11.6	4.1	-	-	NP*	Dolomite
2	11.2	0.6	-	-	NP	Dolomite
3	8.2	1.0	27	25	2	Traprock
4	9.2	2.9	28	25	3	Traprock
5	9.8	1.9	39	37	2	Traprock
6	5.6	0.4	-	-	NP	Siliceous Gravel
7	11.2	1.9	34	31	3	Traprock
8	12.4	0.9	-	-	NP	Dolomite
9	12.1	0.6	-	-	NP	Limestone
10	10.9	0.4	-	-	NP	Limestone
13	12.1	1.5	34	32	2	Gravel
14	10.5	1.2	30	27	3	Gravel
15	12.2	1.2	32	29	3	Limestone
17	12.5	0.2	-	-	NP	Limestone
19	8.6	0.6	34	32	2	Granite
20	8.3	0.7	35	35	NP	Granite
22	8.7	0.4	-	-	NP	Granite
23	8.6	0.8	-	-	NP	Granite
24	9.2	0.9	35	34	1	Granite
25	9.6	0.9	34	32	2	Granite
26	7.2	1.9	39	37	2	Granite
28	8.1	1.3	31	31	NP	Granite
29	7.4	1.4	30	29	2	Granite
30	6.4	0.8	32	31	1	Traprock
31	7.5	0.8	-	-	NP	Traprock
33	7.7	1.5	33	29	4	Siliceous Gravel

*NP = Nonplastic

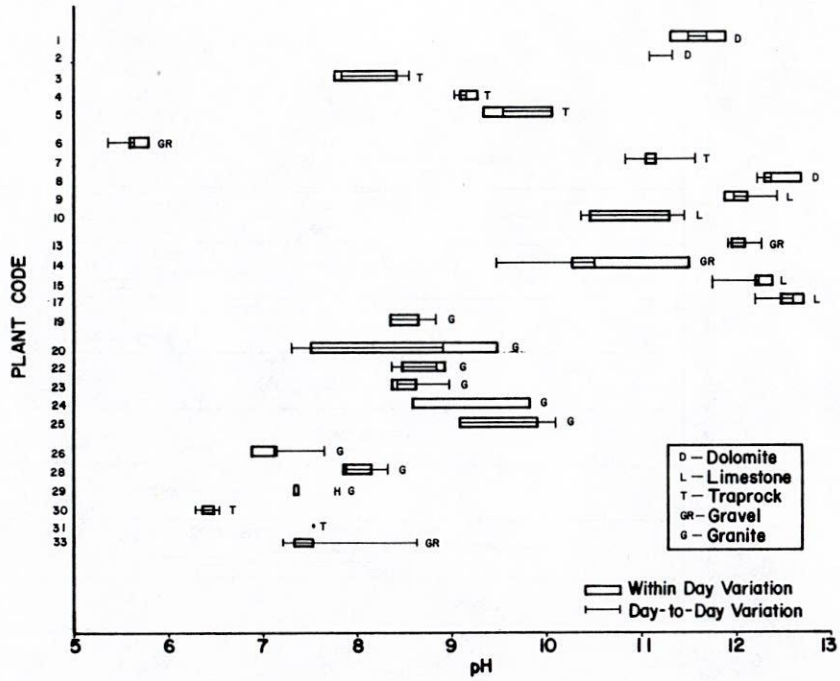


Figure 35. Measurements of pH.

limestone, and 5.6 to 7.7 for siliceous gravel. Values of pH, therefore, do not appear to be useful as an indicator of dust variability.

Hygroscopic Moisture

The average results of the hygroscopic moisture tests are given in Table 9. Except for the samples from Plants 1 and 4, all of the dusts absorbed less than 2 percent moisture at 50 percent relative humidity. The within-day and day-to-day standard deviations were very small, generally less than 0.1 to 0.2 percent. Based on the data collected, hygroscopic moisture offers little promise as a measure of dust variability or as an indicator of dust performance.

Atterberg Limits and Plasticity Index

Average liquid limit, plastic limit, and plasticity index data for each plant are presented in Table 9. All of the dusts meet the requirements of ASTM D 242 (10) which limits the plasticity index to 4.0. As in the case of the data on pH values and hygroscopic moisture, the test results on within-day and day-to-day variability are considered by the researchers not to be significant. The purpose of specifying a plasticity index value is to limit the amount of clay in the dust. It is apparent that the dusts sampled contained little clay. The Atterberg limits test is not considered useful in determining within-day or day-to-day dust variability. It may be helpful in identifying contamination by clay-like fines if that is a problem at a particular plant or for a particular source of aggregate.

Bulk Density

The bulk density of the dust was determined on the composite samples by allowing the sample to settle in a polar and a nonpolar liquid, and by vibrating the dry dust into a graduated cylinder. Bulk specific gravity was used to calculate the porosity of the packed powder bed. The results are shown in Figure 36. The solid line represents the day-to-day variability, and the open bar represents the within-day variability. The porosity calculated from the dry vibrated bulk density was slightly less (5 percent) than the values calculated from the bulk density obtained from the settling tests. No practical differences were observed in the bulk densities obtained from the polar and nonpolar liquid settling tests. For example, dust from Plant 25, which developed a very large degree of stiffening when mixed with asphalt, produced nearly identical bulk densities in polar and nonpolar liquids. Consequently, based on the dusts, asphalts, and settling media studied in this research, it was concluded that the surface activity of the dust, as measured by the polarity of the settling medium, is not a significant factor in the stiffening effect produced by the dust.

The within-day variability and the day-to-day variability are approximately the same for each of the three methods. In general, as was observed for grain-size distribution, day-to-day variability is slightly greater than within-day

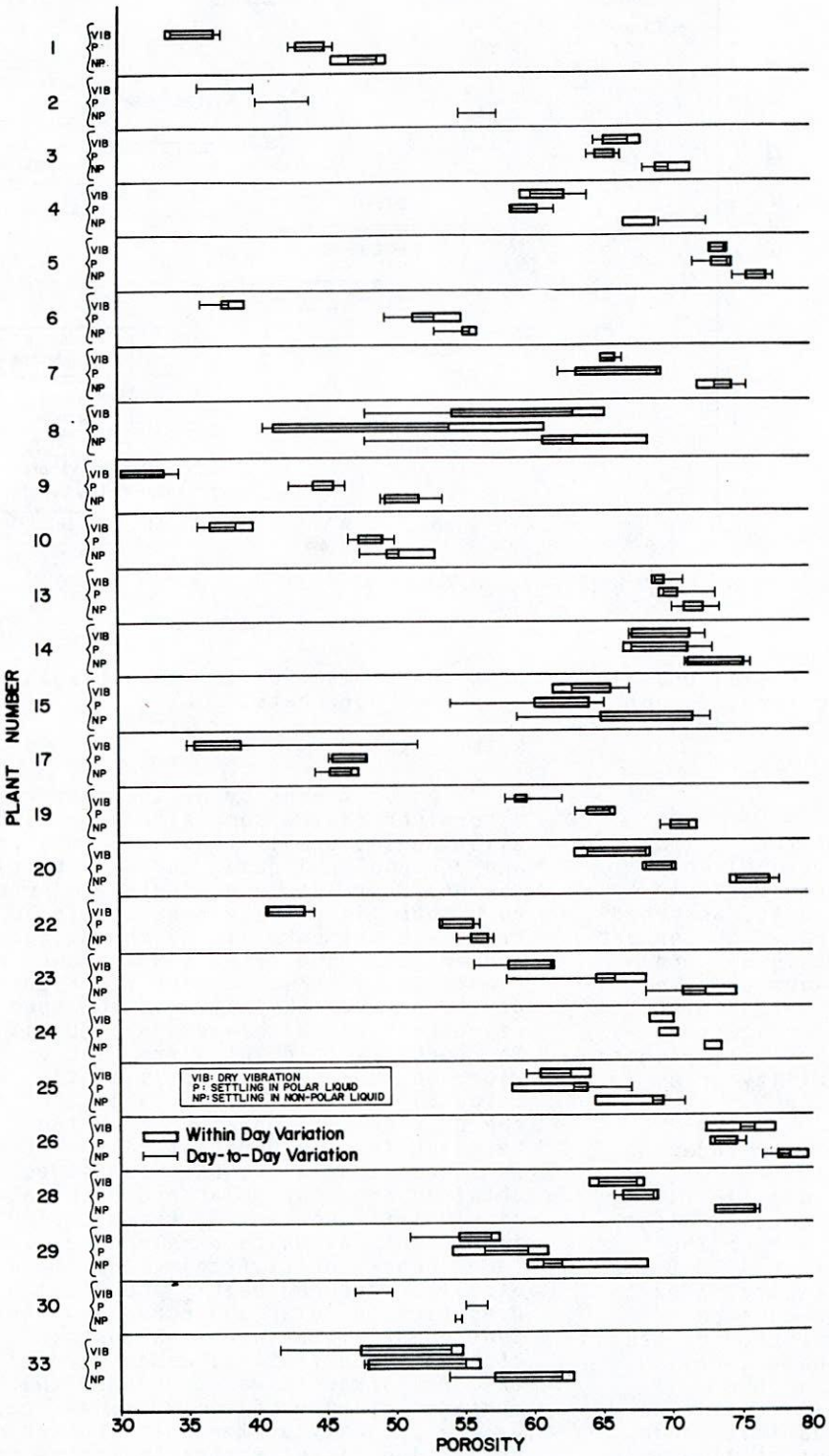


Figure 36. Porosity calculated from bulk density measurements.

variability. In comparing plants with large variability, it appears that large variability in the porosity is associated with large variability in the percentage of dust finer than 10 μm, but not with the other grain-size parameters (percentage passing 75 μm and the D_{50} size). This result is logical if the role of the fine fraction of the dust is to fill the voids of the coarser fraction. Dry compaction produced a denser powder bed than did the dry vibration or the settling in a fluid medium. On the average the bulk density was about 0.4 g/cm^3 less for dry impact compaction than for the other methods (see Figure 37). The correlation between dry impact compaction and the other methods is not considered good. For example, r^2 for the bulk density determined from sedimentation in polar liquid, γ_P, versus bulk density from day compaction, γ_{AP}, is 0.82, Figure 37.

Bulk density measurements can be made more easily than sedigraph measurements and much more rapidly than hydrometer measurements. Therefore, bulk density may be a useful tool to identify variability in the fineness of the dust, especially in the amount of the fine fraction (<10 μm).

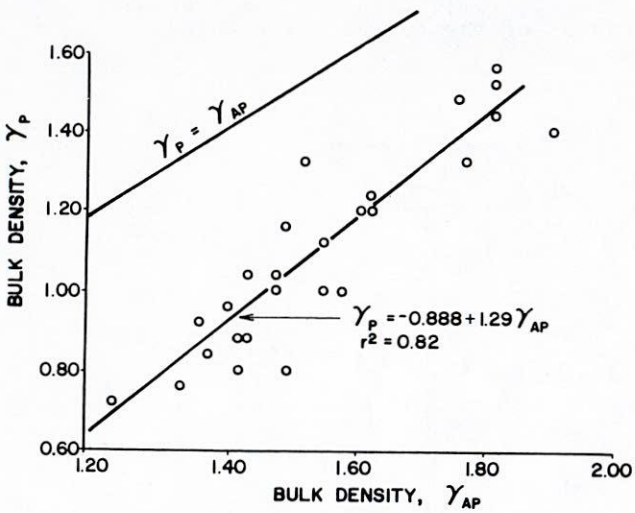


Figure 37. Comparison of bulk density measurements obtained from dry compaction and settling in polar fluid.

Limited Studies--Physical Properties of the Dust

A typical sample of dust from each plant (based on grain-size distribution and the requirement that the dust was from a wearing course) was subjected to additional testing. The purpose of these tests was to determine the range that can be expected in the properties of baghouse fines. Within-plant variability was not determined.

Asphalt Mixing

The asphalt mixing test described by Kandhal (4) was performed on the typical sample from each plant. The results are given in Table 10. The stiffness ratio based on viscosity at 60 C (140 F) versus the balling point and crumbling point is plotted in Figure 38. Neither the balling point nor the crumbling point is a good predictor of stiffening, because the stiffening ratio increases asymptotically for the dusts that produce stiffer mixtures. The tests were easy to perform,

Table 10. Results of asphalt mixing test.

Sample	W_{crumb}(g)	W_{ball}(g)
1-4	79	57
2-2	78	60
3-4-B	50	38
4-2-C	50	39
5-5-C	37	28
6-4	72	48
7-3-D	36	28
8-5-C	55	41
9-1-E	81	58
10-1-C	91	69
13-4	47	34
14-3-C	48	38
15-3-C	36	28
17-3	>280	67
19-3-C	42	33
20-2-C	42	33
22-4-C	59	43
23-1-C	49	40
24-4-C	39	35
25-3	42	35
26-2	33	26
28-2-C	41	33
30-1-C	57	46
31-2	60	40
33-4	55	39

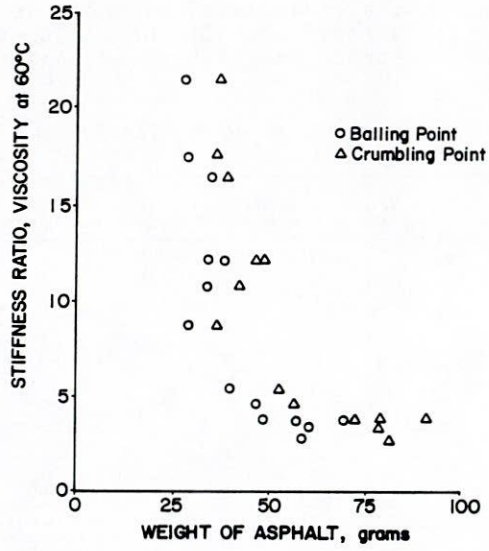


Figure 38. Stiffness ratio versus crumbling and balling points for dust-asphalt mixtures.

and the results could be reproduced within 1 to 2 grams in replicate tests. The dust from Plant 17 was very coarse, and this is reflected in the large amount of dust that could be mixed with the >280 and 67 grams for the crumbling and balling points respectively. On a qualitative basis, the dusts that required more asphalt were noticeably stiffer and had a dry behavior. The dust from Plant 26 was very fine; only 33 and 26 grams of dust were required to obtain the crumbling and balling points respectively. Correlations between these and other data are discussed in Chapter Three.

Water Sensitivity Test

The water sensitivity test, as specified by Michigan (8), was performed on a selected sample of baghouse dust from each plant. The test procedure specifies an SC-250 cutback. In order to use the same asphalt as in the other tests, an MC-250 cutback was made by adding kerosene to asphalt WB, producing a viscosity of 40 cSt at 60 C (140 F) (10).

The results of the water sensitivity tests are given in Table 11. Considerable difficulty was encountered in performing the test. In many cases, during the settling phase of the test the asphalt-fines mixture settled to the bottom of the jar. The results of these tests are indicated as "NA" (not applicable). The asphalt appeared to wet the dust in these cases, and after repeated shaking and settling cycles no dust could be seen to separate from the asphalt. To this extent the results might be construed as being acceptable. Six of the dusts failed the water sensitivity test: more than 25 percent of the fines settled, uncoated, to the bottom of the jar. Of the six dusts, two were traprock and four were granite.

Table 11. Results of water sensitivity test.

Sample No.	Fraction of Settled Fines Relative to Reference (%)	Acceptability
1-4	NA[a]	
2-2	NA	
3-4-B	NA	
4-2-C	NA	
5-5-C	25[b]	Borderline
6-3	NA	
7-3-D	32	Unacceptable
8-5-C	NA	
9-1-E	NA	
10-1-C	NA	
13-4	NA	
14-3-C	0	Acceptable
15-4-C	NA	
17-3	NA	
19-3-C	NA	
20-2-C	0	Acceptable
22-4-C	NA	
23-1-C	44	Unacceptable
24-4-C	42	Unacceptable
25-3	0	Acceptable
26-2	5	Acceptable
28-2-C	42	Unacceptable
30-1-C	NA	
31-2	NA	
33-4	9	Acceptable

a Fines settled with asphalt; determination could not be made.
b Fines are considered acceptable if fraction is less than 25%.

Although the water sensitivity test has conceptual merit, it is difficult to perform. The test cannot be recommended for specification use without some further developmental work. First, the use of an arbitrary SC cutback should be discouraged because many SC materials may contain an antistrip additive that is not present in asphalt cement. Second, recent evidence suggests that asphalt-mineral interactions are asphalt specific, and a properly designed test, therefore, should use the same asphalt that will be used with the dust.

Air Permeability

The limited study sample from each plant was compacted with a drop hammer compactor into a small (3/8-in.-diameter) thimble, and the rate of air flow through the powder was determined. The apparatus, as shown in Figure 39, is low in cost and simple to operate. A series of measurements can be completed in less than 15 minutes, and the associated calculations can be completed on a simple programmable hand calculator. The procedure developed by Kamack (6) was used to calculate the specific surface of the powder, S (m^2/g), and the average particle size, D_S (μm), based on the hydraulic radius of the packed powder bed.

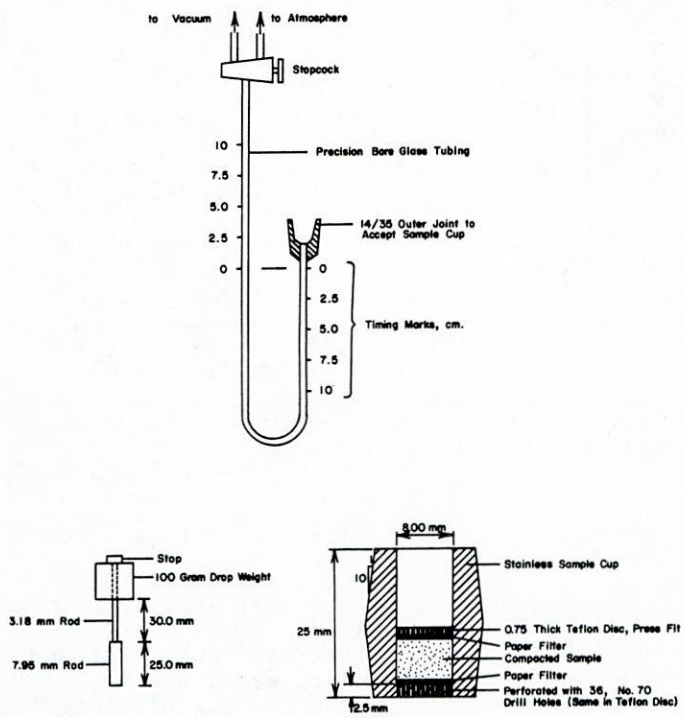


Figure 39. Air permeability apparatus.

The results of the air permeability measurements are given in Table 12. The average particle size obtained from this procedure is considerably finer than the average particle size, D_{50}, obtained from the grain-size analysis (see Table 3). This is an expected result because the calculation of D_s assumes a single-sized powder. The baghouse dusts have a wide range of sizes, and the finer fraction in the dusts controls the hydraulic radius of the packed powder dust. This finding is illustrated in Figure 40, where D_{10}, the percent passing 10 µm, from the composite grain-size analysis is plotted against D_s.

Table 12. Air permeability data.

Sample No.	Average Particle Size (µm)	Specific Surface, m^2/g
1-4	13.1	0.17
2-2	4.3	0.53
3-4-B	1.4	1.45
4-2-C	2.7	0.77
5-5-C	1.3	1.64
6-3	14.6	0.16
7-3-D	1.4	1.48
8-5-C	2.3	0.98
9-1-E	9.1	0.25
10-1-C	9.2	0.25
13-4	1.0	2.18
14-3-C	1.2	1.94
15-3-C	1.4	1.57
17-3	34.5	0.06
19-3-C	1.8	1.21
20-2-C	1.8	1.20
22-4-C	7.1	0.32
23-1-C	2.5	0.86
24-4-C	2.0	1.14
25-3	3.0	0.74
26-2	1.2	1.94
28-2-C	1.8	1.20
29-1-C	1.3	1.71
30-1-C	3.1	0.77
31-2	4.0	0.56
33-4	1.8	1.29

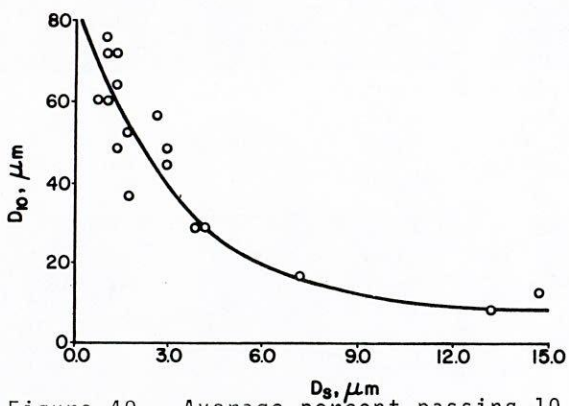


Figure 40. Average percent passing 10 µm versus average grain size from air permeability measurements.

Scanning Electron Microscopy

Scanning electron photomicrographs were taken of each of the limited study samples. A set of typical photomicrographs is shown in Figure 41. No unusual or unexpected particles or particle shapes were observed. The spheres observed by others (26) were also observed in this study. The compositional analysis of these spheres was similar to that of the remainder of the dust, which was blocky or angular. Most likely, the temperature of the small dust particles is very high and may approach the sintering temperature of the mineral. Except for the presence of the spheres and particles of carbon, the particles were blocky or angular and thus representative of finely ground mineral matter. A visual evaluation of the photomicrographs indicated that differences in shape or surface texture are not a factor in determining the effect of the dusts on increases in stiffening or in softening point.

Heat of Immersion

A microcalorimeter designed and operated by Keith Ensley of Hyrax Engineering was used to measure the heat of immersion of several of the dusts from the limited study samples. Because of time limitations and the long and tedious nature of the procedure, it was not possible to test all of the dust-asphalt combinations. The objective of these measurements was exploratory, to see if there is a measurable difference in the interaction between different dusts and asphalts.

The heat of immersion is a measure of the bonding energy between the asphalt and the mineral surface. The data reported in Table 13 are given in millicalories per gram of dust per minute and represent the heat released per minute after allowing the dust and asphalt to mix together.

On the basis of the limited data in Table 13, there are no obvious differences according to aggregate type. The reported values are small given the surface area of the dusts. Heat of immersion values for ground mineral in the range of 300 to 700 µm are typically 1 to 5 mcal/g/min (9). If heat of immersion is directly proportional to surface area, the values for the baghouse dusts should be two orders of magnitude greater than the values reported in Table 13.

The data do indicate that the heat of immersion is asphalt specific. In general, except for the coarse primary sample (24-P4-C), the heat of immersion values are larger for asphalt WB. A more rational treatment of the data would be to base the heat of immersion on surface area, by dividing the heat of immersion by the surface area of the dust. A more reliable measure of surface area than air permeability is required, for example, one measured by gas adsorption. Further study is required to define the relationship, if any, between dust behavior and heat of immersion measurements.

Asphalt Consistency

Dust samples from 15 plants were mixed with two AC-20 asphalt cements at dust/asphalt ratios of 0.2 and 0.4 by volume. Softening point (ASTM D 36) (10) and capillary viscosity (ASTM D 2171) (10) at 60 C were determined. The 15 dusts

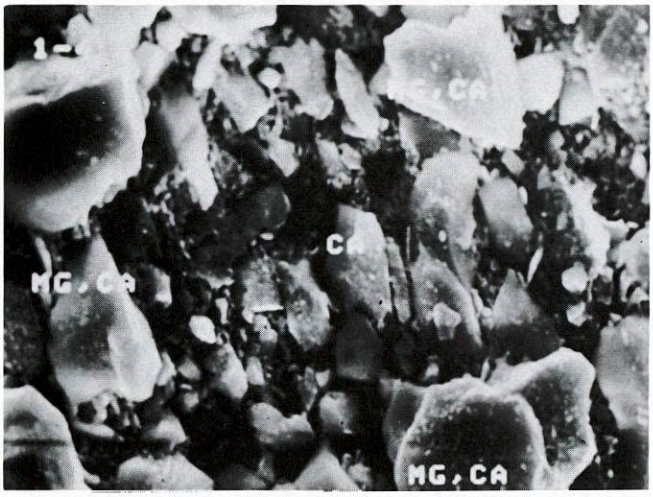
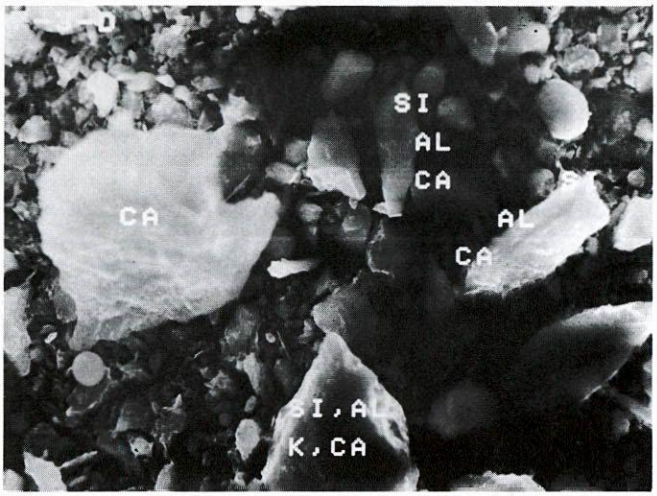
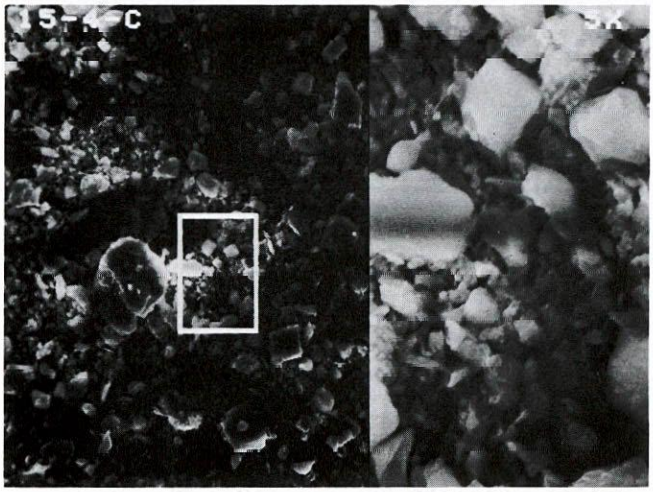


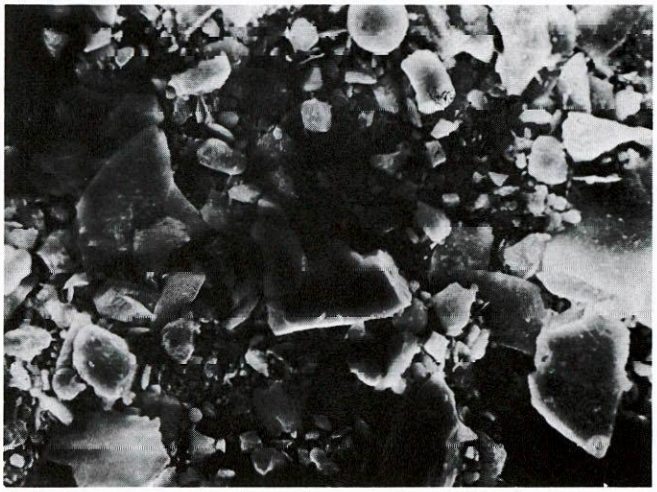
Figure 41. Photomicrographs of selected baghouse dusts. (a) Plant 1, limestone, 1000x.



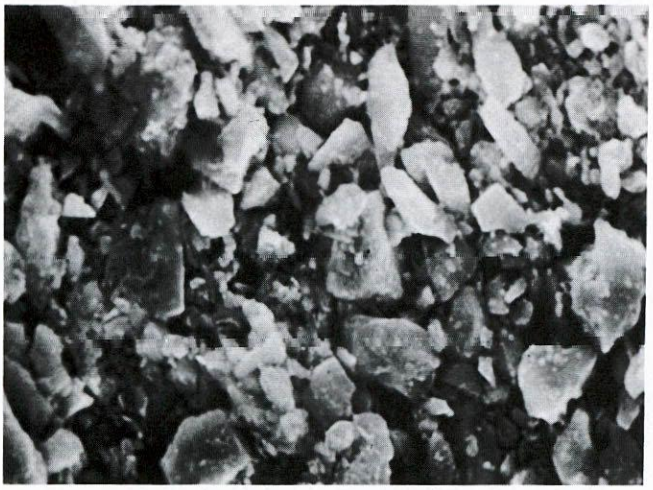
(d) Plant 7, traprock, 1000x.



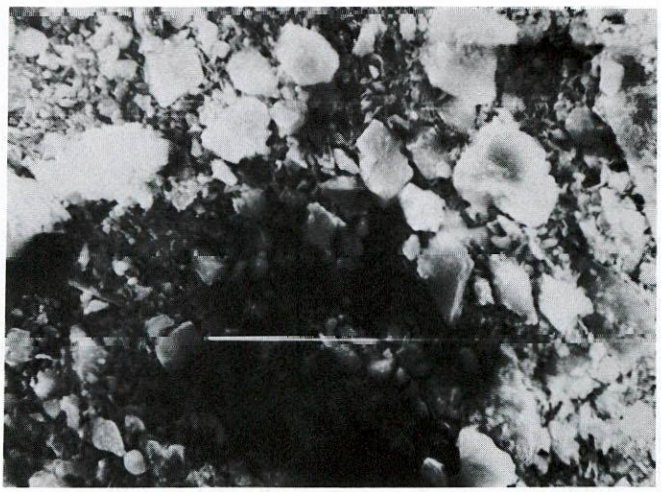
(b) Plant 15, limestone, 387 x (1935x).



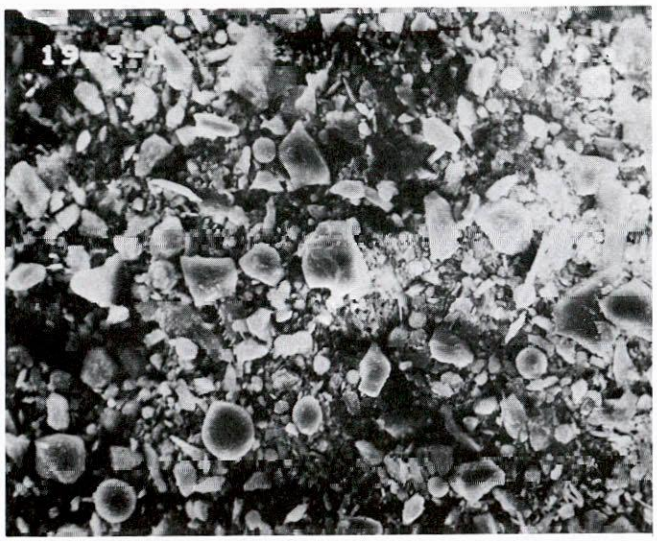
(e) Plant 6, sand and gravel, 388x.



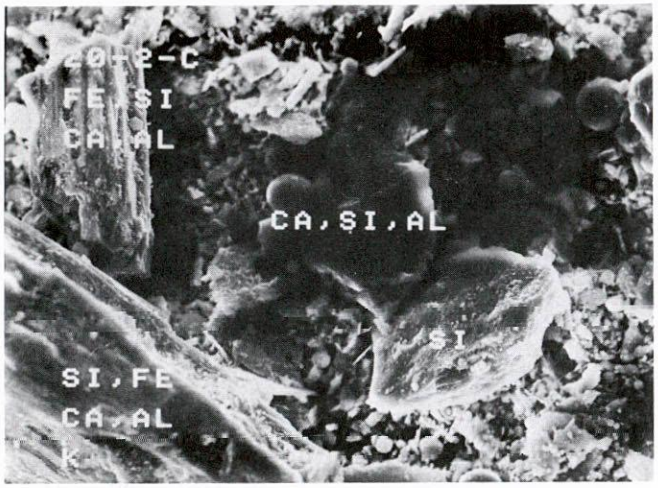
(c) Plant 4, traprock, 1000x.



(f) Plant 13, sand and gravel, 1000x.



(g) Plant 19, granite, 387x.



(h) Plant 20, granite, 293x.

Table 13. Results of heat of immersion tests.

Sample No.	Average Dust Size µm	Specific Surface m^2/g	Aggregate Type	Heat of Immersion, mcal/g/min		
				A	WB	289
1-4	13.1	0.17	Dolomite	1.0	0.80	-
15-4-C	1.4	1.57	Limestone	2.0	3.7	3.2
24-4-C	2.0	1.14	Granite, Baghouse	3.0	8.8	5.3
24-P4-C	-	-	Granite, Primary	2.4	0.7	-
30-1-C	3.1	0.77	Traprock	1.5	2.5	-

were selected to give a representative sampling of fineness and generic aggregate type.

The stiffness ratio, defined as the ratio of the viscosity of the dust-asphalt mixture to the viscosity of the asphalt alone, is given in Table 14. The data for asphalt WB are shown in Figure 42. The stiffening effect produced by the two asphalts is almost identical. For the two asphalts selected, the stiffening effect does not appear to be asphalt specific. As reported in other research (19), this is not always the case, and, therefore, the asphalt used in production should be used in the mixture design and evaluation.

The amount of stiffening is not uniquely related to the fineness of the dust, but in most cases the greatest stiffening was produced by one-sized finer dusts. No definite trend was found according to generic aggregate type. The

Table 14. Stiffening ratios for viscosity at 60 C.

Sample No.	Dust-Asphalt Ratio				Aggregate Type	D_{80} µm	D_{50} µm	D_{20} µm
	Asphalt A		Asphalt WB					
	0.2	0.4	0.2	0.4				
1-4	1.6	3.5	1.7	3.4	Dolomite	100	35	17
2-2	1.7	3.3	1.8	3.6	Dolomite	200	30	7
5-5-C	2.6	21.4	2.8	19.3	Traprock	10	7	3
6-3	1.8	3.8	2.4	4.2	Siliceous Gravel	200	80	15
7-3-D	2.6	17.2	2.9	18.2	Traprock	15	7	3
9-1-E	1.7	2.8	1.6	3.1	Limestone	200	80	16
10-1-C	1.8	3.8	1.8	3.4	Limestone	260	100	12
13-4	2.4	12.0	2.6	11.7	Gravel	19	6	2
14-3-C	2.6	12.0	2.8	12.1	Gravel	50	6	2
15-4-C	2.3	8.7	2.4	8.4	Limestone	12	6	2
20-2-C	2.4	10.6	2.5	10.9	Granite	18	10	4
24-4-C	2.6	16.3	2.7	16.8	Granite	20	10	4
26-2	3.2	100.4	3.6	71.8	Granite	12	5	2
30-1-C	2.0	4.6	2.0	4.1	Traprock	27	10	5
33-4	2.1	5.2	2.2	5.5	Siliceous Gravel	42	10	2

data confirm the findings of others that gradation and mineral properties alone cannot explain the stiffening effect of fine dust. It is important to note, however, that baghouse dust can be very fine but still not produce a large stiffening effect (Plant 15, for example).

Similar results were observed for the softening point data. There was little difference between the two asphalts selected for the study. The relative stiffening effect of the dust was the same for viscosity and softening point. The softening point data for asphalt WB are plotted in Figure 43.

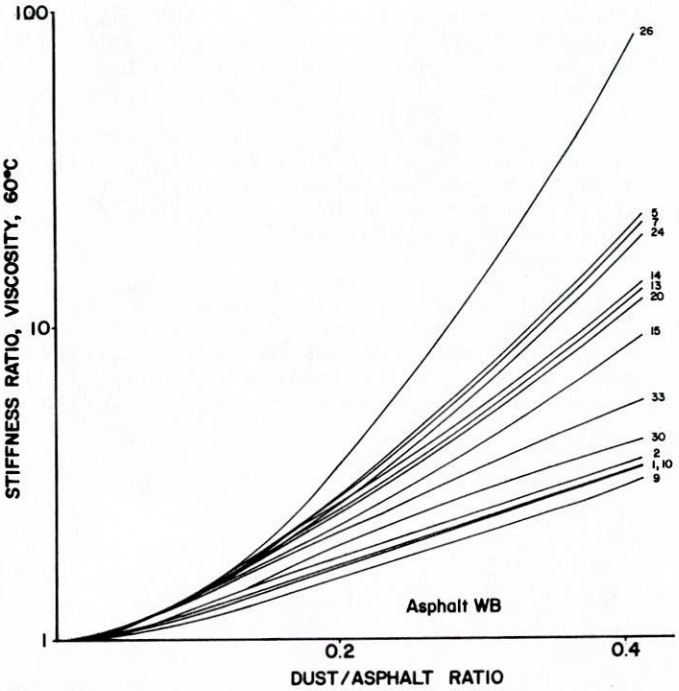


Figure 42. Stiffening ratio for asphalt WB.

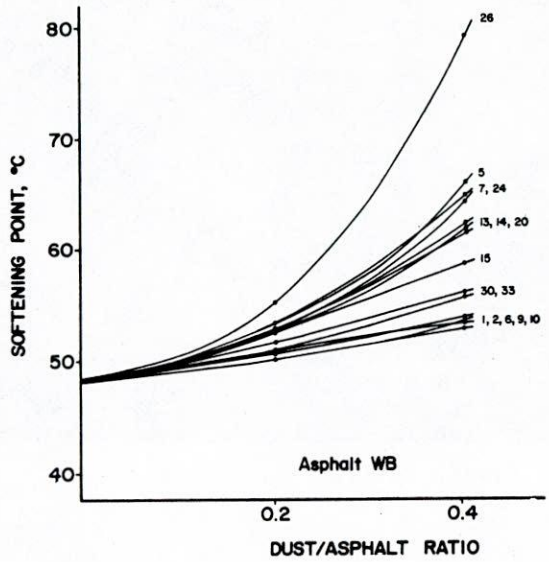


Figure 43. Softening point versus asphalt ratio for asphalt WB.

CHAPTER THREE

INTERPRETATION, APPRAISAL, APPLICATION

INTRODUCTION

Baghouse dust is a relatively new material in asphalt paving technology and, consequently, its properties and effects are not well documented. Several recent field problems have been attributed to baghouse dust, and there has been some hesitancy about using it in paving mixtures. Many state materials engineers consider baghouse dust to be a new material that needs a separate specification. A common misunderstanding is that baghouse dust is always very fine. In fact, it may be relatively coarse, even coarser than the material often specified as mineral filler (ASTM D 242) (10). Many commercial mineral fillers are actually baghouse dusts.

The early literature, prior to 1970, focused on the development of test parameters that could be applied to filler specifications and on the description of the engineering behavior of mineral filler in filler/asphalt mixtures and in asphaltic concrete. Researchers concluded that no single parameter could describe the effect of mineral fillers on the mechanical properties of asphaltic concrete mixtures, although the free asphalt content, as described by Rigden (5) and others, has been successfully used to describe the stiffening effect of mineral fillers. These concepts, however, were not developed into specifications. Most agencies have developed a gradation specification for added mineral filler, but have neglected to specify the gradation of the natural fines. Plastic fines may contribute to moisture damage, and, consequently, several states where plastic fines are likely to occur have adopted and enforced plasticity requirements.

The widespread use of baghouse dust collectors has created a renewed interest in the effect of fines on the behavior of asphalt mixtures. Because these fines are often collected and handled differently from conventional fillers, there is concern about handling procedures in the plant that may affect dust variability. Second, because baghouse dust may be very fine, there is concern about the effect of baghouse dust on mixture behavior. Several states have developed restrictive handling procedures for baghouse fines, despite the fact that these states have performance or end result specifications. Two states have suggested a classification procedure for baghouse fines and have recommended that the quantity of baghouse fines be limited according to this classification.

PLANT OPERATIONS

As discussed in Chapter Two, the characteristics and quantity of the dust entrained in the system gas are a function of the gradation of the cold feed

aggregate, the size of the dryer, moisture content of the aggregate, and the operating characteristics of the dryer. The dust collected in the baghouse depends on each of these variables, but also on the primary collection system. The variability in the dust entrained in the system gas is largely dependent on the velocity of the system gas. The coarseness of the entrained dust increases with increased gas velocity. If the coarse fraction (fraction > 75 μm) is scalped by a primary collector or knockout box, the resulting gradation of the baghouse dust tends to be very uniform, both within-day and day-to-day. However, if there is no primary collection of dust, the variability inherent in the coarse fraction will be reflected in the baghouse dust. Based on the literature survey and on discussions with asphalt technologists and plant personnel, the researchers have concluded that such factors as the condition of the fugitive dust system, moisture content, and aggregate degradation play a secondary role in the fineness of the collected dust.

It is important to note that the drum mix plant is a very efficient dust collector. Given the same aggregate source, the dust collected in a drum plant may be only one-tenth of that collected in a batch plant. The uncollected dust is incorporated as part of the mixture. Dust entrained in the drum mix plant during mixing appears to be representative of the dust in the cold feed, that is, the drum mix plant does not preferentially collect a coarse or a fine fraction of the dust in the cold feed aggregate. Further research is needed to verify this tentative finding. Although many technologists are concerned about dust characteristics and mixture behavior when the dust is collected and returned to the mixture via the hot elevator or weigh hopper (batch plant), there has not been much concern about reintroducing the dust to the mixture inside the plant, as is done in the drum mix plant.

HANDLING PROCEDURES

Handling procedures are important because they affect the uniformity of the quantity of fines returned to the mixture. Surges in the quantity of fines may produce a mixture that is dry, stiff, and difficult to compact. If the dust acts as an asphalt extender, dust surges may produce a mixture that appears to be overasphalted or tender.

Baghouse dust can be returned at three different locations in the batch plant: the hot elevator, the No. 1 hot bin, or the weigh box. However, the actual method by which the dust is returned to each of these locations can vary. Generally, the hot elevator return is the simplest, whereas the return to the weigh box with an attendant storage silo requires the greatest initial capital expense. The advantage of returning the dust to the weigh box is that it ensures that the desired quantity of dust is returned to the mixture. With proper handling equipment, however, such as a surge bin or rotary air locks, the dust can be returned uniformly to the hot elevator or the No. 1 hot bin. A disadvantage of returning the dust to the hot elevator or the No. 1 hot bin is that dust can build up on the walls of the No. 1 hot bin. This buildup can cause a dust slide if the bin is pulled too low during batching operations. Attention to the degree of slope of the hot bin walls, and the use of "Chinese hats" also may help to minimize the possibility of dust slides. (A "Chinese hat" is a tent-shaped baffle plate that is located below the screens in the hot bin.) Another disadvantage is that the operations must be synchronized with the cold feed or dryer operation in order to prevent a layer of fine material in the No. 1 hot bin. Improper synchronization of the cold feed and dryer operation can result in one or two initial batches that contain an excessive amount of dust.

Although return to the weigh box eliminates the problems associated with the hot elevator or hot bin return, an inherent disadvantage is a loss of control over the source of the dust that is introduced to the mixture. Return to the weigh box requires the use of a silo. A plant utilizing more than one aggregate source may fill the silo or surge bin with dust from a nonspecification or commercial mixture. Furthermore, if a plant switches aggregate sources during production, the characteristics of the dust also may change, thereby affecting the uniformity of the dust in the silo. When the dust is metered from the silo, there is no control over its source.

In the drum mix plant, the dust can be returned at four locations: the cold feed conveyor, the drum entrance, the drum discharge, and the point where the asphalt cement is introduced. The last location has been most widely accepted by state agencies and manufacturers of drum mix plants. Introduction of the dust with the asphalt cement eliminates the reentrainment of the dust in the system gas and provides a good distribution of the dust through the coating zone. If the dust is introduced to the cold feed or at the drum entrance, it may be recycled through the system gas; consequently, the practice is not common. The least desirable method is blowing the dust into the mixture at the drum discharge. This may result in uncoated dust particles in the mixture, and this practice should not be allowed.

A rotary air lock is customarily used to return the dust to the drum mix plant, except when the dust is returned to the cold feed conveyor. Rotary air locks, if properly operated, will prevent the delivery of a slug of dust from the baghouse. Many batch plants also return the dust to the hot elevator with rotary air locks. Batch plants, however, frequently use a simple flop gate, which may cause an uneven return of the dust. Its use should be avoided.

VARIABILITY OF DUST PROPERTIES

Grain-size distribution, hygroscopic moisture, settled bulk density, dry vibrated bulk density, and pH were measured to monitor the plant-to-plant and within-plant variations in dust properties. Variations were observed in the grain-size distribution and the bulk density of the dust. Hygroscopic moisture was eliminated as a useful test parameter to monitor dust variability. Similarly, pH varied by generic aggregate type, but the within-plant variability was very small. Thus, pH is not a useful test parameter for controlling dust variability.

The dusts were well graded; none of the dusts was gap graded. The gradation curves (logarithmic scale) were typically "s" shaped with long tails and a relatively straight portion between D_{80} and D_{20} (Figures 24-26 and 33). The ratio D_{80}/D_{20} is a good descriptor of the range of grain sizes in the dust.

Plant-to-Plant Grain-Size Variation

A wide variation from plant to plant was found in the grain-size distribution of the baghouse dust. The observed variations are consistent with the recent study by Eick and Shook (1) and the work of others (24, 25). The most significant factor affecting grain-size distribution was the type of primary collector and its relative efficiency. This is illustrated graphically in Figure 44, where the average dust grain size, D_{50}, for the five different collection systems is presented. In plants without a primary collector, the dust is rather coarse, with an average size greater than 100 µm. The average grain size is reduced by the use of a knockout box (smallest reduction), vertical cyclone, multicone, and dual cyclone (greatest reduction). Similar trends were observed with the average percent passing 10 µm, as shown in Figure 45.

An attempt was made to associate generic aggregate type with grain size or variability in grain size. No trends could be identified in the data. Very fine dust was produced by traprock and granite, but the limestone dust was not as fine as expected. It should be pointed out that the limestone dust was not plastic and did not contain any clay. This undoubtedly affected the fineness of the limestone dust sampled in the project.

The researchers intended to address the question of the quantity of fines produced by different generic aggregate types, and the variability in that quantity. After a review of plant operations, the researchers found that in order to answer this question, mass flow rate measurements in the primary collector, baghouse collector, hot elevator, and cold feed would be required. Therefore, it was not possible, with the funds available, to address this question. However, based on observations at the plants, discussions with plant operators, and a review of the data, the researchers' best judgment is that most of the variability in the quantity of reintroduced dust stems from improper dust

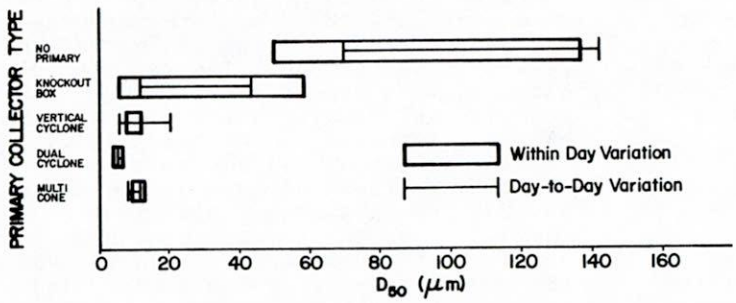


Figure 44. Variation in average dust grain size, D_{50}, by type of primary collector.

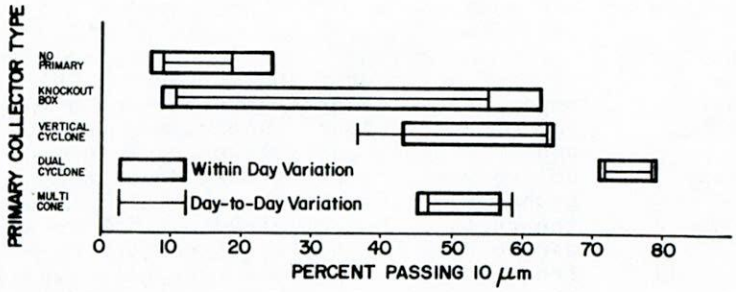


Figure 45. Variation in percent passing 10 µm for dust by type of primary collector.

handling procedures, and that the dust collected in the collection system is largely a reflection of the dust in the cold feed. Further research is needed to address this point.

Within-Plant Grain-Size Variation

Variation within a single plant, both within-day and day-to-day variation, was found predominantly in plants that have no primary system or those that use a knockout box. Plants that have centrifugal primary collectors produce relatively uniform material. A second observation was that for all plants, the grain size below 75 µm was generally very consistent.

These observations may be explained by plant operating conditions. An important factor is the characteristics of the various aggregate feeds. Many plants blend a natural sand and stone screenings to achieve the desired gradation. Generally, the stone screenings contribute significantly to the minus 75-µm fraction of the mixture. As the proportion of these two materials is altered, the plants without a primary collector and those using the generally inefficient knockout box may experience changes in the grain-size distribution of the baghouse dust. This was observed in Plant 9. The effect of changes in the type of mixture being produced on the gradation of the baghouse dust is much less significant in plants that have centrifugal collectors. In these plants the percentage of material passing the 75-µm size is usually greater than 90 percent. An analysis of the data indicates that the baghouse dust in those plants was contributed by the stone screenings, because the natural sand is low in minus 75-µm material. This helps to explain why there is little variation in the minus 75-µm fraction of dust collected in plants lacking a primary collector or equipped only with a knockout box. Of course, if the natural sand is relatively dirty or unwashed, the results will be different.

On the basis of the data collected in the project, changing from one mixture type to another (e.g., from wearing to base or from fine wearing to coarse wearing) had little effect on grain-size distribution. For plants that produced more than one type of mixture during the sampling period, the average change in D_{50} was 3.2 µm, and the average change in percent passing 10 µm was 2.9 percent. These variations are quite small and can be explained by the fact that the mixture changes were accomplished by changing the percentage of each cold feed. A wider variation might result if the plant changed the type of aggregate from one mixture to another, as was done in Plant 9. However, based on the 33 plants documented in the project, it appears that the practice of changing aggregate type from one mixture to another is not common.

Operating conditions at the plants also are significant in explaining observed variation in grain-size distribution. For example, Plant 8 had obvious air-flow problems and Plant 15 experienced improper cyclone operation. Both of these conditions affected the dust samples. In some instances, the operation of the baghouse itself may be a factor. The analysis of special samples from Plants 9 and 23 revealed variations in the fineness of the dust collected at the entrance and the exhaust end of the baghouse. This variation was probably the result of the sudden expansion of the system gas at the baghouse entrance, which caused the coarse fraction to settle. This effect is likely to be more evident in plants without a primary collector. It can be minimized by ensuring that the bags are cleaned in a random sequence and not in a systematic front-to-back or back-to-front sequence. Of course, the cleaning sequence is more important in plants without a primary collector, where there is a significant percentage of coarser material in the dust entering the baghouse.

SPECIFICATIONS AND MIXTURE DESIGN

The development of specifications for baghouse dust may be considered from three aspects: handling procedures, physical properties of the dust or dust-asphalt mixtures, and the effect of the dust on the properties of asphaltic concrete mixtures.

Handling Specifications

The main consideration with respect to handling procedures is to ensure that the quantity of dust added to the mixture is uniform. This may be accomplished in a number of ways. One method is to give the plant operator the option of selecting the most cost-effective handling system for his plant. With this option, it is the responsibility of the operator to demonstrate that appropriate uniformity can be achieved. At the other end of the spectrum, the specifying agency dictates the method of process control at the plant by specifying handling procedures. This approach tends to lead to inflexibility on the part of the specifying agency and to overcontrol, which is not cost effective.

In the opinion of the researchers, the performance or end result strategy is to be preferred. First, each asphalt plant is unique. Asphalt plants, especially batch plants, are often custom manufactured, and the equipment configuration and operation of each plant may be different. Second, the characteristics of the aggregate and crushing, handling, and washing procedures vary from plant to plant. Each of these factors influences the quantity and characteristics of the dust and may necessitate different handling systems. A handling system suitable for a plant with clean aggregate, which must make up fines with commercial fillers, is not appropriate for a plant that uses very dirty aggregate and must waste part of its dust. Handling of the dust may be

especially critical in instances where a plant is using the dust collection system to clean a dirty aggregate.

Dust Properties

In most cases, the baghouse dust constitutes only part of the dust in the mixture. It is inconsistent to apply specifications to baghouse dust when it is the total dust fraction that determines the behavior of the dust in the mixture. This was recognized by Kandhal (4), who suggested that each of the hot bins and the filler silo be sampled and that a composite dust sample be constructed according to the percentage of each component. The process of obtaining a representative sample is difficult. Furthermore, there is no acceptable procedure for removing the dust from the fine and coarse aggregate. Dry sieving is not acceptable because it does not separate all the dust from the coarse and fine aggregate. Many of the finer particles, which may contribute most to asphalt stiffening or asphalt extension, cannot be removed by dry sieving. Wet sieving is inadequate because the dust cannot be removed from the water without drying. Drying at 110 C causes the finer dust particles to agglomerate.

Four factors are of potential concern in the acceptance of a particular dust: the stiffening effect that it produces, its ability to act as an asphalt extender, its effect on the water sensitivity of a mixture, and its effect on mechanical properties such as creep, elastic modulus, and fatigue. The first factor can be assessed by evaluating the void characteristics of the dust, or, more directly, by measuring the stiffening effect of the dust on a dust-asphalt mixture. Although a very rational argument can be made for claiming that the stiffening effect should also be measured on the composite asphaltic concrete sample. The other three factors must be evaluated from measurements on the asphaltic concrete mixture.

On the basis of the literature review and the results of this research, it is concluded that grain-size distribution is not an appropriate specification parameter for controlling the stiffening effect of mineral filler or dust. The stiffening effect may be predicted by the relationship between (1) stiffening and volume of the free asphslt, $\%V_{AFR}$, or (2) stiffening and the percent bulk volume of dust in the dust-asphalt mixture, $\%V_{DB}$. Stiffening may also be predicted by measuring the change in softening point; however, stiffening ratio is preferred because it is a fundamental parameter and the equipment is readily available. Bulk specific gravities measured by dry compaction, vibration, and settled volumes in polar and nonpolar liquids were used to calculate $\%V_{AFR}$ and $\%V_{DB}$. The best correlations were obtained with $\%V_{AFR}$ and $\%V_{DB}$ calculated on the basis of the dry-compacted specific gravity (Table 15).

Rigden (5) has proposed a unique linear relationship between fluidity (reciprocal of viscosity) and $\%V_{DB}$. A plot of fluidity versus $\%V_{DB}$ is presented in Figure 46, and the relationship is clearly curvilinear. Rigden further hypothesized that a viscous-plastic transition occurs as the fluidity approaches zero. On the basis of this concept, Kandhal (4) has proposed the following specification for the minus No. 200 mesh material (not baghouse dust alone) in an asphalt mixture:

1. If the $\%V_{DB}$ is greater than 50 percent, the stiffening effect produced by the minus No. 200 fraction will not significantly affect mixture properties.

2. If the $\%V_{DB}$ is greater than 50 percent, the increase in softening point of the dust-asphalt mixture should be less than 11 C (20 F).

These requirements are reproduced in Figure 47 with several modifications. First, softening point is replaced by stiffening ratio. The two parameters show a high degree of correlation ($r^2 < 0.90$), but stiffening ratio (based on 60 C viscosity) is a fundamental test measure, is more repeatable than softening point tests, and is more commonly used by state agencies. A change in softening point of 11 C (20 F) is equal to a stiffening ratio of approximately 10. Second, $\%V_{DB}$ is replaced by percentage of free asphalt, because it is a more easily understood parameter. It should be noted that $\%V_{AFR} = 100 - \%V_{DB}$. Figure 47 is based on $G_s = 2.70$. With a dust-asphalt ratio of 0.4, seven of the 15 dusts tested in this project would be outside these specification criteria. Further research is needed to establish the relationship between stiffening and various aspects of mixture behavior (such as creep, fatigue, and elastic modulus) before stiffening ratio can be adopted for specification use. As currently proposed, the procedure does not account for the asphalt absorbed by the coarse aggregate, which would give a greater dust-asphalt ratio than that calculated on the basis of total weight. Finally, the question remains as to what fraction should be considered in the dust-asphalt mixture--can the dust be defined simply as the minus 75-μm material?

In terms of specifications, there is merit in limiting the plasticity of the fines. The degree of plasticity is related to the presence of clay minerals; non-clay fines do not exhibit plasticity. Because the presence of clay in a mineral filler has been related to water damage in asphaltic concrete mixtures, some control of clay content is warranted. This can be done by the Atterburg limits test, or perhaps more conveniently by the sand equivalency test. The advantage of the sand equivalency test is that the entire sample can be used; there is no need for dry sieving to remove the fines. However, field studies should be conducted to establish the validity of the relationship

Table 15. Stiffening versus percent bulk volume of dust in dust-asphalt mixtures.

Model	Correlation Coefficient	Basis for Calculating $\%V_{DB}$
$SR = 0.8 - 4.5\ (\%V_{DB}) + 9.2\ (\%V_{DB})^2$	$r^2 = 0.94$	Dry compaction
$SR = 0.2 + 0.9\ (\%V_{DB}) + 0.2\ (\%V_{DB})^2$	$r^2 = 0.88$	Vibration
$SR = 0.1 + 0.8\ (\%V_{DB}) + 0.3\ (\%V_{DB})^2$	$r^2 = 0.80$	Polar settling
$SR = 0.3 + 1.0\ (\%V_{DB}) - 0.3\ (\%V_{DB})^2$	$r^2 = 0.89$	Nonpolar settling
$\Delta SP = 0.4 + 1.3\ (\%V_{DB}) + 1.1\ (\%V_{DB})^2$	$r^2 = 0.94$	Dry compaction
$F = 3.19 - 3.01\ (\%V_{DB})$	$r^2 = 0.87$	Dry compaction
$F = 1.82 - 8.57\ (\%V_{DB}) + 4.17\ (\%V_{DB})^2$	$r^2 = 0.94$	Dry compaction

SR = Ratio, viscosity dust-asphalt mixture/viscosity neat asphalt, ASTM D 2171, 60 C (140 F).

ΔSP = Change in softening point, °F, dust-asphalt mixture minus neat asphalt.

F = Fluidity, reciprocal of viscosity, 60 C (140 F), ASTM D 2171 $(Pa \cdot s)^{-1} \times 10^3$.

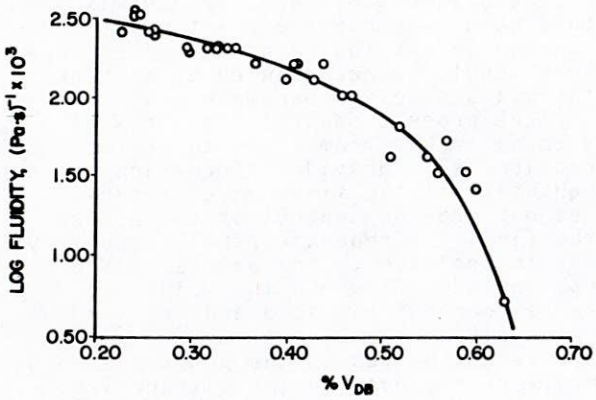


Figure 46. Fluidity versus bulk volume of dust in dust-asphalt mixtures.

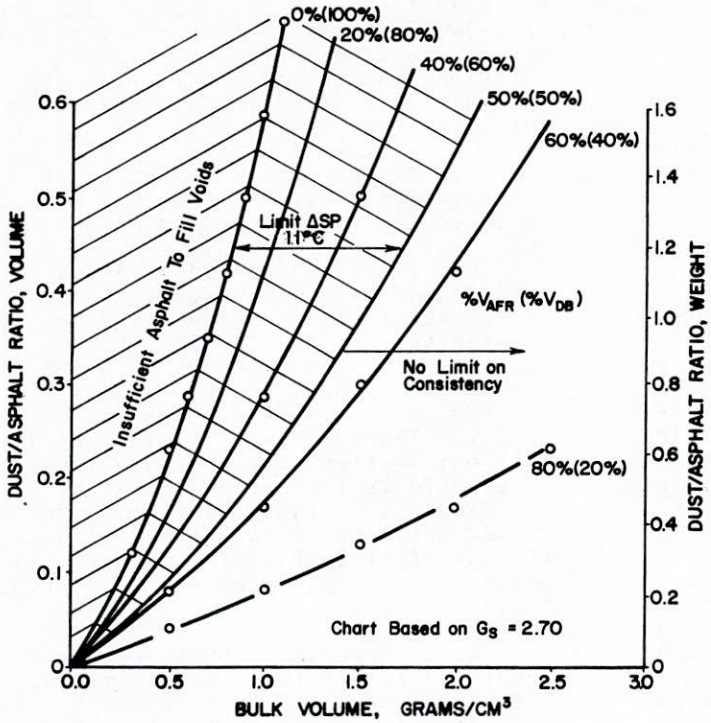


Figure 47. Dust/asphalt ratio versus bulk volume of baghouse dust.

between sand equivalency and moisture damage before it is adopted as a specification criterion. Such work is currently under way in Arizona.

The other tests conducted in this study do not have a role in specifications. Further development of a water sensitivity test for the dust or dust-asphalt mixtures may be warranted, but it should be based on the behavior of the entire mixture and not just on the dust-asphalt component. The possibility that water-induced damage might be caused by the dust should be evaluated as part of the mixture design process, just as it is for the coarse or fine aggregate. No correlations were found in the heat of immersion, hygroscopic moisture, pH, or water sensitivity tests. Heat of immersion, hygroscopic moisture, and pH measurements do not appear to have merit as specification criteria. Because of its complexity, the heat of immersion test probably will not become a routine specification test. Its use as a research tool should be continued, particularly in light of the anomalously low heat of wetting predicted by the procedure.

Mixture Design Practice

Mixture design practice and testing procedures vary considerably throughout the country. A number of states base their mixture designs on dry rather than washed sieve analyses, which can underestimate the quantity of fines in an aggregate. Many states do not conduct an ash correction for extraction tests, which can lead to an error of up to a percentage point in the amount of asphalt in a mixture.

Whenever possible, the cold feed or the job aggregate should be used in the mixture design. This is especially important if water sensitivity tests are to be performed. Standard fines or fillers for mixture design should be avoided. The use of the cold feed aggregate is especially important in drum mix plants because most of the dust will be retained in the mixture.

Extension of the asphalt by the dust can be accounted for during mixture design and is another reason why production fines should be used during mixture design. If production fines are not available, adjustments should be made when the job mix formula is established. A job mix formula should be routine plant practice. Any change in the source of the fines in a mixture should be accompanied by a check of the mixture design parameters.

Plant process control practices also vary considerably from state to state. Extraction tests provide information about the quantity of the fines in a mixture, but cannot provide control of the nature of the fines. Although Marshall stability may be insensitive to the nature of the fines, Marshall flow and the voids criteria (percent air void and voids in the mineral aggregate, V_{MA}) are sensitive to changes in the properties and quantity of the dust in the mixture (29).

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

The following conclusions are based on the research described in this report.

1. Considerable plant-to-plant variability exists in baghouse dust. This variability is related mainly to the efficiency of the primary collection system and the nature of the cold feed aggregate.

2. Generic aggregate type is not a primary factor in determining the fineness or the quantity of the dust entrained in the system gas. There is no basis for developing specifications on the basis of generic aggregate type.

3. The greatest day-to-day and within-day variability in the fineness of the collected dust occurs in the coarse fraction of the dust, > 50-75 μm. For a given aggregate source, the coarseness of the dust entrained in the collection system gas depends primarily on the drum gas velocity.

4. Day-to-day and within-day variability in the fineness of the dust is largely dependent on the efficiency of the primary dust collector. The more efficient the primary collector, the less variable the fineness of the baghouse dust.

5. Baghouse dust can be quite coarse, exceeding the limits generally accepted for mineral filler (ASTM D 242).

6. Based on limited data and on qualitative observations, it is the researchers' best judgment that most of the variability associated with the quantity of baghouse fines returned to the mix is due to handling procedures.

7. There are wide variations in the stiffening effects of baghouse fines. These effects are not explained by either the fineness or the gradation of the dust. Consequently there is little validity for the use of classification systems based on grain size for the specification of baghouse fines.

8. Stiffening effects can be predicted from bulk volume measurements on baghouse dust (or mineral filler). The free-asphalt volume is a valid concept for

predicting the stiffening effect of baghouse dust. A more appropriate procedure is to prepare a dust-asphalt or filler-asphalt mixture using the ratio to be used in the asphaltic concrete mixture and to measure directly the viscosity of the mixture at 60 C (140 F) (ASTM D 2171).

9. It is inconsistent to develop a specification for baghouse dust without specifying the entire fine (filler) fraction in the mixture. The baghouse dust may constitute only a small percentage of the filler, but it is the behavior of the entire filler fraction that is significant.

10. There appears to be little justification for developing a new specification for either baghouse dust or the filler fraction until the role of the dust or filler is better understood. A specification based on gradation or size classification cannot be justified, for neither stiffening nor asphalt extension can be uniquely related to gradation.

11. Each asphalt plant must be considered as a unique system because of variations in manufacturers' designs, plant configuration, and aggregate characteristics. Consequently, dust handling systems should be selected according to the particular conditions at each plant. General guidelines for dust handling procedures, for batch and drum mix plants, are presented below.

On the basis of the review of the literature, discussions with state materials engineers and plant operators, and an analysis of the data collected in the project, the following general guidelines are recommended for handling baghouse dust:

1. Drum mix plants

Dust should be introduced at the beginning of the coating zone in the drum simultaneously with the introduction of the asphalt cement.

2. Batch plants

a. The preferred method is direct return of the dust to the hot elevator or the No. 1 hot bin, if proper control of uniformity can be obtained. This requires close synchronization of the operation of the dryer and the baghouse with the feed to the hot bin or the hot elevator. Care should be taken that the No. 1 hot bin is not operated too low.

b. A surge bin and a positive feed system may be added to improve metering uniformity.

c. If the systems in (a) and (b) do not ensure uniformity in the quantity of fines, it may be necessary to meter the dust into the weigh hopper.

d. A storage silo does not provide good control when it is used to store baghouse dust and commercial filler if the dust and filler have different properties. A storage silo system may increase uniformity in the quantity of fines in the mix but this may be at the expense of uniformity in the properties of the dust.

SUGGESTED RESEARCH

On the basis of the research described in this report, it is recommended that additional research be conducted on the role of baghouse dust and fillers on the behavior of asphaltic concrete mixtures. This research should address the following points.

1. The nature and extent of the physical and physicochemical interactions between the fine fraction (filler, including primary and secondary dust) and the asphalt must be better defined. Whereas parameters based on the bulk volume of the filler ($\%V_{DB}$ and $\%V_{AFR}$) can explain much of the stiffening effect of the fine fraction, certain dusts exhibit anomalous behavior.

2. The effect of dusts on the compactibility of asphaltic concrete mixtures must be defined.

3. The range of dust properties that enhances asphalt extension and the effect of extension on mixture stiffness, fatigue, and the aging characteristics of the asphalt cement should be investigated.

4. The influence of the stiffening effect of filler (including primary and secondary dust) on the fatigue and mechanical behavior of asphalt mixtures needs to be studied.

5. Further research should be conducted in order to determine the variability in the quantity of fines that are introduced into the mix. This research should consider plant handling procedures, plant equipment, plant operating conditions, and generic aggregate types.

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APPENDIX A

STATE EXPERIENCES WITH BAGHOUSE FINES/CURRENT AGENCY PRACTICES

ALABAMA

In Alabama, a few plant operators are replacing their baghouses with wet systems. These operators think that the baghouses are too inflexible with respect to temperature changes. Currently, batch plants return the fines to the hot elevator. Drum plants return them through the mineral filler line, and surges of these fines are being noted. The State uses granites, limestones, and slags as aggregates. No particular specifications exist for baghouse fines. Currently, no specification changes are expected.

ARIZONA

Arizona is initiating a new specification for the use of collector fines. The mix design will be performed with the natural aggregates, including the minus No. 200 fraction. The contractor must demonstrate, however, that the collector fines are not detrimental before they may be incorporated during production. A check on the mix design parameters, including the immersion-compression test, will be performed on mixes with and without the collected fines. The natural aggregates contain colloidal material, and stripping has been observed. The contractor must also provide a method to ensure that the fines are returned uniformly to the mix. Until now, the Atterburg limits test has been performed on the natural aggregates. This test is to be replaced with the sand equivalency analysis, which, it is believed, will be more indicative of the magnitude of the colloidal material present.

ARKANSAS

Approximately 50 percent of the plants have baghouses. In only one instance was baghouse fines associated with a problem. This occurred in a drum mix plant using a limestone aggregate. The mix appeared greasy and was rejected. The State, in turn, prohibited the contractor from returning the baghouse fines. After this change, the mix was acceptable for laydown. The State's main aggregates are limestone and sandstone. Batch plants are allowed to return the dust directly to the hot elevator through use of a screw feeder.

Mix Design: Marshall, using stockpile aggregate and a washed sieve analysis

Special Tests: Immersion-Compression

Plant Control Practices: Daily extractions, Marshall stability, flow and density

Specification Philosophy: Process control

CALIFORNIA

Prompted by problems of spotty bleeding and tenderness, the State conducted a study on baghouse fines in 1976. It was determined that occasional batches containing excessive minus No. 200 material were occurring in plants returning the baghouse dust to the hot elevator. The following specification changes were made. A maximum of 3 percent baghouse fines may be incorporated into the mix, and the fines must be returned to the weigh box. The quantity of baghouse fines returned to the mix must be specified in the mix design. At the present time, the 3 percent limitation has been relaxed. Dust collected by primary collectors--skimmers, knockout boxes, cyclones, etc.--may be returned to the hot elevator uniformly.

Since the study of 1976, drum mix plants have come into use. The first drum mix plant utilized a baghouse to return dust to the cold-feed conveyor. Analysis of the subsequent mix revealed no substantial variability in the minus No. 200 content, and the return method was approved. The second drum mix plant returned baghouse dust to the point of the asphalt cement introduction. This method also received approval. A tighter cold-feed control of the drum mix system, compared with that of the batch plant, is associated with the approval of the various drum mix plant return methods.

Mix Design: Hveem, utilizing the hot bin and baghouse dust material

Specification Philosophy: Process control

COLORADO

No problems at present or in the past have been associated with baghouse fines.

The typical aggregate is a crushed alluvial gravel, predominantly a granite, although sandstone gravels exist. Small amounts of granite and limestone are quarried. Thirty percent of the plants are the drum mix type. The batch plants are allowed to return dust through use of a screw feeder to the boot of the hot elevator. No future specification changes are foreseen.

Mix Design: Hveem, using stockpile material and a washed sieve analysis

Special Tests: Immersion-compression

Plant Control Practices: Extractions, 1/500 tons produced; design check, 1/10,000 tons

Specification Philosophy: End result, based on asphalt cement content, density, and the 3/4-in., No. 4, No. 8, and No. 200 sieves.

CONNECTICUT

The addition of baghouse fines has not been associated with any problems at present or in the past. Crushed traprock supplies 80 percent of aggregate needs, with the remaining 20 percent consisting of gravels. Batch plants predominate, with return to the boot of the hot elevator permitted. This return may be accomplished with a screw feeder to return the dust directly to the hot elevator. No specification changes are currently foreseen.

Mix Design: Marshall, using hot bin material and a dry sieve analysis

Plant Control Practices: Extractions, 3 to 5/day
Daily check on Marshall stability and flow

Specification Philosophy: End result based on asphalt cement content and 3/4-in., 3/8-in., No. 4, No. 8, and No. 200 sieves. Density is included for maintenance work only.

DELAWARE

No pavement problems at present or in the past have been associated with baghouse fines. Approximately 30 percent of plants have baghouses, and this percentage is considered stable. A drum mix plant was noted as having excessive minus No. 200 content in the final mix. Batch plants in the area, using the same aggregate source and returning the dust, were within specification limits; however, they were reaching the upper limit. The minus No. 200 content of the standard mix is 10 to 13 percent. The problem was alleviated by reducing the minus No. 200 content in the cold feed aggregate. The State notes that, generally, plants with baghouses appear to be reaching the minus No. 200 upper limit. Limestones are the predominant aggregate, with granites, traprocks, and a small percentage of gravels used. Open-graded friction courses are growing in popularity. No future specification changes with respect to baghouse fines are foreseen. Currently, the return of the fines directly to the hot elevator through use of a screw feeder is permitted.

Mix Design: Marshall, utilizing stockpile material and a dry sieve analysis

Plant Control Practices: Extractions, 1/800 tons; ash correction is performed. Marshall stability and flow, 2 cores/800 tons

Specification Philosophy: Process control

FLORIDA

No pavement problems have been noted at present or in the past resulting from baghouse fines. Ninety percent of the plants are the batch type and are permitted to return dust to the boot of the hot elevator. The remaining plants are drum mix, the majority of which return the baghouse dust to the point of asphalt cement introduction. The limestone is a high-carbonate and soft, which restricts its use to base material. Granites imported from Georgia and Alabama, one steel slag source, and a limited amount of gravel located in West Florida constitute the friction course materials. It was noted that "occasional" minus No. 200 variability occurred. However, this was attributed to the contractor driving on the piles, resulting in segregation and degradation of the aggregate. An excess of minus No. 200 material was also occurring throughout the State. A requirement to wash the aggregates alleviated this condition. No future specification changes with respect to baghouse fines are foreseen.

Mix Design: Marshall, utilizing stockpile material and a washed sieve analysis

Plant Control Practices: Extractions, 1/1000 tons; ash correction is performed. Hot bin or Marshall stability, contractor's choice.

Specification Philosophy: End result based on asphalt cement content, density, surface tolerance, and the No. 10 and No. 200 sieves

GEORGIA

Occasional pavement problems are associated with the addition of baghouse fines. Tender and bleeding spots along the highway are attributed to dust slides in the No. 1 hot bin. These slides occur in plants that return fines to the boot of the hot elevator and in plants where the fines are metered into the No. 1 hot bin. Granites constitute 80 percent of the

aggregate used, and only occasional slides are associated with this aggregate. The problem aggregate is a chalky limestone of northern Georgia, in the Mt. Region area. It is noted that 3 percent of this lot aggregate is being processed through the baghouse. The tentative specification would have required batch plants to install a silo to meter the baghouse fines into the weigh box. Drum plants would be required to install a blending unit for the fines and the asphalt. A contractors' concern that these specifications might not be cost effective prompted the State to postpone enactment of the handling requirements. Instead, the master job range was changed from 2 to 12 percent passing the No. 200 sieve, to 4 to 7 percent, with a ± 2 percent variation. This change requires the contractors to determine the best way to satisfy the specifications. Alternatives range from washing the aggregates to wasting the dust. The State has also studied the grain-size distribution of the dust collected from various plants. It was determined that the distribution varied among plants and aggregate sources.

Mix Design: Marshall, utilizing stockpile aggregates and a washed sieve analysis

Special Tests: Lottman and boiling tests

Plant Control Practices: Extractions, 3/day

Specification Philosophy: Described as a combination of process control and end result. End result based on asphalt cement content, density, smoothness, and the No. 8 sieve.

ILLINOIS

Concern was expressed that baghouse fines are associated with tender pavements and moisture damage. Of the plants in the State, 60 to 80 percent are equipped with baghouses. Large quantities of limestone plus some traprock and slag are used in Illinois. The problems have been associated only with the limestone aggregates.

Almost all batch plants possess a primary collector. Dust return from the primary collector is accomplished through a small surge bin to the hot elevator. The baghouse collector dust is routed through a storage silo and returned to the weigh box. Many plants also use a commercial mineral filler that is added through the same silo with the baghouse dust. One plant is reported to use a dual silo system, one for filler and a second for baghouse dust. Drum mix plants must return the baghouse dust at the point of the asphalt cement introduction. No dust-associated problems are being observed with the drum mix plants.

One plant in the State does not have a primary collector and also must supplement the natural material with a mineral filler. Without the action of the primary collector, the baghouse dust is much coarser than the mineral filler. To prevent the mixing of these two materials, the State is permitting the contractor, under trial conditions, to return the baghouse dust to the hot elevator.

Mix Design: Marshall, utilizing stockpile material, a dry sieve analysis, and a standard filler

Special Tests: Lottman test

Plant Control Practices: Contracts by process control--extractions and hot bin analysis; contracts by end result--contractor's option.

Specification Philosophy: Described as combination of process control and end result. End result based upon asphalt cement content, density, 1/2-in., No. 4, No. 10, No. 40, and No. 200 sieves.

INDIANA

Current and past problems were noted, but these problems are of a different nature. An isolated problem involving a particular contractor existed in the past. Spotty bleeding patches occurred along the roadway and were attributed to the baghouse, which was returning the dust to the hot elevator, continuing to run while the plant was shut down. This procedure resulted in a buildup of fines in the No. 1 hot bin. Subsequently, this buildup found its way into one or two batches. The State specification requires the dust collector to be constructed so as to waste or return uniformly to the hot elevator all or any part of the material collected. This requirement entails a metering system to return the dust. Enforcement of the specification eliminated the contractor's problem. Plants can satisfy this specification by using a small surge bin with a rotary air lock. Many plants also use a waste screw to waste dust during dryer shutdown. Drum mix plants must return the baghouse dust to the point where the asphalt cement is introduced.

At the present time, 20 to 40 percent of the plants are equipped with baghouses, and a higher percentage is expected in the future. Concern was expressed about isolated instances of poor compactibility. The predominant aggregates used in Indiana are a crushed stone or gravel limestone and some slag. No plants using slag are equipped with baghouses. Only the limestones appear to be associated with poor compactibility. Variability in the minus No. 200 content has been eliminated as the cause, but the grain-size variability of the fines has not been ruled out. Plant inspectors have been asked to carefully monitor the return of the fines to the hot elevator.

Mix Design: Hveem, utilizing the stockpile aggregate

Special Tests: Boiling test

Plant Control Practices: Extractions, 1/1000 tons; ash correction performed

Specification Philosophy: End result based on committee

IOWA

Iowa has been experiencing a poor compactibility/brittleness problem in which baghouse fines have not been ruled out as a cause. In particular, concern was expressed over variability in the minus No. 200 content of the mix and in the quantity of dust airborne in the dryer and consequently becoming trapped in the baghouse. It was also reported that the mixes appear dry. Baghouses exist on 40 to 60 percent of all plants. Iowa uses crushed limestone, of which a large portion is dolomitic, plus shale and limestone gravels. Problems have been associated with what was described as a shale-limestone possessing a high percentage of fines of low plasticity index. Gravels have also occasioned problems. The plasticity index of the gravel baghouse fines is approximately 20. This State has been importing granites and traprocks with no pavement problems resulting from their use. Batch plants generally return dust to the hot elevator. A recent memorandum limits the filler-asphalt ratio to 1:3 based on volume. Specification changes are foreseen as the problems become better documented.

KANSAS

No pavement problems are considered to be associated with the use of baghouse fines. This may be the result of limited experience with baghouses. Less than 10 percent of all plants are so equipped; these plants are located in urban areas and rarely perform state work. An increase in baghouse use is not expected. The eastern part of the State uses a crushed limestone, while sand is used in the western half.

KENTUCKY

Pavement problems related to the use of baghouse fines have not been observed. However, tight control over plant operations is enforced. Batch plants must use a separate weigh system to return the fines to the weigh box if 40 percent or more of the mix is not composed of a natural or manufactured sandstone sand. To avoid problems with drum plants, tight cold-feed control is required. The aggregate in this state is predominantly crushed limestone with some slag. A friable sandstone of eastern Kentucky is just coming into use. High hauling costs for superior aggregates justify use of this marginal aggregate. The incorporation of baghouse fines in mix design is foreseen as a possible specification change. This State is currently evaluating baghouse fines in response to contractors' inquiries about utilizing the fines as an asphalt extender. To date, fines from 25 to 30 plants have been evaluated by grain-size distribution and Atterburg limits. The grain-size distribution and plasticity index have been found to be comparable to those of commercial mineral fillers. Storage of the baghouse dust and the mineral filler in the same silo is therefore permitted. Generally, plants possess a primary collector which returns dust to the hot elevator.

Mix Design: Marshall, utilizing stockpile material and a dry sieve analysis

Plant Control Practices: Extractions

Specification Philosophy: Combination of process control and end result

LOUISIANA

Baghouse fines have not been related to any pavement problems. Less than 10 percent of all plants currently possess a baghouse, although this figure is expected to increase. Batch plants constitute 85 percent of all plants. Concern over the conclusions of the Asphalt Institute study prompted this State to perform a small, undocumented study in early 1980. In particular, information was sought on the uniformity in quantity and size distribution of dust discharged from the baghouse. Hydrometer studies revealed the grain-size distribution of the fines to be acceptably uniform. However, the discharge quantity was not. The rate of discharge was determined by filling 55-gallon drums from the baghouse discharge in a fixed time. It was concluded that the quantity of dust becoming airborne was not the source of the problem. The variability of discharge quantity is associated instead with nonuniformity of cold feed or nonuniformity in the bag-cleaning system. To maintain a positive effect a uniform feed rate with an indicator at the baghouse discharge is required. Fines are returned to the boot of the hot elevator in the batch plant, adjacent to the asphalt cement line in the drum plant. Gravel and sand consisting of a cherty limestone are used predominantly, although a crushed limestone is gaining in popularity. No future specification changes with respect to baghouse fines are foreseen.

MAINE

It was reported that 80 to 100 percent of all plants have baghouses, but that no pavement problems have ever been associated with baghouse fines. Gravel and sand consisting of granitic and shale limestones are the predominant aggregates. Also, small quantities of crushed stone,

granites, and limestones are used. The plants are permitted to return the fines to the boot of the hot elevator.

Mix Design: Hveem, utilizing stockpile material and a dry sieve analysis

Special Tests: Sand equivalency test performed on minus No. 200 material in mix

Plant Control Practices: Extractions, 1/500 tons

Specification Philosophy: End result based on density and gradation

MARYLAND

Currently, no pavement problems are being associated with the use of baghouse fines. However, a number of adjustments to the mix design and operating conditions were initiated shortly after baghouses came into use. First, concern over the extension of asphalt with baghouse fines prompted a reduction in the minus No. 200 content from 7 to 8 percent to 3 to 5 percent in the master job mix. The asphalt content was not changed. Second, the state tightened the handling controls on baghouse fines, requiring a uniform return of the baghouse dust. Hot elevator return is permitted.

Mix Design: Marshall, utilizing stockpile material and a dry sieve analysis

Plant Control Practices: Hot bin analysis and Marshall density

Specification Philosophy: Process control

MASSACHUSETTS

An isolated problem of poor compactibility and spotty bleeding has been linked to a particular contractor. The problem has two sources. First, the contractor permits high amounts of minus No. 200 content. Second, dust slides are occurring in the No. 1 hot bin. In this plant, the fines are returned to the hot elevator. The contractor is adding equipment to provide uniform metering of fines. The State, rather than enacting legislation, tries to allow the contractor to solve his problems.

MICHIGAN

Occasional tenderness and serious uniform bleeding were observed when plants first switched from wet to dry collection systems. The cause was the high level of the minus No. 200 content; the dust being added to the mix was much finer than before. The following corrective measures were initiated in 1978, and the problems have since ceased. First, the mix design was opened to allow more air. Second, traffic was prohibited from riding on the hot mat for two hours after laydown. Third, storage of the fines was prohibited; they must be returned immediately to the mix through the hot elevator. This requirement is designed to prevent any fines from commercial work finding their way into a state mix. The State may also require a contractor to install a small surge bin between the baghouse and the hot elevator to prevent sudden slugs of fines. However, no uniformity problems have been reported that would warrant enforcement of this specification. The predominant aggregate is a dense-graded limestone gravel, and the reported problems occurred with this aggregate. Traprock, sandstone, and slags are also used. No future specification changes are foreseen, and 40 percent of all plants currently have a baghouse.

Mix Design: Marshall, utilizing stockpile aggregates and a washed sieve analysis

Plant Control Practices: Extractions; an assumed ash correction is applied

Specification Philosophy: Process control

MINNESOTA

Minnesota reported that no problems have been linked to the use of baghouse fines. Gravels are the predominant aggregate, and return of all or any part of the fines uniformly to the hot elevator is required. The method to achieve uniformity is chosen by the plant operator. A screw feeder to return the fines directly is permitted. However, if the plant inspector observes slugs of fines, the State will require the contractor to install a surge system.

Mix Design: Marshall, utilizing stockpile material and a dry sieve analysis

Plant Control Practices: Contractor's option

Specification Philosophy: Process control

MISSOURI

This State reported that the use of baghouse dust has not resulted in any pavement failures. Return of the dust to the boot of the hot elevator is permitted, but this applies only to dust from the mineral aggregate being incorporated into a state mixture. A mineral filler consisting of pulverized limestone is required in the surface mix to equal the amount of natural No. 200 mesh material in the combined aggregates. No specification changes with respect to baghouse dust are expected.

NEBRASKA

No baghouse fines problems exist. From 40 to 60 percent of the plants have

baghouses, and an increase in their use is not expected. The aggregate in use is a siliceous river gravel. This gravel is very clean, containing only 1 percent minus No. 200 material. Mineral filler must have a plasticity index value of less than 6.

NEW HAMPSHIRE

Ninety-five percent of all plants have a baghouse. However, no conclusions about problems related to the use of baghouse fines have been reached. The plants are permitted, through use of a screw feeder, to return the dust directly to the boot of the hot elevator. About 90 percent of the mixes utilize gravels. These gravels are a mixture of various rocks, including gabbro, granites, schists, quartz, rhyolite, and traprocks (basalt).

NEW JERSEY

No major pavement problems have been associated with the addition of baghouse fines. But concern over the uniformity in quantity and quality of the baghouse fines was expressed. With respect to handling, the specifications read that the plant must be equipped with a dust collector capable of wasting or uniformly returning to the plant all or any part of the material collected as directed. Currently, approximately one-half of the batch plants return the dust to the hot elevator. The remaining plants return the dust to the weigh box by means of a storage silo.

NEW MEXICO

Though all plants have baghouses, the state rarely permits the baghouse fines to be returned to the mix because the natural material is generally high in minus No. 200 material. The state reported a stripping/moisture damage problem associated with sand and gravels.

NEW YORK

In a state where 40 to 60 percent of all plants have baghouses, baghouse fines are associated with tenderness, uniform bleeding, and stripping/ moisture damage problems. In particular, concern was expressed about the use of these fines to extend the asphalt and about variability in the quantity of dust being returned. This State uses all five aggregate groups: granites, limestones, traprocks, sandstones, and slags. However, the fines of the Adirondack granite gravels are associated with stripping/moisture damage. This State reports that specification changes with respect to dust and handling methods are conceivable. However, the extent of these changes has not been decided. Approximately 3 years ago, an effort to improve mix design practices was initiated. It is believed that as practices improve, the material failures will be alleviated. Currently, return to the hot elevator boot is permitted by any method the contractor chooses.

Mix Design: Marshall, utilizing hot bin material and a dry sieve analysis

Plant Control Practices: Extractions, hot bin analysis, and Marshall stability and flow

Specification Philosophy: Process control; end result is being phased in with a check on density

NORTH CAROLINA

No pavement problems have been noted. It is reported, however, that since baghouses became popular 2 to 3 years ago, an increase in the minus No. 200 content has been observed. The predominant aggregate is granite used as a crushed stone. Small amounts of limestones and traprocks are also used. This State allows the return of the fines directly to the hot elevator through use of a screw feeder. However, any plant reported to have slugs of fines returned is required to install equipment to ensure uniformity. Currently, no specification changes are foreseen, but the minus No. 200 content is being monitored.

Mix Design: Marshall, utilizing the stockpile material and a washed sieve analysis

Plant Control Practices: Extractions; a set ash correction is applied

Specification Philosophy: Process control

OHIO

No pavement problems associated with baghouse fines have been observed. The State specifications require all or part of the baghouse fines to be uniformly returned to the hot elevator; however, a contractor would be permitted to return the dust to the weigh box. The predominant aggregate is limestone, with sandstones and slags used to a lesser degree.

Mix Design: Marshall, utilizing stockpile or hot bin material and a dry sieve analysis

Plant Control Practices: Extractions, 1/500 tons; Marshall density

Specification Philosophy: Currently changing to an end result specification based on asphalt cement content and the 1/2-in., No. 4, No. 8, and No. 100 sieves.

OREGON

It was reported that problems involving uniform bleeding have occurred, but have since been corrected. It was determined that the ultra-fine dust was extending the asphalt. The contractors were not exceeding the minus No. 200 content limit of 7 percent, but they were approaching this limit. Start-up problems resulting in dust slides in the first batch or two were also noted. To correct the problem, the State convinced the contractors to cut down the minus No. 200 content. Often this is accomplished by returning only a portion of the baghouse fines. Oregon allows the contractor to choose the baghouse fines handling method. Traprocks, mostly basalt, occur as a crushed stone or river gravel. Sandstone is used along the coast.

PENNSYLVANIA

A study of baghouse fines has been performed by the State and was discussed in Chapter Two. A conclusion of this study was that plants should return the baghouse material to the weigh box. The State is in the process of converting to an end result specification. For this reason, no specification will be enacted. The handling method is to be the contractor's option. A problem of poor compactibility was observed in the past. This problem was alleviated by reducing the amount of minus No. 200 material in the master job range.

Mix Design: Marshall

Plant Control Practices: Changing to contractor's option

Specification Philosophy: Converting to end result based on asphalt cement content, density, and the No. 200 sieve.

RHODE ISLAND

A serious tenderness and spotty bleeding problem was observed 2 years ago when baghouses first came into use. The cause of the problem was believed to be variability in the minus No. 200 content and variability in the grain-size distribution. Also, the problem was evident where the fines were returned to the hot elevator, but not where they were weighed into the weigh box. Two effective steps were taken to correct the problem. First, the plants' baghouse dust is used in the mix design. This resulted in a reduction of 0.5 percent in the asphalt content. Second, the plants are now required to weigh the baghouse fines into the weigh box. Traprocks are the predominant aggregate.

Mix Design: Marshall, utilizing the hot bin material and the baghouse dust

Plant Control Practices: Extractions; an ash correction factor is applied; Marshall stability and flow

Specification Philosophy: Process control with the possibility that end result specifications will be phased in.

SOUTH CAROLINA

Isolated tenderness and spotty bleeding are currently being reported in this State, where 40 to 60 percent of the plants have baghouses. These problems are associated with the variability in the quantity of dust being returned to the mix, often resulting in excessive minus No. 200 content. This is especially evident in batch plants that return the fines to the boot of the hot elevator. No conclusion has been reached with respect to drum mix plants. Granites and limestones are used. However, it is the crusher run material that is causing a problem when excessive fines are produced in the crushing operation. Because the present problems are isolated, no future specification changes are foreseen.

Mix Design: Marshall, utilizing the stockpile material, a dry sieve analysis, and the job asphalt

Plant Control Practices: Extractions; perform ash correction, Marshall stability

Specification Philosophy: End result based on asphalt cement content and the entire gradation

TENNESSEE

Tennessee reported a past problem that has been corrected. Irregularity in the minus No. 200 content was observed. This problem was evident in the middle and eastern parts of the State which use a limestone aggregate. The western part uses gravels and the problem was not evident there. An additional difficulty observed was that the baghouse would continue to operate while the dryer was shut down. This practice resulted in a buildup of fines in the No. 1 hot bin, and, consequently, the batches contained excessive quantities of fines. Corrective measures required the contractors to use a surge tank to collect the baghouse fines. From the surge tank, the contractors may volumetrically auger the fines into the hot elevator or hot bin, or they may use a separate system to weigh the fines into the weigh box. Many plants possess mineral filler systems and have tied their baghouse return through these systems. A washed analysis for mix design is also required.

Mix Design: Marshall, utilizing the stockpile material, job asphalt and a washed sieve analysis

Plant Control Practices: Extractions

Specification Philosophy: Process control. A phase-in of end result specifications is expected to begin in 1982, based on asphalt cement content, density, ride, and the 3/4-in., No. 4, No. 8, and No. 200 sieves.

TEXAS

Texas has experienced serious tenderness and stripping/moisture damage problems. No conclusion has been reached with respect to the role of baghouse fines in these problems. However, variability in the minus No. 200 content has been observed and linked to the return of the baghouse fines to the mix at the boot of the hot elevator. The State admits that baghouse fines need to be investigated further; however, more serious problems will take precedence.

VERMONT

During the past year spotty bleeding has occurred in this State, where most plants have baghouses. Hydrometer tests have shown little variability in the size distribution of baghouse fines within a plant; however, plant-to-plant variability does exist. The quantity of dust becoming airborne and returned to the mix at a given instant is an object of concern. Crushed limestone and a crushed quartz gravel are the predominant aggregates. The limestone aggregate has been associated with the bleeding problems. Future specification changes are foreseen with regard to either restricting use of the fines or applying handling controls.

Mix Design: Marshall, utilizing stockpile material and a dry sieve analysis

Plant Control Practices: Extractions, 1/500 tons; Marshall stability, flow, and density: 1/500 tons

Specification Philosophy: End result based on ride

VIRGINIA

No pavement-related failures associated with baghouse fines have been observed, although the State has studied the effect of baghouse fines on mix behavior, as discussed in Chapter Two. Less than 20 percent of the plants in the State are equipped with baghouses, and the method returning the dust return is left to the contractor.

Mix Design: Marshall, utilizing stockpile material and a washed sieve analysis

Plant Control Practices: Extractions; Marshall parameters are checked in the state laboratory.

Specification Philosophy: End result based on asphalt cement content, field density, and the 1/2-in., No. 4, No. 30, and No. 200 sieves

WASHINGTON

Occasional spotty bleeding and uniform bleeding problems are currently found. The problem is associated with variability in dust properties (grain size) and variability in the minus No. 200 content. Traprock (basalt) is the predominant aggregate. However, it is the gravels that are being linked to baghouse fines problems. It is noted that the drum mix plants use wet systems. The batch plants either auger the material as uniformly as possible into the hot elevator, or they use a separate bin to meter the fines into the weigh box. No specification changes are foreseen at this time.

Mix Design: Hveem, utilizing stockpile material and a washed sieve analysis

Special Tests: Modified Lottman

Plant Control Practices: Extractions

Specification Philosophy: Process control. An end result specification with respect to density is being phased in.

WEST VIRGINIA

This State has examined the question of baghouse fines. Currently, plants are using screw feeders to return the fines directly to the hot elevator. This practice is reported to cause variations in the quantity of fines being incorporated into the mix. However, no bleeding problems have been reported; poor compactibility of thin overlays is the chief concern.

A proposed specification for the use of collector fines is under review. The following are the key points. First, although the report notes that all collector dust must be weighed or metered into the mix, the proposed specification requires this procedure only for the baghouse fines. This is to be accomplished by use of a storage silo to meter or weigh the fines into the weigh box. Second, the baghouse fines will be classified according to three grades of fineness. In the case of the two finest grades, the minus No. 200 content will be reduced. This change is in response to the asphalt-extending potential of these fines. The State does not wish to lower the asphalt content because the filler-asphalt ratio would increase and might result in further compaction problems and brittleness through the increased stiffening of the mix.

Mix Design: Marshall

Plant Control Practices: Contractor's option

Specification Philosophy: End result

WISCONSIN

Almost all plants use baghouses, and no problems have been associated with baghouse fines. The predominant aggregate is a carbonate gravel. Until recently, the practice has been to return baghouse dust to the lot aggregate. The State does not employ a calibrated cold feed, thus making this practic possible. However, the specification that went into effect in the fall of 1981 requires the dust to be uniformly returned to the elevator by a method chosen by the contractor.

APPENDIX B

PLANT EQUIPMENT AND OPERATION

The 33 plants participating in the study represent a variety of plant types, collection systems, and aggregates. Each plant is described separately, giving details concerning dust-handling, equipment and procedures, and types and sizes of aggregate used.

Abbreviations

(C) =coarse
D =dolomite
G =granite
GR =gravel
L =limestone
NA =not applicable
NS =natural sand
NU =cold feed not used
S =screenings
SL =slate
SS =stone sand
T =traprock
(W) =washed

PLANT CODE 1

Type: 300 TPH Batch

Dryer: 78 in. x 38 ft Center outlet

Aggregate

Coarse: Dolomite

Fine: Washed natural sand
Dolomite screenings

Fuel: #4 oil

Exhaust Damper: Manual, set wide open

Fugitive Dust Return: After primary

Primary Collector: Knockout box

Baghouse Collector: Barber-Greene; replaced a wet system

Dust Handling System: Open

Primary Dust Handling

Dust exits from the knockout box through a rotary air lock into a screen conveyor for return to the hot elevator.

Baghouse Dust Handling

Only dust from the first third of the baghouse has the potential to be returned to the mix. Dust from the second two-thirds is wasted. This method responds to the excessive fine material encountered in the feed materials. Dust to be returned enters a screw conveyor and is transported to a small surge bin adjacent to the hot elevator. To ensure uniformity, material is drawn from this bin by a variable speed, rotary air lock, which may be disengaged during dryer shutdown. Dust overflow from this bin is wasted.

Additional Comments

This plant utilizes a cap in the hot bins to prevent the fine dust from accumulating along the incoming wall in the No. 1 hot bin, thus reducing the potential of a dust slide.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	D	D	D	NS	D				
			S	(W)	<1/4"				

PLANT CODE 2

Type: 180 TPH Batch

Dryer: 84 in. x 32 ft Counterflow

Aggregate:

Coarse: Dolomite

Fine: Dolomite stone sand
Washed natural sand
Washed dolomite screenings

Fuel: Reclaimed oil

Exhaust Damper: Manual

Fugitive Dust Return: After primary

Primary Collector: Single vertical cyclone

Baghouse Collector: McCarter; installed with plant

Dust Handling System: Open

Primary Dust Handling

Dust exits from the cyclone through a rotary air lock and enters a pair of pants. One leg returns dust to the hot elevator, while the second leg transports dust not required to the baghouse.

Baghouse Dust Handling

Dust exiting the baghouse enters a fluidizer which pneumatically transports the dust to a storage silo. From this silo, dust is added to the weigh hopper simultaneously with the addition of material from the No. 1 hot bin. The proper proportioning is determined by trial and error. This dust constitutes 1 to 2-1/2 percent of the total mix.

The plant originally attempted to return the baghouse dust as a separate component during batching, but the scales were not sufficiently sensitive to this relatively small quantity of material.

Additional Comments

This plant utilizes a cap in the hot bins to reduce the possibility of dust slides.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	D S (W)	D S (W)	NS (W)	D <1/4"	D <1/2"	D			

PLANT CODE 3

Type: 400 TPH Batch

Dryer: 112 in. x 40 ft Counterflow

Aggregate:

Coarse: Traprock

Fine: Washed natural sand
Traprock screenings

Fuel: Natural gas

Exhaust Damper: Manual

Fugitive Dust Return: Before primary

Primary Collector: Multicone

Baghouse Collector: Esstee; replaced wet system

Dust Handling System: Closed

Primary Dust Handling

Material exits through a flop gate and falls through a duct to the boot of the hot elevator. It was reported that the small-diameter cones are not being repaired as they wear out. The collector is effectively being reduced to a knockout box.

Baghouse Dust Handling

Dust exits from the baghouse and is returned to the hot elevator via a screw conveyor. No changes have occurred in this method since the equipment was installed in 1977. It was noted that care is given to stopping the baghouse return during dryer shutdown, to prevent a buildup of fine dust in the No. 1 hot bin.

Additional Comments

Dust slides in the baghouse hopper were reported in the production of cold mixes during early morning start-up. Consideration is being given to installation of vibrators on the baghouse hopper to prevent this dust buildup.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	50% NS (W) 50% T S	T <3/8"	T <1/2"	T <3/4"	T <1-1/4"				

PLANT CODE 4

Type: 180 TPH Batch

Dryer: 96 in. x 30 ft Counterflow

Aggregate:

Coarse: Traprock

Fine: Washed traprock stone sand

Fuel: Natural gas

Exhaust Damper: Automatic

Fugitive Dust Return: After primary

Primary Collector: Multicone

Baghouse Collector: Dustex; replaced wet system in 1975

Dust Handling System: Closed

Primary Dust Handling

Dust exits through a flow gate and flows through a duct to the hot elevator. Worn cones are not being repaired effectively, thus reducing the collector to a knockout box. The flop gate was redesigned to prevent it from sticking shut.

Baghouse Dust Handling

Dust exits from the baghouse and is returned to the hot elevator via a screw conveyor. The procedure to stop the screw conveyor during dryer shutdown was reported to be as follows. The baghouse cleaning mechanism is disengaged when the cold feed stops, and the screw conveyor is permitted to operate until the aggregate has flowed through the dryer.

Additional Comments

The major change in plant operation when the baghouse replaced the wet system was a reduction in the minus 200 content of the stockpile material. To account for a loss of material to the wet system, the percent passing the 200 mesh in the feed was fixed at 8-9 percent. After the baghouse installation, it was found that this figure had to be reduced to 5-6 percent. A baffle plate was installed on the No. 1 hot bin to prevent a buildup of dust along the incoming wall.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	T SS (W)	T <3/8"	T <1/2"	T <3/4"	T <1-1/4"				

PLANT CODE 5

Type: 300 TPH Batch

Dryer: 108 in. x 36 ft Counterflow

Aggregate:

Coarse: Traprock

Fine: Washed natural sand
Washed traprock screenings
Unwashed traprock screenings

Fuel: Natural gas

Exhaust Damper: Automatic

Fugitive Dust Return: Before primary

Primary Collector: Twin 100-in. vertical cyclones

Baghouse Collector: Stansteel; installed with plant

Dust Handling System: Closed

Primary Dust Handling

All material exits each cone through a flop gate and enters a screw conveyor for direct return to the hot elevator.

Baghouse Dust Handling

Currently, all baghouse dust exits from the collector through a rotary air lock, enters a screw conveyor, and is returned to the hot elevator. Originally, the plant returned the baghouse dust to the weigh box via a storage silo. This system was abandoned after the first year because a hot elevator return was considered more cost effective and practical. When the change occurred, the baghouse cleaning sequence had to be altered. The baghouse uses an individual pressure-pulse cleaning system that cleans two adjacent rows at a time. Formerly, the cleaning sequence began at the back of the baghouse and continued sequentially to the front. This procedure resulted in a slug of material being fed to the air lock at the completion of each cycle. To provide a better balance, the pulsing sequence is now staggered.

Control over the minus 200 content is accomplished by blending washed and unwashed screenings and a washed natural sand at the cold feed. Experience with the silo return reveals that approximately 1 percent of the aggregate is being processed through the baghouse.

Additional Comments

The major problem during the first two years was an occasional batch with an excessive percentage (>12) of material passing the minus 200 sieve. This was attributed to inexperience with the baghouse. In conjunction with the staggered baghouse cleaning arrangement, the importance of synchronizing the baghouse dust return with the cold feed and dryer operation was realized. If aggregate remains in the dryer during a short shutdown, then the baghouse dust return is stopped when the cold feed and the dryer stop. If the dryer is to be emptied out, then the baghouse dust return is stopped when the last of the aggregate exits from the dryer.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	T S	T <1/2"	T <3/8"	T <1-1/4"	T S (W)	NS (W)			

PLANT CODE 6

Type: 150 TPH Batch

Dryer: 84 in. x 20 ft Counterflow

Aggregate:

Coarse: Washed siliceous gravel

Fine: Washed natural sand
Unwashed natural sand

Fuel: #2 oil

Exhaust Damper: Manual

Fugitive Dust Return: Not applicable

Primary Collector: None

Baghouse Collector: Barber-Greene; replaced a wet wash system in 1978

Dust Handling System: Closed

Fuel: #2 oil

Primary Dust Handling

Not applicable.

Baghouse Dust Handling

Dust exits from the baghouse and enters a screw conveyor, passes through a rotary air lock, and falls into the hot elevator. Batches containing excessive dust occurred after the baghouse was installed. Corrective action included reducing the minus 200 content in the feed, adding vibrators to the No. 1 hot bin to prevent a dust buildup along the bin wall, and shutting down the screw conveyor when the aggregate dryer was shut down.

Additional Comments

An occasional batch still contains excessive dust. This occurs when the dust in the tower settles in a layer during a shutdown. During subsequent batching, the layer is funneled together. The interview with the operator revealed that the fugitive dust dampers are currently clogged and ineffective. A possible cause of the settling is that the fugitive system is not removing this dust.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	GR <1/2" (W)	GR <3/8" (W)	GR <1/4" (W)	NS	NS (W)				

PLANT CODE 7

Type: 200 TPH Batch

Dryer: 96 in. x 31 ft Counterflow

Aggregate:

Coarse: Traprock

Fine: Natural sand
Traprock screenings

Fuel: #2 oil

Exhaust Damper: Manual

Fugitive Dust Return: After primary

Primary Collector: Single vertical cyclone

Baghouse Collector: Western Precipitation; replaced a wet system

Dust Handling System: Closed

Primary Dust Handling

All dust passes through a flop gate and then through a duct into the hot elevator.

Baghouse Dust Handling

Dust exits from the baghouse and is returned to the hot elevator through a screw conveyor. The plant has a filler silo. Before the baghouse installation, mineral filler was used to compensate for the material lost to the wet system. A pneumatic blower is set up to transport the baghouse dust to the silo, but the silo has never been used to return the baghouse dust.

After the baghouse installation, batches containing excessive dust were observed to be associated with the plant's start-up and shutdown procedures. It was determined that the baghouse return system must lag the cold feed operation by approximately four minutes to account for the time it takes the aggregate to flow through the dryer. If these two operations are engaged at the same time, then, for approximately four minutes, only dust is entering the hot elevator. If the baghouse dust return is shut down when the cold feed is stopped, the final aggregate from the dryer is devoid of baghouse dust. However, if the baghouse dust return continues for longer than four minutes after cold feed shutdown, then the aggregate will have passed through the dryer and only baghouse dust will enter the hot elevator.

Additional Comments

This plant has installed high, normal, and low hot-bin indicators. It was reported that these indicators are always kept in good working order to prevent the No. 1 hot bin from being drawn low, which would result in a dust slide. The usual number of indicators is two (high and low).

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	T <1-1/4"	T <3/4"	NS	T S	T <1/4"	NU	NU	T <3/8"	

PLANT CODE 8

Type: 120 TPH Batch

Dryer: 84 in. x 20 ft Counterflow

Aggregate:

Coarse: Dolomite

Fine: Washed natural stone

Fuel: #2 oil

Exhaust Damper: Manual

Fugitive Dust Return: Not applicable

Primary Collector: None

Baghouse Collector: Barber-Green; installed with the plant

Dust Handling System: Closed system with a commercial mineral filler added

Primary Dust Handling

Not applicable.

Baghouse Dust Handling

Dust exits from the baghouse and enters a screw conveyor. Passing through a rotary air lock, the dust enters a second screw conveyor, which returns the dust to the hot elevator.

Additional Comments

The plant supplements the feed aggregate with a commercial mineral filler which is added at the weigh hopper. The minus 200 content for surface courses is 5 to 7 percent. The feed aggregate provides only about 2 percent of the minus 200 material.

Feed No.	1	2	3	4	5	6.	7	8	9
Comments	NS (W)	D <1/4"	D <1/2"	D <3/4"					

PLANT CODE 9

Type: 200 TPH Batch

Dryer: 96 in. x 34 ft Counterflow

Aggregate:

Coarse: Limestone

Fine: Washed natural sand
Limestone stone sand

Fuel: 260 diesel

Exhaust Damper: Manual

Fugitive Dust Return: Not applicable

Primary Collector: None

Baghouse Collector: Western precipitation; installed with the plant

Dust Handling System: Open

Primary Dust Handling

Not applicable.

Baghouse Dust Handling

Currently, 60 percent of the dust collected in the baghouse is returned to the hot elevator by a screw conveyor. This is accomplished by running the baghouse screw in reverse (away from the hot elevator). At a location approximately 60 percent of the baghouse length, a rotary air lock removes material, passing it to a screw conveyor which returns the dust to the hot elevator. The remaining dust exits from the baghouse into a storage pit, where water may be added to reduce nuisance dust.

This is the third baghouse dust-handling method utilized at the plant. The first method returned the baghouse dust directly from the baghouse screw to the hot elevator. Because of a change in the state specification which reduced the required minus 200 content, a variable speed screw was installed. This resulted in dust backing up in the baghouse, jamming and breaking the screw during start-up. Therefore, the present system was adopted. Its advantage is that the baghouse can be purged during a plant shutdown.

Additional Comments

This plant has a cap over the No. 1 hot bin to distribute the dust throughout the bin to prevent dust slides.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	NS (W)	L <3/16"	L <3/4"	L <1-1/2"					

PLANT CODE 10

Type: 180 TPH Batch

Dryer: 96 in. x 40 ft Center outlet

Aggregate:

Coarse: Limestone (base)
Washed gravel (surface)

Fine: Washed natural sand
Limestone stone sand

Fuel: #2 oil

Exhaust Damper: Manual

Fugitive Dust Return: Not applicable

Primary Collector: None

Baghouse Collector: McCarter; installed when plant was moved to present location

Dust Handling System: Closed

Primary Dust Handling

Not applicable.

Baghouse Dust Handling

Material exits from the baghouse and enters a screw conveyor for return to the hot elevator. A second screw conveyor is used to waste the dust and purge the baghouse during dryer shutdown. The plant personnel emphasized the importance of synchronizing the baghouse return with the aggregate flow through the dryer. Hand signals and the batchman and a worker listening for the aggregate at the hot elevator were found effective when initially setting up the synchronization.

Additional Comments

To assist in combating dust slides, this plant utilizes the three hot-bin indicator approach and a cap over the No. 1 hot bin to distribute the fine material. The plant also performs a sieve analysis of new shipments of aggregates to check uniformity.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	NS	GR	L <1"						

PLANT CODE 11

Type: 300 TPH Batch

Dryer: 108 in. x 30 ft Counterflow

Aggregate:

Coarse: Washed gravel

Fine: Washed natural sand

Other: Unwashed gravel for commercial work

Fuel: Natural gas

Exhaust Damper: Automatic

Fugitive Dust Return: Before primary: hot elevator and weigh box; after primary: hot screens

Primary Collector: Horizontal cyclone

Baghouse Collector: Standard Havens; replaced wet system in 1977

Dust Handling System: Closed

Primary Dust Handling

Dust exits from the collector by a screw conveyor. The material is then transported to a second main screw conveyor which returns the dust to the hot elevator.

Baghouse Dust Handling

Dust exits from the baghouse through a rotary air lock and enters a pair of pants. One leg enters a small storage bin; the other leg leads to a screw conveyor which is used to waste the dust and purge the baghouse during dryer shutdown. From the storage bin, the dust is drawn by a second rotary air lock and enters a screw conveyor which transports the material to the main screw conveyor at the point where the primary dust is returned. This system permits all or part of the baghouse dust to be returned by an adjustable damper located at the pair of pants. Control of the cold feed material, however, permits all the dust to be returned.

Additional Comments

This plant uses a three bin indicator approach to reduce the potential for dust slides. Also, the No. 1 hot bin has an offset to assist in distributing the fine dust throughout the bin.

A drum mix plant utilizing a wet system was installed at the location and received most of the production. The batch plant, therefore, did not have sufficient production to accomplish the sampling program.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	NS (W)	GR (W)	GR (W)	GR					

PLANT CODE 12

Type: 350 TPH Drum mix

Dryer: 96 in. x 32 ft Parallel flow

Aggregate:

Coarse: Limestone, gravel or slag, depending on mix requirements

Fine: Washed natural sand

Exhaust Damper: Automatic

Fugitive Dust Return: Not applicable

Primary Collector: Coating zone and knockout box

Baghouse Collector: Standard Havens; installed with the plant

Dust Handling System: Closed

Primary Dust Handling

The dust return of the coating zone and the knockout box is an integral part of the process.

Baghouse Dust Handling

The dust exits from the baghouse through a rotary air lock and is pneumatically blown back into the drum. It is introduced at the point of the asphalt cement injection. The start-up and the shutdown of this system are interlocked with the asphalt cement injection.

Additional Comments

It was noted that during a start-up with an empty drum, more dust is forwarded to the baghouse than is encountered during a continuous operation. This is due to the absence of the coating zone to scrub dust from the gas. The result is that the first material through the drum has less minus 200 material. To prevent this dust surge during a short shutdown, the drum is permitted to remain full.

Because of the small amount of production, this plant was unable to supply samples.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	NS	*	*	*					

*See additional comments.

PLANT CODE 13

Type: 300 TPH Batch

Dryer: 108 in. x 36 ft Counterflow

Aggregate:

Coarse: Crushed washed gravel

Fine: Washed natural sand

Fuel: Natural gas

Exhaust Damper: Automatic

Fugitive Dust Return: After primary

Primary Collector: Multicone

Baghouse Collector: McCarter; replaced wet system in 1971

Dust Handling System: Open

Primary Dust Handling

All dust exits through a rotary air lock and falls through a duct to the hot elevator.

Baghouse Dust Handling

The dust exits from the baghouse through a rotary air lock and enters a pair of pants. An adjustable damper splits the dust into two fractions. One enters a screw conveyor for return to the hot elevator; the second part is wasted to a settling pond. During dryer shutdown, the damper is shifted to waste all the baghouse dust, which occurs during the baghouse purge.

Additional Comments

This plant has three hot-bin indicator levels. A mineral filler system at the plant adds mineral filler only during the production of a curb mix. Plant 13 uses aggregate from the same source as Plant 14.

A contemplated change in the baghouse dust handling system is to tie it in with the existing mineral silo and return the baghouse dust to the weigh box. The advantages are seen to be control over the quantity of material returned and a cleaner batch tower. The contractor has not yet installed this system because the state specification requires that the dust must be returned to the hot elevator.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	NS (W)	NU	GR (C) (W) <1/2"	GR (C) (W) <1"					

PLANT CODE 14

Type: 400 TPH Batch

Dryer: 96 in. x 38 ft Parallel flow

Aggregate:

Coarse: Crushed washed gravel

Fine: Washed natural sand

Exhaust Damper: Manual

Fugitive Dust Return: Not applicable

Primary Collector: Coating zone and knockout box

Baghouse Collector: McCarter; installed with the plant

Dust Handling System: Open

Primary Dust Handling

The dust return of the coating zone and the knockout box is an integral part of the process.

Baghouse Dust Handling

Two rotary air locks are located adjacent to each other at the end of the baghouse screw. The inside air lock draws material which is pneumatically transferred to the drum and discharged where the asphalt cement is injected. The second air lock handles material not drawn by the first. This material is wasted in the settling pond. Approximately 75 percent of the dust collected in the baghouse is returned to the mix.

Additional Comments

This plant uses the same aggregate source as Plant 13. The asphalt cement introduction point is approximately halfway up the drum.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	NS (W)	NS (W)	GR (C) (W) <1/2"		GR (C) (W) <1/2"				

PLANT CODE 15

Type: 325 TPH Drum mix

Dryer: 96 in. x 45 ft Center outlet and parallel flow

Aggregate:

Coarse: Limestone

Fine: Washed natural sand
Limestone screenings

Exhaust Damper: Automatic

Fugitive Dust Return: Not applicable

Primary Collector: Coating zone, knockout box, single vertical cyclone

Baghouse Collector: Astec; installed with the plant

Dust Handling System: Open

Primary Dust Handling

The dust return for the coating zone and the knockout box is an integral part of the process. The dust collected in the cyclone exits through a rotary air lock and falls into a storage silo. From this silo, which also stores the baghouse dust, the dust is fed through a variable-speed, rotary air lock, pneumatically blown to the drum, and introduced at a point where the asphalt cement is introduced (see additional comments).

Baghouse Dust Handling

The material exits from the baghouse through a rotary air lock and is pneumatically transported to the storage silo, where it is returned to the mix with the cyclone dust (see additional comments).

Additional Comments

This plant employs a unique exhaust outlet just prior to the point where the asphalt cement is introduced into the drum. Because the limestone used is not wasted and contains excessive fine material, a conventional drum mix plant is impractical. The purpose of the special exhaust outlet is to remove as much dust as possible through entrainment in the system gas. In essence, the radiation zone of this drum mix is similar to a batch plant dryer. As a consequence of the higher level of particulate emissions, compared with conventional drum mix dryers, a single vertical cyclone is used as a primary collector.

For state surface mixes, no dust from the storage silo is returned to the drum. For commercial work, as much dust as possible is returned.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	NS (W)	L S	L <1/2"	L <1"					

PLANT CODE 16

Type: 195 TPH Drum

Dryer: 96 in. x 26 ft Parallel flow

Aggregate: See additional comments

Fuel: Butane

Exhaust Damper: Automatic

Fugitive Dust Return: Not applicable

Primary Collector: Coating zone and knockout box

Baghouse Collector: Astec; installed with the plant

Dust Handling System: See additional comments

Primary Dust Handling

The dust return for the coating zone and the knockout box is an integral part of the process.

Baghouse Dust Handling

The dust exits from the baghouse through a rotary air lock and is pneumatically returned to the drum. The dust is introduced at the point where the asphalt cement is added.

Additional Comments

This plant had recently been purchased used and was experiencing operational problems because of unfamiliarity with the plant. First, the rotary air lock did not have sufficient capacity to adequately handle all the dust being collected. The result was that the dust backed up into the baghouse, requiring a cleanout at the end of the day. Second, the pressure drop through the baghouse was abnormally high, causing incomplete combustion of the fuel. Dust that had been wasted the previous day showed fuel contamination.

At the time of the site visit the plant was using a sand and a gravel. The plant was shortly moved thereafter to a site where a limestone would be used. The plant never attained sufficient production to supply baghouse samples.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	*	*	*	*					

*See additional comments.

PLANT CODE 17

Type: 100 TPH Batch

Dryer: Counterflow

Aggregate:

Coarse: Washed limestone (base and wearing)
Washed granite (wearing)

Fine: Washed limestone screenings
Washed granite river sand

Fuel: #4 oil

Exhaust Damper: Automatic

Fugitive Dust Return: Not applicable

Primary Collector: None

Baghouse Collector: Esstee; added to the plant in 1976-77

Dust Handling System: Closed

Primary Dust Handling

Not applicable.

Baghouse Dust Handling

Dust exits from the baghouse through a flop gate and enters a screw conveyor which returns the dust to the hot elevator. At the time of the site visit, the plant was attempting to use washed screenings instead of a natural sand. The high haulage costs associated with natural sand provided the stimulus for this change. The plant set up its own washing system for the screenings, which reduced the minus 200 content from 12-14 percent to 6-7 percent. However, excessive fine material accumulated in the baghouse. To remove this material, the plant must occasionally shut down, draw the hot bins, and purge the baghouse. Consideration is being given to installing a second screw conveyor, which will be used to waste part of the dust during production and to waste material during the baghouse purge during shutdown.

Additional Comments

This plant uses a granite for the state wearing mixes. During sampling, granite occurred in sample 17-4. All the other samples were collected during production of mixes using limestone aggregates.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	L S (W) *		L <1/2" (W) *	L <3/4" (W)					

*See additional comments.

PLANT CODE 18

Type: 300 TPH Batch

Dryer: 108 in. x 36 ft Counterflow

Aggregate:

Coarse: Washed granite

Fine: Granite screenings
Natural sand

Fuel: #4 oil

Exhaust Damper: Automatic

Fugitive Dust Return: Not applicable

Primary Collector: None

Baghouse Collector: McCarter; replaced a dual cyclone and wet system in 1977

Dust Handling System: Closed

Primary Dust Handling

Not applicable.

Baghouse Dust Handling

The dust exits from the baghouse and enters a pair of pants, but the waste leg is not used. The duct is transferred to the hot elevator by a screw conveyor.

Additional Comments

The plant personnel noted no changes in the mix performance after the baghouse. The baghouse has provided an economic advantage to the plant. With the wet system a higher percentage of screenings had to be fed to the dryer to compensate for the material lost to the settling pond. With the baghouse a closed system for material use was developed, balancing the cold feed with the production requirements.

The hot bins have a cap to assist in distributing the fine material throughout the No. 1 hot bin. The plant also has high and low hot-bin indicators. The plant is interlocked, with the low indicator preventing batching when the bins are low.

An operation reported to affect the dust was a change to a different fuel type. The plant had been using #2 oil and then switched to #4 oil. After the change, incomplete combustion occurred, resulting in contamination of the dust. The plant installed a preheater for the #4 oil, which alleviated the problem.

This plant did not achieve sufficient production to provide the baghouse samples.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	NS	G S	G <1/2" (W)	G <3/4" (W)	G <1-1/2" (W)				

PLANT CODE 19

Type: Batch

Dryer: 120 in. x 34 ft Counterflow

Aggregate:

Coarse: Washed granite
Washed slate

Fine: Granite screenings
Natural sand

Exhaust Damper: Automatic

Fugitive Dust Return: After primary

Primary Collector: Horizontal cyclone

Baghouse Collector: Astec; replaced a wet system in 1977

Dust Handling System: Closed

Primary Dust Handling

Dust is removed from the horizontal cyclone by a screw conveyor and is deposited into a duct which returns it to the hot elevator. A flop gate is used within the duct to prevent any false air from entering the collector.

Baghouse Dust Handling

Dust exits from the baghouse through a rotary air lock and enters a screw conveyor for return to the hot elevator.

Additional Comments

At one time two other company plants returned baghouse dust pneumatically to the No. 1 hot bin. This method was abandoned in favor of the hot elevator return because it was believed that the blowers wore out prematurely.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	SL <3/4" (W)	G (W)	G <1/2" (W)	G (W)	G S	SL <3/4" (W)	G S	NS	NS

PLANT CODE 20

Type: 250 TPH Batch

Dryer: 100 in. x 36 ft Counterflow

Aggregate:

Coarse: Washed granite

Fine: Granite screenings
Natural sand

Fuel: Natural gas

Exhaust Damper: Manual

Fugitive Dust Return: After primary

Primary Collector: Single vertical cyclone

Baghouse Collector: Astec; replaced another baghouse in 1975-76 that was too small to handle the grain-loading

Dust Handling System: Closed

Primary Dust Handling

The dust exits from the cyclone through a flop gate and flows through a duct to the hot elevator.

Baghouse Dust Handling

All dust exits from the baghouse through a flop gate, flows through a short duct, and enters the hot elevator.

Additional Comments

It was reported that the flight design was altered to raise the dryer exhaust temperature so that condensation would not occur in the baghouse.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	G (W)	G <3/4" (W)	G <1/2" (W)	NS	NS	NS	G S	G S	

PLANT CODE 21

Type: 150 TPH Batch

Dryer: 100 in. x 28 ft Counterflow

Aggregate:

Coarse: Washed limestone

Fine: Washed limestone screenings

Fuel: #6 oil

Exhaust Damper: Automatic

Fugitive Dust Return: After primary

Primary Collector: Single vertical cyclone

Baghouse Collector: Flex-Clean; added to plant in 1972

Dust Handling System: Closed

Primary Dust Handling

Dust exits from the cyclone and falls through a duct to the hot elevator.

Baghouse Dust Handling

The dust exists from the twin-hopper arrangement into a common screw conveyor. This conveyor leads to a second screw conveyor which returns the dust to the hot elevator. Originally a rotary air lock separated these two screw conveyors, but its capacity was insufficient to adequately move the material. As a result, material backed up into the baghouse.

Additional Comments

This plant is also equipped with a mineral filler silo. Occasionally, for state work, a mineral filler is needed to supplement the natural aggregate.

During the plant visit, holes in the ductwork and the cyclone were observed. The effect was to reduce the volume of air flowing through the dryer. The plant was taken out of service for repairs and never sustained sufficient production to supply samples of baghouse dust.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	L S (W)	L S (W)	L <1/2" (W)	L <3/4" (W)					

PLANT CODE 22

Type: 210 TPH Batch

Dryer: 88 in. x 28 ft Counterflow

Aggregate:

Coarse: Granite

Fine: Granite screenings
Washed natural sand

Fuel: Natural gas

Exhaust Damper: Manual

Fugitive Dust Return: Not applicable

Primary Collector: None

Baghouse Collector: Aero Pulse; replaced wet system in 1974

Dust Handling System: Closed

Primary Dust Handling

Not applicable.

Baghouse Dust Handling

Dust exits from the baghouse screw through a flop gate and enters a duct which returns the dust to the hot elevator.

Additional Comments

The significant plant practice that was affected by the change to a baghouse

was reported to be the adjustment of the cold feed. With the wet system, the sand and screening feeds had to be adjusted to compensate for the material lost to the ponds. The baghouse installation eliminated the need for this adjustment.

Dust slides were not reported to be a problem. The small storage capacity of these bins may account for this fact.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	G	NS (W)	G S	G	G				

PLANT CODE 23

Type: 550 TPH Batch

Dryer: 120 in. Counterflow

Aggregate:

Coarse: Granite

Fine: Granite screenings
Natural sand

Exhaust Damper: Automatic

Fugitive Dust Return: Unknown

Primary Collector: Multicone

Baghouse Collector: Micro-Pul; installed with the plant

Dust Handling System: Closed

Primary Dust Handling

The dust exits the multicone through a flop gate and enters a screw conveyor for return to the hot elevator. It was reported to be important to shut down the screw conveyor at the same time as the cold feed to prevent a buildup of dust in the No. 1 hot bin.

Baghouse Dust Handling

All dust exits from the baghouse screw conveyor into a second screw. This screw transports the material to a fluidizer which pneumatically transfers it to a storage silo. From the silo the necessary material is weighed on a separate scale and then added to the weigh box.

Additional Comments

It was reported that the baghouse dust constituted approximately 2 percent of the mix and that this percentage would increase as the multicone system wears. Hydrometer analysis of the baghouse dust is irregularly performed as a measure of wear of the multicone collector. A second method is for the plant personnel to observe the level in the storage silo as recorded by bin indicators. If the dust level rises, then either the cold feed has excessive minus 200 content or the multicone has decreased in efficiency and the percentge of baghouse dust added to the mix must be increased.

This plant uses three hot-bin indicators, and the aggregate level of the No. 1 hot bin is not permitted to fall below the low indicator to prevent a dust slide.

A spitter conveyor is used to quickly transport the feed material away from the exhaust breeching, and a means of reducing the entrainment of dust in the system gas. An expansion section is used in the exhaust breeching ductwork to keep the exhaust gas velocity to a minimum.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	G S	NS	G <3/8"	G <3/8"	G <1/2"	G <1/2"			

PLANT CODE 24

Type: 200 TPH Batch

Dryer: Counterflow

Aggregate:

Coarse: Granite

Fine: Granite screenings
Natural sand

Exhaust Damper: Automatic

Fugitive Dust Return: Before primary

Primary Collector: 12-ft-diameter single vertical cyclone

Baghouse Collector: Micro-Pul; replaced a wet system

Dust Handling System: Closed

Primary Dust Handling

The dust exits from the cyclone through a flop gate and enters a screw feeder which returns the material to the hot elevator. It was reported that the screw must be shut down with the cold feed to prevent a buildup of dust in the No. 1 hot bin.

Baghouse Dust Handling

The dust exits from the baghouse and enters a screw conveyor which transfers the dust to a pneumatic blower. This blower transports the dust to a storage silo. The dust is added to the weigh box as a separate component during batching.

Additional Comments

Approximately 1 to 1-1/2 percent of the mix is composed of baghouse dust.

analysis of the baghouse dust to monitor the efficiency of the primary collector.

It was reported that after replacement of the wet system, the addition of baghouse dust resulted in a very slight increase in the optimum asphalt content.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	G <1/2"	G S	NS	G <3/8"					

PLANT CODE 25

Type: 240 TPH Batch

Dryer: 96 in. x 30 ft Counterflow

Aggregate:

Coarse: Granite
Gravel

Fine: Granite screenings
Washed natural sand

Fuel: #2 oil

Exhaust Damper: Manual

Fugitive Dust Return: After primary

Primary Collector: 12-ft-diameter, single vertical cyclone

Baghouse Collector: Rees; installed with the plant

Dust Handling System: Open

Primary Dust Handling

The dust exits from the collector through a flop gate and falls through a duct to the hot elevator.

Baghouse Dust Handling

This plant wastes all its baghouse dust to a settling pond (see additional comments).

Additional Comments

This plant was originally constructed to return all the baghouse dust to the hot elevator. However, it was soon discovered that the cleaning arrangement resulted in dust surges being fed to the elevator. Though the plant has a mineral filler silo system, it elected to waste the dust instead of tying into this system.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	GR <3/8"	G <1"	G <3/8"	G <1/2"	G <3/4"	G S	NS (W)	NS (W)	

PLANT CODE 26

Type: 400 TPH Batch

Dryer: 108 in. x 36 ft Counterflow

Aggregate:

Coarse: Washed granite

Fine: Washed natural sand
Unwashed natural sand

Fuel: Natural gas

Exhaust Damper: Automatic

Fugitive Dust Return: After primary

Primary Collector: Twin 100-in. vertical cyclones

Baghouse Collector: Astec; replaced original baghouse

Dust Handling System: Closed

Primary Dust Handling

The dust exits from the cyclones through flop gates and enters a screw conveyor for return to the hot elevator. These cyclones are double-lined and are relined every year to maintain high efficiency.

Baghouse Dust Handling

The dust exits from the baghouse and enters a screw conveyor. From there the dust may be diverted to the hot elevator, or it may enter a fluidizer where it is transferred to a storage silo. From the silo, the dust is weighed into the weigh box as a separate component of the batch. The baghouse dust constitutes approximately 1 percent of the mix. The plant returns the baghouse dust through the silo system, keeping the hot elevator return as a backup should a mechanical breakdown occur in the silo return. To reduce the likelihood of dust slides, high and low hot-bin indicators are used. Also, the plant installed a baffle arrangement along the incoming wall of the No. 1 hot bin.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	NS	NS (W)	NS (W)	G <3/8" (W)	G <1/2" (W)	G <3/4" (W)			

PLANT CODE 28

Type: 200 TPH Batch

Dryer: 84 in. x 24 ft Counterflow

Aggregate:

Coarse: Granite

Fine: Natural sand
Granite screenings

Fuel: Natural gas

Exhaust Damper: Manual

Fugitive Dust Return: After primary

Primary Collector: 10-ft-diameter, single vertical cyclone

Baghouse Collector: Western Precipitation; replaced a wet system

Dust Handling System: Closed

Primary Dust Handling

The dust exits from the cyclone through a flop gate, falls through a duct, and is returned to the hot aggregate just prior to entering the hot elevator.

Baghouse Dust Handling

The dust exits from the baghouse through a rotary air lock and is transferred to a storage silo by a continuous blower. From the silo, the dust is moved by a screw conveyor to a filler elevator which transports it to a small surge bin in the batch tower. The baghouse dust is then weighed into the batch as a separate component, constituting approximately 0.75 percent of the mix.

Additional Comments

This filler silo was part of the plant prior to the baghouse installation. The plant operator elected to tie the baghouse into this weigh-box return method instead of to the hot elevator return. It was reported that no changes in mix performance were observed after the installation of the baghouse.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	G <3/4"	G <1/2"	G <3/8"	G S	NS				

PLANT CODE 29

Type: 250 TPH Batch

Dryer: 96 in. x 30 ft Counterflow

Aggregate:

Coarse: Granite

Fine: Granite screenings

Exhaust Damper: Manual

Fugitive Dust Return: After primary

Primary Collector: 12-ft-diameter, single vertical cyclone

Baghouse Collector: Western Precipitation; replaced a wet system

Dust Handling System: Closed

Primary Dust Handling

The dust exits from the cyclone through a flop gate, and falls through a duct which returns it to the hot elevator.

Baghouse Dust Handling

The dust exits from the baghouse through a rotary air lock and is transferred to a storage silo by a continuous blower. From the silo, the dust is moved by a screw conveyor to a filler elevator which transports it to a small surge bin in the batch tower. The baghouse dust is then weighed into the batch as a separate component, constituting approximately 0.75 percent of the mix.

Additional Comments

This filler silo was part of the plant prior to the baghouse installation. The plant operator elected to tie the baghouse into this weigh-box return method instead of to the hot elevator return. It was reported that no changes in mix performance were observed after the installation of the baghouse.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	G S	G	G						

PLANT CODE 30

Type: 600 TPH Batch

Dryer: 126 in. x 30 ft Counterflow

Aggregate:

Coarse: Washed traprock

Fine: Washed traprock stone sand

Exhaust Damper: Manual

Fugitive Dust Return: After primary

Primary Collector: 14-ft-diameter, single vertical cyclone

Baghouse Collector: W.A.G., Inc.; replaced a multicone and wet system

Dust Handling System: Closed

Primary Dust Handling

The dust exits from the cyclone through double tipping valves and enters a screw conveyor for return to the hot elevator.

Baghouse Dust Handling

The dust exits from the baghouse and enters a screw conveyor for return to the hot elevator. The dust passes through a flop gate just prior to entering the elevator.

Additional Comments

There is a storage silo which could be used to return the baghouse dust to the weigh box; however, it is not utilized.

It was observed that when the baghouse/cyclone system replaced the wet/multicone system, the minus 200 content increased by approximately 1 percent point.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	T	T	T						
	SS	<1/2"-1/4"	<3/4"-1/2"						

PLANT CODE 31

Type: Drum Mix

Dryer: Parallel flow

Aggregate:

Coarse: Traprock

Fine:

Exhaust Damper: Unknown

Fugitive Dust Return: Not applicable

Primary Collector: Coating zone and knockout box

Baghouse Collector: Aero Pulse; installed with the plant

Dust Handling System: Closed

Primary Dust Handling

The dust return of the coating zone and knockout box is an integral part of the process.

Baghouse Dust Handling

The dust exits from the baghouse through a rotary air lock, where a continuous blower returns it to a point in the drum adjacent to the asphalt cement introduction.

Additional Comments

Though originally scheduled to be visited, the plant had been moved to another site for a job and had not been returned as expected. Thus, the plant details were obtained, and the sampling schedule arranged, by telephone. After the plant's return to its home base, a combination of low production and poor weather enabled the plant to obtain only three samples.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	T	T	T	T					
	<3/4"-3/8	<3/8"-#4	<#4-0	<#4-0					

PLANT CODE 32

Type: Drum mix

Dryer: Parallel flow

Aggregate:

Coarse: Crushed siliceous gravel

Fine: Screenings
Natural sand

Exhaust Damper: Unknown

Fugitive Dust Return: Not applicable

Primary Collector: Coating zone and knockout box

Baghouse Collector: Installed with the plant

Dust Handling System: Closed

Primary Dust Handling

The dust return of the coating zone and knockout box is an integral part of the process.

Baghouse Dust Handling

The dust exits from the baghouse through a rotary air lock, where a continuous blower returns it to a point in the drum adjacent to the asphalt cement introduction.

Additional Comments

This plant was not visited. The plant details were obtained, and the sampling program arranged, by telephone. The plant never obtained sufficient production to collect the baghouse dust samples.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	*	*	*	*					

*See additional comments.

PLANT CODE 33

Type: Drum mix

Dryer: Parallel flow

Aggregate:

Coarse: Crushed siliceous gravel

Fine: Screenings
Natural sand

Exhaust Damper: Unknown

Fugitive Dust Return: Not applicable

Primary Collector: Coating zone and knockout box

Baghouse Collector: Barber-Greene; installed with the plant

Dust Handling System: Closed

Primary Dust Handling

The dust return of the coating zone and knockout box is an integral part of the process.

Baghouse Dust Handling

The dust exits from the baghouse through a rotary air lock, where a continuous blower returns it to a point in the drum adjacent to the asphalt cement introduction.

Additional Comments

This plant was not visited. The plant details were obtained, and the sampling program arranged, by telephone.

Cold Feed

Feed No.	1	2	3	4	5	6	7	8	9
Comments	GR <3/4"	GR <1/2"	GR <3/8"	NS	GR S				

APPENDIX C

DOCUMENTATION OF PLANT OPERATING CONDITIONS DURING SAMPLING

This appendix presents a concise summary of the plant operations as they existed during the collection of the baghouse samples. The data for each plant include: aggregate and gas temperatures, burner and dryer operation, production rate, damper information, baghouse pressure drop, and mix type being produced. The air flow through the dryer was not documented because this information was not recorded in the plant.

Some problems were encountered in the sampling program because of a drastically reduced work load in the plants in 1981 as compared with the 1980 paving season. Plant estimates of the extent of the reductions ranged between 30 and 60 percent. Although 33 plants had agreed to participate in the study, only 27 were able to supply samples, and only 23 of these completed the sampling procedure.

A second problem resulting from the reduced work load was the difficulty in obtaining five consecutive production days to perform the sampling. The nature of the paving industry often allows a plant to schedule production only one week in advance. Often the plant operator elected to delay sampling until production increased. A more continuous operation was required also if the sampling time was to be randomly selected. The net effect was a longer lag than expected between the plant visit and the receipt of the baghouse dusts. This, in turn, affected the testing schedule. Most plants were generally able to adhere to the random sampling schedule discussed during the plant visit. Alterations included switching days to better fit in with the plant's production operations.

For the most part, documentation of plant operations was completed as discussed during the plant visit. Plants 23, 24, and 29 did not provide precise cold feed information. Plants 2, 7, and 15 provided no documentation because the booklet was misplaced during the sampling process. Despite these problems, sampling and documentation procedures produced adequate and useful data.

Sample No.	Agg. Temp. Set.	Agg. Temp. From Dryer	Burner Output	Dryer Exhaust Temp.	Stack Exhaust Temp.	Prod. Rate	Dryer Oper.	Damper Setting (%)	Press. Drop Bag-House	Mix Type	Feed No. % of Total Feed 1	2	3	4	5	6	7	8
Plant 1																		
1-1-A	310	310	40/70	290	-	200	Start-up	100	-	Sand 1			80	20				
1-1-B	310	290	18/70	310	-	200	Continuous	100	-	Sand 1			80	20				
1-1-C	310	310	90/70	290	-	200	Continuous	100	-	Bind 1	60	5	25	10				
1-1-D	310	310	22/70	260	-	200	Continuous	100	-	Sand 1			80	20				
1-1-E	310	310	25/70	280	-	200	Continuous	100	-	Sand 1			80	20				
1-S	310	310	60/70	280	-	150	Start-up	100	-	Sand 1			80	20				
1-2	310	290	45/70	290	-	150	Continuous	100	-	Sand 1			80	20				
1-3	310	310	10/50	280	-	150	Start/Stop	100	-	Base 1	50		35	15				
1-4	310	300	90/75	280	-	150	Start/Stop	100	-	Wear 1		50	35	15				
1-5	310	295	95/75	280	-	150	Start/Stop	100	-	Wear 1		50	35	15				
Plant 2 No documentation forwarded																		
Plant 3																		
3-1	325	325	100	250	-	450	Continuous	100	-	Bind 1	54		46					
3-S	325	300	100	285	-	450	Start-up	100	-	Bind 1	54		46					
3-2	325	300	100	285	-	450	Continuous	100	-	Bind 1	54		46					
3-3	325	300	100	250	-	450	Continuous	100	-	Bind 1	54		46					
3-4-A	325	325	80	290	-	300	Start-up	100	-	Sand 1	100							
3-4-B	325	325	70	300	-	300	Continuous	100	-	Sand 1	100							
3-4-C	325	300	100	260	-	450	Continuous	100	-	Bind 1	54		46					
Plant 3 (continued)																		
3-4-D	325	310	100	260	-	450	Continuous	100	-	Bind 1	54		46					
3-4-E	325	320	100	265	-	450	Continuous	100	-	Bind 1	54		46					
3-5	325	310	100	265	-	450	Continuous	100	-	Bind 1	54		46					
Plant 4																		
4-1	315	310	65	425	-	150	Continuous	-	-	Wear 1	65	35						
4-2-A	320	310	75	415	235	250	Start-up	-	-	W/Bn 1	40	30	30					
4-2-B	315	310	70	400	225	175	Continuous	-	-	W/Cm 1	40	35	25					
4-2-C	315	310	75	415	225	200	Continuous	-	-	W/Bn 1	40	30	30					
4-2-D	325	315	90	425	225	220	Continuous	-	-	W/Cm 2	60	10	30					
4-2-E	325	315	85	415	250	175	Continuous	-	-	W/Cm 2	60	10	30					
4-3	325	310	90	425	225	200	Continuous	-	-	W/Bn 1	40	30	30					
4-S	325	315	85	415	225	225	Start-up	-	-	W/Cm 1	40	35	25					
4-4	325	315	90	425	225	200	Continuous	-	-	W/Bn 1	40	30	30					
4-5	325	310	85	415	225	175	Continuous	-	-	W/Cm -	-	-	-					
Plant 5																		
5-S	335	335	70	250	-	200	Start-up	25	-	Com 1	5*	20	60		20	35		
5-1	335	350	80	275	-	225	Continuous	50	-	Com 1	5	20	60		20	35		
5-2	330	330	60	250	-	200	Continuous	40	-	Com 1	5	20	60		20	35		
5-3	325	325	50	200	-	250	Continuous	40	-	Com 2	5	25	50		20	40		
5-4	325	337	55	225	-	175	Continuous	38	-	Com 3	25	28	40		20	55		
5-5-A	325	337	75	250	-	200	Start-up	40	-	Com 4	10	65	35		25	75		

*Numbers for this plant represent dial settings and not percentage of total feed.

Sample No.	Agg. Temp. Set.	Agg. Temp. From Dryer	Burner Output	Dryer Exhaust Temp.	Stack Exhaust Temp.	Prod. Rate	Dryer Oper.	Damper Setting (%)	Press. Drop Bag-House	Mix Type	Feed No. % of Total Feed 1	2	3	4	5	6	7	8
Plant 5 (continued)																		
5-5-B	325	350	70	250	-	200	Continuous	45	-	Com 5	15*	60	35		30	70		
5-5-C	325	332	70	275	-	225	Continuous	45	-	Com 6	10	70	70		35	50		
5-5-D	325	335	70	260	-	200	Continuous	45	-	Com 7	10	70	72		35	50		
5-5-E	325	330	60	225	-	200	Continuous	40	-	Com 8	10	25	40		20	50		
Plant 6																		
6-1	370	350	15	230	235	125	Start/Stop	100	-	Wear 1		50		50				
6-2	370	365	15	225	230	125	Start/Stop	100	-	Wear 2			20		80			
6-3	370	365	15	235	235	125	Start/Stop	100	-	Wear 1		50		50				
6-4	370	365	15	230	230	125	Start/Stop	100	-	Wear 1		50		50				
6-5	370	360	15	225	235	125	Start/Stop	100	-	Wear 2			20		80			
6-A	370	380	20	270	250	125	Start-up	100	-	Wear 3		45	10	10	35			
6-B	400	360	20	275	240	125	Continuous	100	-	Wear 3		45	10	10	35			
6-C	390	390	30	275	260	125	Continuous	100	-	Wear 4		50	10	10	30			
6-D	375	355	18	285	265	125	Continuous	100	-	Wear 5		60		10	30			
6-E	360	350	18	255	225	125	Continuous	100	-	Wear 5		60		10	30			
Plant 7 No documentation forwarded																		

*Numbers for this plant represent dial settings and not percentage of total feed.

Sample No.	Agg. Temp. Set.	Agg. Temp. From Dryer	Burner Output	Dryer Exhaust Temp.	Stack Exhaust Temp.	Prod. Rate	Dryer Oper.	Damper Setting (%)	Press. Drop Bag-House	Mix Type	Feed No. % of Total Feed 1	2	3	4	5	6	7	8
Plant 8																		
8-1	320	320	2.5	390	-	100	Continuous	100	-	Wear 1	60*		50					
8-2	320	320	2.5	390	-	80	Start/Stop	100	-	Wear 1	60		50					
8-3	315	315	2.2	380	-	60	Start/Stop	100	-	Wear 1	60		50					
8-4	320	320	2.5	390	-	60	Start/Stop	100	-	Wear 1	60		50					
8-S	320	320	2.5	300	300	60	Start-up	100	-	Wear 1	60		50					
8-5-A	320	320	2.5	390	-	70	Start/Stop	100	-	Wear 1	60		50					
8-5-B	320	320	2.5	390	-	60	Start/Stop	100	-	Wear 1	60		50					
8-5-C	320	320	2.5	390	-	80	Start/Stop	100	-	Wear 1	60		50					
8-5-D	320	320	2.5	390	-	70	Start/Stop	100	-	Wear 1	60		50					
8-5-E	320	320	2.5	390	-	70	Start/Stop	100	-	Wear 1	60		50					
Plant 9																		
9-1-A	350	340	65	185	-	190	Start-up	NC**	4.0	Base 1		50		50				
9-1-B	350	340	65	210	-	190	Continuous	NC	4.0	Base 1		50		50				
9-1-C	350	335	80	180	-	190	Start/Stop	NC	3.5	Wear 1	16	45	39					
9-1-D	350	340	70	200	-	190	Start/Stop	NC	3.5	Wear 1	16	45	39					
9-1-E	350	335	70	210	-	190	Start/Stop	NC	3.5	Wear 1	16	45	39					
9-2	350	340	75	220	-	190	-	NC	3.5	Wear 1	16	45	39					
9-S	350	340	65	200	-	190	Start-up	NC	4.0	Base 1		50		50				
9-3	350	340	65	210	-	190	Continuous	NC	4.0	Base 1		50		50				
9-4	350	340	60	200	-	-	Continuous	NC	3.5	Wear 1	16	45	39					
9-5	350	335	-	-	-	190	Start/Stop	NC	3.5	Wear 1	16	45	39					

*Numbers for this plant represent dial settings and not percentage of total feed.
**NC = not changed

Sample No.	Agg. Temp. Set.	Agg. Temp. From Dryer	Burner Output	Dryer Exhaust Temp.	Stack Exhaust Temp.	Prod. Rate	Dryer Oper.	Damper Setting (%)	Press. Drop Bag-House	Mix Type	Feed No. % of Total Feed 1	2	3	4	5	6	7	8
Plant 10																		
10-1-A	340	320	3/1	280	-	160	Start-up	NC*	-	Base 1	32		68					
10-1-B	340	320	3/1	280	-	160	Start/Stop	NC	-	Base 1	32		68					
10-1-C	340	320	3/1	280	-	160	Start/Stop	NC	-	Base 1	32		68					
10-1-D	340	320	3/1	280	-	160	Start/Stop	NC	-	Base 1	32		68					
10-1-E	335	320	3/1	280	-	160	Start/Stop	NC	-	Base 1	32		68					
10-2	330	310	3/1	280	-	160	Start/Stop	NC	-	Base 1	32		68					
10-3	330	310	3/1	280	-	160	Start/Stop	NC	-	Base 1	32		68					
10-S	340	320	3/1	280	-	160	Start-up	NC	-	Base 1	32		68					
10-4	320	300	2.5/1	280	-	160	Start/Stop	NC	-	Base 1	32		68					
10-5	340	320	3/1	280	-	160	Start/Stop	NC	-	Base 1	32		68					
Plant 11 No samples forwarded																		
Plant 12 No samples forwarded																		
Plant 13																		
13-1	350	350	90	300-325	275-300	275	Continuous	50	2	Bind 1	40		20	40				
13-S	350	350	90	300-325	275-300	275	Start-up	50	2	Bind 1	40		20	40				
13-2	350	350	90	300-325	275-300	275	Continuous	50	2	Bind 1	40		20	40				

*NC = not changed

Sample No.	Agg. Temp. Set.	Agg. Temp. From Dryer	Burner Output	Dryer Exhaust Temp.	Stack Exhaust Temp.	Prod. Rate	Dryer Oper.	Damper Setting (%)	Press. Drop Bag-House	Mix Type	Feed No. % of Total Feed 1	2	3	4	5	6	7	8
Plant 13 (continued)																		
13-3-A	350	350	90	300-325	275-300	275	Start-up	50	2	Bind 1	40		20	40				
13-3-B	350	350	90	300-325	275-300	275	Continuous	50	2	Bind 1	40		20	40				
13-3-C	350	350	90	300-325	275-300	275	Continuous	50	2	Bind 1	40		20	40				
13-3-D	350	350	90	300-325	275-300	275	Continuous	50	2	Bind 1	40		20	40				
13-3-E	350	350	90	300-325	275-300	275	Continuous	50	2	Bind 1	40		20	40				
13-4	350	350	90	300-325	275-300	275	Continuous	50	2	Wear 1	50		50					
13-5	350	350	90	300-325	275-300	275	Continuous	50	2	Wear 1	50		50					
Plant 14																		
14-1	300	300	70	300	275	275	Continuous	75	3	Wear 1	25	25	25		25			
14-2	300	300	70	300	275	275	Continuous	75	3	Wear 1	25	25	25		25			
14-3-A	300	300	70	300	275	275	Start-up	75	3	Wear 1	25	25	25		25			
14-3-B	300	300	70	300	275	275	Continuous	75	3	Wear 1	25	25	25		25			
14-3-C	300	300	70	300	275	275	Continuous	75	3	Wear 1	25	25	25		25			
14-3-D	300	300	70	300	275	275	Continuous	75	3	Wear 1	25	25	25		25			
14-3-E	300	300	70	300	275	275	Continuous	75	3	Wear 1	25	25	25		25			
14-S	300	300	70	300	275	275	Start-up	75	3	Wear 1	25	25	25		25			
14-4	300	300	70	300	275	275	Continuous	75	3	Wear 1	25	25	25		25			
14-5	300	300	70	300	275	275	Continuous	75	3	Wear 1	25	25	25		25			
Plant 15 No documentation forwarded																		

Sample No.	Agg. Temp. Set.	Agg. Temp From Dryer	Burner Output	Dryer Exhaust Temp.	Stack Exhaust Temp.	Prod. Rate	Dryer Oper.	Damper Setting (%)	Press. Drop Bag-House	Mix Type	Feed No. % of Total Feed 1	2	3	4	5	6	7	8
Plant 16 No samples forwarded																		
Plant 17																		
17-1	300	320	25	285	260	95	Continuous	60	-	Bind 1	48		24	28				
17-2	300	300	42.5	270	250	85	Continuous	75	-	Wear 1	60		40					
17-S	300	250	50	270	250	90	Start-up	75	-	Wear 1	60		40					
17-3	300	305	25	270	250	90	Continuous	75	-	Wear 1	60		40					
17-4	300	310	30	300	260	90	Start/Stop	60	-	Wear 2	23	23	27	27				
17-5-A	300	290	47	270	300	90	Start-up	75	-	Bind 2	50		5	45				
17-5-B	300	310	25	350	285	90	Continuous	100	-	Bind 2	50		5	45				
17-5-C	300	275	20	245	260	90	Continuous	75	-	Bind 2	50		5	45				
17-5-D	300	330	35	280	255	90	Start/Stop	75	-	Bind 2	50		5	45				
17-5-E	300	305	27	295	275	90	Start/Stop	75	-	Bind 2	50		5	45				
Plant 18 No samples forwarded																		
Plant 19																		
19-1	290	300	25	275	225	80	Continuous	20	7	Base 1	35	35					12	18
19-2	300	290	30	325	275	12	Start/Stop	20	8	Wear 1			30				45	25
19-3-A	290	300	35	275	225	130	Start-up	100	5	Base 2	33	37					10	20
19-3-B	290	290	25	300	250	130	Continuous	100	6	Base 2	33	37					10	20
19-3-C	290	290	25	300	250	130	Continuous	100	5	Base 2	33	37					10	20

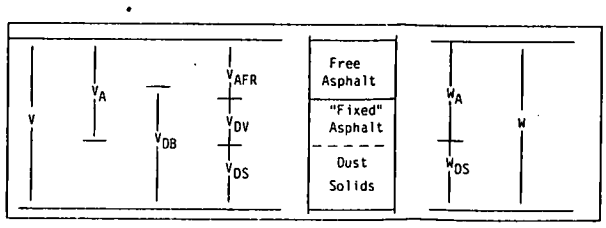
Sample No.	Agg. Temp. Set.	Agg. Temp. From Dryer	Burner Output	Dryer Exhaust Temp.	Stack Exhaust Temp.	Prod. Rate	Dryer Oper.	Damper Setting (%)	Press. Drop Bag-House	Mix Type	Feed No. % of Total Feed 1	2	3	4	5	6	7	8
Plant 19 (continued)																		
19-3-D	290	290	20	280	225	130	Continuous	100	7	Base 2	33	37					10	20
19-3-E	290	290	20	280	225	130	Start/Stop	100	6	Base 2	33	37					10	20
19-S	290	310	40	300	275	100	Start-up	100	7	Base 3	30	40					10	20
19-4	290	290	25	275	225	100	Continuous	100	7	Base 3	30	40					10	20
19-5	290	290	30	280	225	65	Start/Stop	100	7	Base 2	33	37					10	20
Plant 20																		
20-1	320	300	40	270	240	160	Start/Stop	100	9.5	Wear 1			30			30	40	
20-2-A	330	310	50	275	255	150	Start-up	100	9	Wear 2			33			33	33	
20-2-B	310	295	60	310	285	170	Continuous	100	9	Wear 2			33			33	33	
20-2-C	310	295	80	275	260	180	Start/Stop	100	8.5	Wear 3			33		33			33
20-2-D	295	280	85	265	260	180	Continuous	100	8.5	Wear 3			33		33			33
20-2-E	315	300	30	225	220	180	Start/Stop	100	8.5	Wear 3			33		33			33
20-S	340	320	40	200	190	180	Start-up	100	9	Wear 3			33		33			33
20-3	310	295	50	275	260	180	Start/Stop	100	-	Wear 3			33		33			33
20-4	300	285	80	320	260	160	Continuous	100	8.5	Wear 4			45		25			30
20-5	315	290	40	275	225	190	Continuous	100	8.5	Wear 5			40		35			25
Plant 21 No Samples Forwarded																		

Sample No.	Agg. Temp. Set.	Agg. Temp. From Dryer	Burner Output	Dryer Exhaust Temp.	Stack Exhaust Temp.	Prod. Rate	Dryer Oper.	Damper Setting (%)	Press. Drop Bag-House	Mix Type	Feed No. % of Total Feed 1	2	3	4	5	6	7	8
							Plant 22											
22-1	300	300	45	325	-	170	Start/Stop	100	7.5	Wear 1		25	28	47				
22-2	300	300	50	380	-	185	Continuous	100	6	Wear 1		25	28	47				
22-3	300	300	45	375	-	180	Start/Stop	100	6	Wear 1		25	28	47				
22-4-A	300	300	35	300	-	145	Start-up	100	7	Wear 1		25	28	47				
22-4-B	300	300	50	350	-	185	Start/Stop	100	6	Wear 1		25	28	47				
22-4-C	300	310	45	320	-	-	Start/Stop	100	6	Wear 1		25	28	47				
22-4-D	300	295	55	390	-	190	Continuous	100	6	Wear 1		25	28	47				
22-4-E	300	300	45	340	-	180	Start/Stop	100	6	Wear 1		25	28	47				
22-5	300	295	50	380	-	185	Start-up	100	6.5	Wear 1		25	28	47				
22-5	300	295	45	390	-	180	Start/Stop	100	7	Wear 1		25	28	47				
							Plant 23											
23-1-A	375	320-350	24	220	200	275	Start-up	75	0	1	-	-	-	-	-	-		
23-1-B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
23-1-C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
23-1-D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
23-1-E	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		
23-2	375	320-350	24	220	200	300	Continuous	75	0	1	-	-	-	-	-	-		
23-3	-	-	-	-	-	300	-	-	-	-	-	-	-	-	-	-		
23-5	-	-	-	-	-	275	-	-	-	-	-	-	-	-	-	-		
23-4	-	-	-	-	-	275	-	-	-	-	-	-	-	-	-	-		
23-5	-	-	-	-	-	300	-	-	-	-	-	-	-	-	-	-		

APPENDIX D

DUST-ASPHALT VOLUME RELATIONSHIPS

Dust and asphalt volume relationships have been used by many researchers in an attempt to define the behavior of dust-asphalt systems. These systems are usually described as a two-phase system composed of asphalt and dust, as represented in Figure D-1.



V = Total volume

V_A = Volume of asphalt

V_{DB} = Bulk volume of compacted dust

V_{DS} = Volume of dust solids

V_{AFR} = Volume of "free" asphalts

V_{AFX} = Volume of "fixed" asphalts

G_A = Specific gravity of asphalt

G_S = Specific gravity of dust solids

$\%V_{BD}$ = Percentage, bulk volume of compacted dust divided by total volume

$\%V_{AFR}$ = Percentage, volume of free asphalt divided by total volume

D/A = Dust/asphalt ratio: volume of dust solids divided by volume of asphalt

α_{DB} = Bulk density of dust

α_W = Density of water

ρ = Porosity of bed of powder

W_{DS} = Weight of solids in dust

W_A = Weight of asphalt

W = Total weight

Figure D-1. Weight-volume relationships.

It is useful to divide the asphalt in a dust-asphalt mixture into a "fixed" and a "free" part. The fixed part is defined as occupying the void volume that results when the powder is compacted or allowed to settle to some arbitrary density. This density may be determined from dry compaction or from a test procedure in which the dust is allowed to settle in a liquid. Free asphalt is defined as any asphalt in excess of the fixed asphalt. The total asphalt volume, therefore, is the sum of the fixed and the free asphalt volumes.

The following relationships are useful in describing the behavior of dust-asphalt systems:

1. Porosity of compacted bed of powder, ρ

$$\rho = \frac{\text{Void Volume}}{\text{Total Volume}} \times 100\% = 1 - \frac{\rho_{DB}}{\rho_W G_S} \quad 100\% \qquad \text{(D-1)}$$

2. Porosity of dust-asphalt system, ρ

$$\rho = \frac{\text{Total Asphalt Volume}}{\text{Total Volume of System}} \times 100\% = \frac{W_S\ G_A\ \rho_W}{W_S\ G_A\ \rho_W + \rho_{DB}\ W_A} \times 100\% \qquad \text{(D-2)}$$

3. Void ratio in compacted bed of powder, e

$$e = \frac{\text{Void Volume}}{\text{Volume of Solids}} = \frac{G_S\ \rho_W}{\rho_{DB}} - 1 \qquad \text{(D-3)}$$

4. Void ratio in dust-asphalt system, e

$$e = \frac{\text{Total Asphalt Volume}}{\text{Volume of Solids}} = \frac{W_A\ G_S}{W_S\ G_A} \qquad \text{(D-4)}$$

5. Volumetric dust/asphalt ratio, D/A

$$D/A = \frac{V_{DS}}{V_A} = \frac{G_A\ W_{DS}}{G_{DS}\ W_A} \qquad \text{(D-5)}$$

6. Total volume of dust/asphalt mixture, V

$$V = \frac{G_S\ W_A + G_A\ W_{DS}}{G_A\ G_{DS}\ \rho} \qquad \text{(D-6)}$$

7. Bulk volume of dust expressed as percentage of total volume, $\%V_{DB}$

$$\%V_{DB} = \frac{\rho_W}{\ell_{DB}} \quad \frac{W_{DS}\ G_A\ G_S}{G_{DS}\ W_A + G_A\ W_{DS}} \times 100\% \qquad \text{(D-7)}$$

8. Volume of free asphalt, V_{AFR}

$$V_{AFR} = \frac{W_A\ G_S\ \rho_{DB} - W_{DS}\ G_A\ G_S\ \rho_W + W_{DS}\ G_A\ \rho_{DB}}{G_A\ G_S\ \rho_W\ \rho_{DB}} \qquad \text{(D-8)}$$

9. Volume of free asphalt expressed as a percentage of total volume, $\%V_{AFR}$

$$\%V_{AFR} = \frac{W_A\ G_S\ \rho_{DB} - W_{DS}\ G_A\ G_{DS}\ \rho_W + W_{DS}\ G_A\ \rho_{DB}}{\rho_{DB}\ (G_S\ W_A + G_A\ W_{DS})} \times 100\% \qquad \text{(D-9)}$$

APPENDIX E.

DATA COLLECTED ON DUST SAMPLES

Plant no. 1										
Sample	S	1-A	1-B	1-C	1-D	1-E	2	3	4*	5
Mix Type	SAND1	SAND1	SAND1	BIND1	SAND1	SAND1	SAND1	BASE1	WEAR1	WEAR1
% Passing:										
No. 30	96.	99.	99.	99.	99.	99.	98.	98.	99.	99.
50	91.	96.	96.	97.	97.	97.	96.	93.	97.	97.
200	35.	58.	61.	64.	71.	64.	60.	44.	70.	68.
Microns 50	93.	90.	92.	91.	86.	93.	90.	92.	95.	89.
30	57.	55.	51.	55.	40.	58.	52.	62.	64.	58.
20	32.	30.	26.	33.	12.	34.	25.	39.	38.	35.
10	12.	12.	10.	13.	6.	15.	8.	17.	16.	15.
5	5.	3.	3.	3.	1.	6.	2.	7.	6.	5.
3	3.	2.	1.	2.	4.	4.	1.	4.	3.	4.
1	2.	1.		1.		2.	4.	3.	2.	2.
0.8	2.					2.		3.	1.	2.
0.6	2.					2.		3.	1.	2.
Plasticity: PL,%										
LL,%										
PI,%		NP	NP	NP	NP	NP	NP	NP	NP	NP
pH		11.7	11.6	11.2	12.	11.5	11.5	11.6	11.6	11.5
Density: Dry-Vib,g/cm3		1.86	1.81	1.72	1.79	1.81	1.81	1.77	1.73	1.75
Polar,g/cm3		1.58	1.59	1.52	1.52	1.57	1.56	1.61	1.52	1.50
Non-Polar,g/cm3		1.47	1.52	1.43	1.39	1.47	1.52	1.47	1.43	1.43
Moisture: Initial,%		3.8	3.4	4.1	3.9	4.2	4.1	3.3	3.2	3.7
Final,%		3.8	3.6	4.6	3.9	4.4	4.2	3.7	4.	4.3
Specific Gravity										2.78

			SP,F	Vis,P,140F
Asphalt A	F/A	0.2	123.0	3944.0
		0.4	130.0	7858.0
Asphalt B	F/A	0.2	124.0	3124.0
		0.4	129.0	6976.0

Air Perm:	Surface Area,m2/g	0.17
	Avg Size,microns	13.1
	Density,g/cm3	1.82
Mixing:	Ball Point,g	57
	Crumble Point,g	79

* - Sample used in limited testing

Plant no. 2

Sample	S	1	2*	3
Mix Type				
% Passing:				
No. 30	99.	98.	98.	99.
50	91.	85.	88.	92.
200	67.	57.	61.	69.
Microns 50	96.	96.	96.	97.
30	81.	81.	83.	81.
20	67.	67.	69.	66.
10	42.	43.	44.	41.
5	22.	22.	25.	22.
3	13.	14.	14.	13.
1	3.	3.	5.	5.
0.8	1.	1.	3.	3.
0.6	0	0	1.	1.
Plasticity: PL,%				
LL,%				
PI,%		NP	NP	NP
pH		11.3	11.1	11.3
Density: Dry-Vib,g/cm3		1.67	1.65	1.57
Polar,g/cm3		1.52	1.57	1.47
Non-Polar,g/cm3		1.17	1.17	1.11
Moisture: Initial,%		0.4	0.5	0.5
Final,%		0.8	0.5	0.5
Specific Gravity			2.622	

			SP,F	Vis,P,140F
Asphalt A	F/A	0.2	122.0	4051.0
		0.4	128.0	8318.0
Asphalt B	F/A	0.2	122.5	3430.0
		0.4	128.0	6546.0

Air Perm:	Surface Area,m2/g	0.53
	Avg Size,microns	4.3
	Density,g/cm3	1.82
Mixing:	Ball Point,g	60
	Crumble Point,g	78

* - Sample used in limited testing

Plant no. 3

Sample	S	1	2	3	4-A	4-B*	4-C	4-D	4-E	5
Mix Type	BIND1	BIND1	BIND2	BIND3	SAND1	SAND1	BIND1	BIND1	BIND1	BIND1
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	100.	99.	100.	100.	99.	100.	100.	100.	100.	100.
200	93.	87.	93.	89.	89.	92.	93.	88.	92.	91.
Microns 50	98.	98.	98.	99.	98.	100.	98.	97.	99.	98.
30	91.	91.	91.	90.	89.	94.	90.	88.	90.	90.
20	79.	80.	79.	78.	76.	85.	77.	75.	78.	78.
10	52.	56.	52.	51.	51.	59.	50.	48.	51.	51.
5	28.	32.	31.	27.	26.	35.	25.	29.	30.	28.
3	19.	20.	19.	18.	16.	21.	23.	16.	18.	17.
1	8.	9.	10.	7.	5.	8.	4.	8.	7.	10.
0.8	6.	8.	6.	6.	4.	6.	3.	6.	5.	6.
0.6	4.	5.	5.		3.	5.			3.	5.
Plasticity: PL,%		23.	25.	24.	28.	25.	28.	25.	26.	22.
LL,%		25.	27.	25.	29.	29.	29.	26.	28.	27.
PI,%		2.	2.	1.	1.	4.	1.	1.	2.	5.
pH		8.3	8.7	7.9	7.8	7.7	8.	8.4	8.4	8.1
Density: Dry-Vib,g/cm3		0.98	0.92	1.02	0.98	0.9	0.98	0.98	0.94	0.98
Polar,g/cm3		0.98	0.95	1.04	1.02	0.97	1.	1.	0.97	0.98
Non-Polar,g/cm3		0.9	0.87	0.9	0.9	0.8	0.84	0.88	0.84	0.85
Moisture: Initial,%		0.4	0.3	0.3	0.5	0.4	0.6	0.3	0.3	0.6
Final,%		1.	0.9	0.9	1.	1.2	1.	0.9	1.1	1.
Specific Gravity				2.855						

			SP,F	Vis,P,140F
Asphalt A	F/A	0.2		
		0.4		
Asphalt B	F/A	0.2		
		0.4		

Air Perm:	Surface Area,m2/g	1.45
	Avg Size,microns	1.4
	Density,g/cm3	1.58
Mixing:	Ball Point,g	38
	Crumble Point,g	50

* - Sample used in limited testing

Plant no. 4

Sample	S	1	2-A	2-B*	2-C	2-D	2-E	3	4	5
Mix Type	W/CM1	WEAR1	W/BN1	W/CM1	W/BN1	W/CM2	W/CM2	W/BN1	W/BN1	W/CM
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
200	87.	93.	93.	96.	93.	95.	93.	91.	94.	94.
Microns 50	97.	100.	99.	98.	98.	99.	98.	98.	100.	100.
30	91.	94.	92.	91.	91.	92.	92.	92.	94.	94.
20	82.	86.	82.	81.	80.	81.	83.	82.	83.	84.
10	56.	61.	55.	52.	51.	56.	56.	57.	85.	57.
5	31.	36.	29.	27.	26.	30.	31.	31.	32.	33.
3	20.	20.	17.	15.	14.	17.	19.	19.	19.	20.
1	9.	9.	5.	3.	4.	2.	10.	6.	8.	10.
0.8	7.	5.	4.	2.					7.	7.
0.6	5.		4.						6.	6.
Plasticity: PL,%		26.	26.	25.	23.	27.	24.	24.	24.	23.
LL,%		27.	28.	28.	27.	29.	27.	26.	28.	28.
PI,%		1.	2.	3.	4.	2.	3.	2.	4.	4.
pH		9.2	9.1	9.2	9.3	9.3	9.2	9.2	9.1	9.1
Density: Dry-Vib,g/cm3		1.10	1.10	1.18	1.17	1.18	1.08	1.09	1.16	1.0
Polar,g/cm3		1.19	1.19	1.19	1.17	1.14	1.14	1.14	1.12	1.09
Non-Polar,g/cm3		0.82	0.88	0.96	0.95	0.92	0.92	0.76	0.88	0.83
Moisture: Initial,%		1.	0.4	0.9	0.4	0.7	0.9	0.6	0.9	0.8
Final,%		2.9	3.	2.9	2.8	2.9	2.9	2.8	2.7	3.1
Specific Gravity						2.873				

		SP,F	Vis,P,140F
Asphalt A F/A	0.2		
	0.4		
Asphalt B F/A	0.2		
	0.4		

Air Perm:	Surface Area,m2/g	0.77
	Avg Size,microns	2.7
	Density,g/cm3	1.49
Mixing:	Ball Point,g	39
	Crumble Point,g	50

* - Sample used in limited testing

Plant no. 5

Sample	S	1	2	3	4	5-A	5-B	5-C*	5-D	5-E
Mix Type	COM1	COM1	COM1	COM2	COM3	COM4	COM5	COM6	COM7	COM8
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
200	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
Microns 50	99.	99.	99.	99.	99.	99.	99.	100.	99.	100.
30	99.	99.	99.	99.	99.	99.	99.	99.	98.	100.
20	95.	96.	94.	95.	95.	95.	95.	95.	95.	97.
10	73.	76.	71.	72.	74.	70.	72.	72.	71.	76.
5	42.	46.	40.	42.	41.	38.	41.	40.	39.	42.
3	26.	30.	23.	25.	24.	23.	24.	24.	22.	26.
1	7.	10.	6.	7.	7.	4.	6.	7.	5.	8.
0.8	5.	7.	4.		5.	3.	5.	5.	3.	6.
0.6	3.	3.	3.		4.	2.	3.	3.	2.	4.
Plasticity: PL,%		39.	34.	38.	37.	38.	38.	37.	37.	36.
LL,%		41.	39.	42.	39.	39.	39.	38.	38.	39.
PI,%		2.	4.	3.	2.	1.	1.	1.	1.	3.
pH		9.8	9.9	10.	9.3	9.8	9.3	10.	10.1	9.3
Density: Dry-Vib,g/cm3		0.75	0.75	0.74	0.73	0.73	0.72	0.72	0.76	0.76
Polar,g/cm3		0.75	0.79	0.78	0.7	0.75	0.7	0.73	0.74	0.74
Non-Polar,g/cm3		0.73	0.71	0.62	0.73	0.64	0.66	0.66	0.69	0.68
Moisture: Initial,%		0.7	0.7	0.8	0.8	0.5	0.7	1.2	0.7	0.8
Final,%		1.8	2.	1.8	2.	1.4	2.	2.1	1.8	2.1
Specific Gravity							2.781			

		SP,F	Vis,P,140F
Asphalt A F/A	0.2	127.0	6510.0
	0.4	150.0	44580.0
Asphalt B F/A	0.2	128.0	5230.0
	0.4	151.0	42830.0

Air Perm:	Surface Area,m2/g	1.64
	Avg Size,microns	1.3
	Density,g/cm3	1.32
Mixing:	Ball Point,g	28
	Crumble Point,g	37

* - Sample used in limited testing

Plant no. 6

Sample	S	1	2	3*	4	5	A	B	C	D
Mix Type	WEAR5	WEAR1	WEAR2	WEAR1	WEAR1	WEAR2	WEAR3	WEAR3	WEAR4	WEAR
% Passing:										
No. 30	99.	99.	99.	99.	99.	99.	99.	99.	99.	99.
50	96.	95.	94.	93.	94.	95	93.	95.	94.	94.
200	47.	39.	46.	46.	37.	44.	43.	44.	44.	40.
Microns 50	92.	92.	93.	93.	90.	94.	95.	96.	88.	91.
30	70.	72.	73.	74.	67.	75.	74.	78.	64.	66.
20	51.	55.	55.	60.	48.	57.	55.	61.	47.	47.
10	24.	28.	26.	32.	24.	31.	28.	31.	23.	21.
5	7.	9.	8.	12.	6.	12.	10.	11.	7.	5.
3	1.	3.	2.	5.	1.	6.	4.	4.	2.	0.
1						0.				
0.8										
0.6										
Plasticity: PL,%										
LL,%										
PI,%	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
pH	5.8	5.4	5.7	5.4	5.4	5.5	5.7	5.8	5.6	5.6
Density: Dry-Vib,g/cm3	1.71	1.75	1.75	1.71	1.79	1.74	1.74	1.69	1.72	1.70
Polar,g/cm3	1.26	1.35	1.38	1.35	1.43	1.29	1.37	1.32	1.32	1.25
Non-Polar,g/cm3	1.22	1.28	1.28	1.22	1.32	1.21	1.25	1.19	1.19	1.22
Moisture: Initial,%	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2
Final,%	0.2	0.5	0.5	0.5	0.4	0.4	0.2	0.2	0.2	0.2
Specific Gravity				2.655						

			SP,F	Vis,P,140F
Asphalt A	F/A	0.2	123.0	5564.0
		0.4	129.5	9731.0
Asphalt B	F/A	0.2	123.5	3564.0
		0.4	130.0	7644.0

Air Perm:	Surface Area,m2/g	0.16
	Avg Size,microns	14.6
	Density,g/cm3	1.77
Mixing:	Ball Point,g	48
	Crumble Point,g	72

* - Sample used in limited testing

Plant no. 7

Sample	S	1	2	3-A	3-B	3-C	3-D*	3-E	4	5
Mix Type										
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	100.	100.	100.	100.	100.	100.	100.	100.	99.	99.
200	100.	100.	100.	100.	100.	100.	100.	100.	98.	98.
Microns 50	99.	100.	100.	98.	100.		100.	100.	99.	100.
30	97.	98.	98.	98.	97.		97.	98.	96.	98.
20	89.	91.	91.	95.	90.		91.	91.	89.	91.
10	63.	64.	64.	64.	62.		65.	65.	61.	65.
5	33.	35.	35.	36.	35.		35.	36.	34.	36.
3	19.	21.	22.	22.	22.		21.	23.	21.	23.
1	4.	7.	7.	8.	7.		7.	8.	7.	10.
0.8	2.	6.	5.	6.	6.		5.	6.	5.	8.
0.6	1.	4.	3.	4.	4.		4.	5.	0	6.
Plasticity: PL,%		29.	30.	30.	32.	32.	32.	30.	30.	33.
LL,%		33.	35.	33.	35.	34.	33.	34.	33.	34.
PI,%		4.	4.	4.	3.	2.	2.	4.	3.	2.
pH		11.8	11.3	11.	11.1		11.1	11.1	10.9	11.1
Density: Dry-Vib,g/cm3		0.97	0.96	1.01	0.98		0.98	0.99	1.	0.97
Polar,g/cm3		0.96	0.91	0.96	1.05		0.89	0.9	1.17	0.94
Non-Polar,g/cm3		0.71	0.71	0.78	0.72		0.77	0.8	0.75	0.73
Moisture: Initial,%		0.6	0.6	0.6	0.4		0.5	0.6	0.5	0.6
Final,%		1.8	1.9	2.	2.1		1.9	2.	1.8	1.7
Specific Gravity				2.864						

			SP,F	Vis,P,140F
Asphalt A	F/A	0.2	127.0	6638.0
		0.4	148.0	41890.0
Asphalt B	F/A	0.2	127.0	5298.0
		0.4	148.0	34560.0

Air Perm:	Surface Area,m2/g	1.48
	Avg Size,microns	1.4
	Density,g/cm3	1.39
Mixing:	Ball Point,g	28
	Crumble Point,g	36

* - Sample used in limited testing

Plant no. 8

Sample	S	1	2	3	4	5-A	5-B	5-C*	5-D	5-E
Mix Type	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	97.	90.	91.	95.	92.	99.	99.	99.	98.	96.
200	76.	33.	32.	55.	33.	90.	88.	76.	71.	55.
Microns 50	98.	96.	94.	94.	90.	97.	99.	98.	98.	96.
30	82.	80.	75.	75.	72.	88.	91.	89.	85.	83.
20	68.	63.	57.	57.	55.	76.	77.	74.	69.	67.
10	41.	35.	31.	30.	30.	48.	48.	44.	41.	38.
5	19.	14.	12.	12.	12.	23.	23.	19.	17.	16.
3	12.	7.	6.	6.	5.	12.	12.	11.	8.	8.
1	3.	2.	2.	2.	1.	2.	2.	4.	1.	2.
0.8	2.	1.			1.	1.	1.	2.		1.
0.6	1.	1.				1.	1.	1.		1.
Plasticity: PL,%										
LL,%										
PI,%	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
pH		12.3	12.3	12.4	12.2	12.4	12.4	12.8	12.6	12.3
Density: Dry-Vib,g/cm3		1.71	1.72	1.4	1.46	0.97	1.	1.01	1.1	1.34
Polar,g/cm3		1.39	1.39	1.25	1.32	1.73	1.13	1.39	0.98	1.22
Non-Polar,g/cm3		1.32	1.32	1.19	1.32	0.85	0.88	0.96	0.98	1.11
Moisture: Initial,%		0.	0.1	0.2	0.2	0.1	0.	0.2	0.1	0.1
Final,%		0.5	0.6	0.7	0.6	1.	1.	1.2	1.	0.8
Specific Gravity		2.69								

		SP,F	Vis,P,140F
Asphalt A	F/A 0.2		
	0.4		
Asphalt B	F/A 0.2		
	0.4		

Air Perm:	Surface Area,m2/g	0.98
	Avg Size,microns	2.3
	Density,g/cm3	1.51
Mixing:	Ball Point,g	41
	Crumble Point,g	55

* - Sample used in limited testing

Plant no. 9

Sample	S	1-A	1-B	1-C	1-D	1-E*	2	3	4	5
Mix Type	BASE1	BASE1	BASE1	WEAR1	WEAR1	WEAR1	WEAR1	BASE1	WEAR1	WEAR1
% Passing:										
No. 30	99.	99.	99.	100.	99.	100.	100.	99.	100.	100.
50	93.	92.	93.	94.	93.	95.	94.	93.	94.	94.
200	54.	52.	51.	37.	42.	47.	37.	54.	45.	49.
Microns 50	95.	93.	93.	94.	90.	91.	95.	93.	93.	95.
30	79.	75.	73.	70.	67.	68.	76.	75.	70.	77.
20	64.	61.	57.	55.	52.	52.	60.	60.	55.	62.
10	42.	40.	37.	35.	33.	30.	38.	40.	34.	37.
5	24.	23.	19.	19.	16.	15.	20.	20.	18.	19.
3	16.	16.	13.	12.	10.	8.	13.	14.	11.	11.
1	8.	8.	7.	5.	5.	4.	6.	8.	6.	5.
0.8	6.	6.	5.	3.	3.	2.	4.	6.	4.	4.
0.6	4.	5.	4.	2.	2.	1.	3.	5.	3.	3.
Plasticity: PL,%										
LL,%										
PI,%	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
pH		11.8	12.	11.9	12.	12.1	12.2	12.2	12.4	12.3
Density: Dry-Vib,g/cm3		1.72	1.73	1.81	1.76	1.75	1.81	1.69	1.77	1.71
Polar,g/cm3		1.43	1.39	1.43	1.43	1.43	1.39	1.43	1.52	1.39
Non-Polar,g/cm3		1.25	1.25	1.32	1.28	1.28	1.36	1.22	1.25	1.22
Moisture: Initial,%		0.2	0.3	0.2	0.1	0.	0.1	0.2	0.2	0.2
Final,%		0.7	0.8	0.5	0.5	0.6	0.5	0.7	0.7	0.5
Specific Gravity		2.578						2.583		

		SP,F	Vis,P,140F
Asphalt A	F/A 0.2	122.0	3694.0
	0.4	129.0	7035.0
Asphalt B	F/A 0.2	122.5	3342.0
	0.4	129.0	5654.0

Air Perm:	Surface Area,m2/g	0.25
	Avg Size,microns	9.1
	Density,g/cm3	1.82
Mixing:	Ball Point,g	58
	Crumble Point,g	81

* - Sample used in limited testing

Plant no. 9S

Sample	S	1-A	1-B	1-C	1-D	1-E	2	3	4	5
Mix Type										
% Passing:										
No. 30	99.	99.	100.	100.	100.	100.	100.	100.	100.	100.
50	89.	95.	96.	96.	98.	96.	96.	95.	96.	97.
200	45.	64.	66.	56.	65.	54.	48.	61.	54.	55.
Microns 50	92.	88.	90.	86.	85.	90.	91.	93.	90.	87.
30	75.	70.	70.	67.	64.	70.	74.	76.	72.	68.
20	62.	58.	57.	52.	51.	56.	61.	63.	57.	56.
10	43.	40.	37.	34.	31.	36.	42.	43.	35.	36.
5	25.	23.	20.	18.	17.	20.	24.	27.	18.	17.
3	17.	15.	13.	11.	10.	12.	14.	18.	10.	9.
1	7.	9.	5.	5.	5.	4.	6.	10.	1.	2.
0.8	6.	8.	4.	5.	5.	4.	6.	9.	1.	1.
0.6	5.	8.	4.	4.	4.	3.	5.	8.	1.	1.
Plasticity: PL,%										
LL,%										
PI,%										
pH										
Density: Dry-Vib,g/cm3										
Polar,g/cm3										
Non-Polar,g/cm3										
Moisture: Initial,%										
Final,%										
Specific Gravity										

		SP,F	Vis,P,140F		
Asphalt A	F/A 0.2			Air Perm: Surface Area,m2/g	
	0.4			Avg Size,microns	
Asphalt B	F/A 0.2			Density,g/cm3	
	0.4			Mixing: Ball Point,g	
				Crumble Point,g	

* - Sample used in limited testing

Plant no. 10

Sample	S	1-A	1-B	1-C*	1-D	1-E	2	3	4	5
Mix Type	BASE1	BASE1	BASE1	BASE1	BASE1	BASE1	BASE1	BASE1	BASE1	BASE1
% Passing:										
No. 30	93.	94.	97.	96.	96.	96.	95.	93.	93.	96.
50	88.	88.	93.	85.	85.	85.	90.	85.	87.	89.
200	29.	29.	41.	38.	38.	39.	32.	32.	28.	47.
Microns 50	93.	95.	97.	96.	95.	96.	94.	93.	92.	96.
30	67.	74.	78.	81.	78.	80.	72.	77.	66.	82.
20	51.	59.	64.	68.	65.	68.	58.	63.	52.	68.
10	35.	49.	45.	48.	45.	47.	39.	44.	35.	45.
5	22.	22.	27.	30.	27.	28.	21.	25.	20.	25.
3	15.	14.	19.	20.	18.	18.	13.	16.	13.	16.
1	8.	7.	9.	11.	9.	9.	5.	7.	5.	7.
0.8	7.	6.	8.	9.	8.	8.	4.	6.	4.	6.
0.6	5.	4.	6.	7.	6.	6.	3.	5.	3.	5.
Plasticity: PL,%										
LL,%										
PI,%	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
pH		10.4	10.5	11.2	11.2	11.2	11.1	11.2	10.4	11.6
Density: Dry-Vib,g/cm3		1.72	1.61	1.64	1.63	1.62	1.68	1.69	1.66	1.62
Polar,g/cm3		1.4	1.36	1.39	1.39	1.35	1.43	1.42	1.39	1.39
Non-Polar,g/cm3		1.32	1.25	1.36	1.32	1.25	1.39	1.39	1.39	1.32
Moisture: Initial,%		0.5	0.3	0.4	0.8	0.7	0.7	0.6	1.	0.6
Final,%		0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.3	0.5
Specific Gravity									2.666	

		SP,F	Vis,P,140F		
Asphalt A	F/A 0.2	124.0	4199.0	Air Perm: Surface Area,m2/g	0.25
	0.4	128.0	7874.0	Avg Size,microns	9.2
Asphalt B	F/A 0.2	124.0	3564.0	Density,g/cm3	1.90
	0.4	129.0	7524.0	Mixing: Ball Point,g	69
				Crumble Point,g	91

* - Sample used in limited testing

Plant no. 13

Sample	S	1	2	3-A	3-B	3-C	3-D	3-E	4*	5
Mix Type	BIND1	BIND1	BIND1	BIND1	BIND1	BIND1	BIND1	BIND1	WEAR1	WEAR1
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	99.	100.	100.	100.
50	100.	100.	100.	100.	100.	100.	99.	100.	100.	100.
200	95.	96.	96.	96.	96.	96.	96.	96.	97.	96.
Microns 50	98.	97.	96.	97.	95.	99.	98.	98.	99.	97.
30	92.	91.	90.	90.	89.	94.	92.	91.	93.	89.
20	85.	83.	81.	82.	80.	86.	83.	82.	86.	81.
10	65.	64.	63.	60.	60.	66.	63.	63.	68.	60.
5	43.	41.	42.	38.	37.	44.	41.	40.	46.	40.
3	31.	29.	30.	26.	26.	31.	29.	27.	33.	27.
1	13.	13.	13.	9.	11.	12.	14.	11.	14.	12.
0.8	13.	11.	11.	7.	10.	10.	11.	10.	12.	10.
0.6	12.	10.	10.	6.	8.	9.	7.	9.	10.	8.
Plasticity: PL,%		32.	33.	32.	31.	33.	30.	31.	32.	34.
LL,%		33.	34.	32.	32.	35.	33.	34.	35.	35.
PI,%		1.	1.	1.	1.	2.	2.	2.	2.	1.
pH		12.1	12.	11.9	12.	12.1	12.1	12.1	12.3	12.2
Density: Dry-Vib,g/cm3		0.82	0.85	0.84	0.82	0.83	0.84	0.85	0.8	0.79
Polar,g/cm3		0.84	0.77	0.81	0.81	0.8	0.78	0.85	0.74	0.71
Non-Polar,g/cm3		0.78	0.73	0.78	0.77	0.75	0.79	0.75	0.70	0.82
Moisture: Initial,%		0.2	0.1	0.2	0.1	0.2	0.2	0.2	0.4	0.3
Final,%		2.2	1.3	1.3	1.3	1.4	1.3	2.	1.3	2.
Specific Gravity		2.704						2.695		

			SP,F	Vis,P,140F
Asphalt A	F/A	0.2	127.5	5998.0
		0.4	144.0	26910.0
Asphalt B	F/A	0.2	127.0	4897.0
		0.4	144.0	24140.0

Air Perm:	Surface Area,m2/g	2.18
	Avg Size,microns	1.0
	Density,g/cm3	1.41
Mixing:	Ball Point,g	34
	Crumble Point,g	47

* - Sample used in limited testing

Plant no. 14

Sample	S	1	2	3-A	3-B	3-C*	3-D	3-E	4	5
Mix Type	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	99.	99.	99.	99.	99.	99.	99.	99.	100.	99.
200	77.	82.	85.	78.	77.	82.	87.	87.	87.	83.
Microns 50	99.	98.	99.	98.	97.	98.	98.	98.	98.	97.
30	93.	92.	94.	93.	90.	92.	93.	94.	93.	92.
20	87.	86.	90.	86.	84.	87.	88.	89.	87.	86.
10	71.	74.	78.	73.	70.	76.	73.	77.	73.	72.
5	52.	56.	62.	56.	53.	57.	56.	59.	57.	56.
3	38.	42.	45.	41.	38.	42.	41.	43.	42.	41.
1	12.	15.	16.	15.	14.	15.	14.	15.	13.	15.
0.8	8.	12.	14.	13.	12.	12.	9.	13.	10.	12.
0.6	6.	9.	11.	11.	8.	9.	6.	9.	8.	8.
Plasticity: PL,%		28.	26.	26.	29.	29.	29.	26.	26.	28.
LL,%		32.	30.	28.	30.	29.	33.	31.	28.	30.
PI,%		4.	3.	2.	1.	1.	4.	4.	2.	2.
pH		10.3	10.5	10.4	11.1	10.2	11.4	11.6	9.7	9.3
Density: Dry-Vib,g/cm3		0.85	0.78	0.9	0.85	0.81	0.75	0.76	0.73	0.76
Polar,g/cm3		0.84	0.74	0.91	0.93	0.81	0.76	0.75	0.73	0.76
Non-Polar,g/cm3		0.71	0.64	0.8	0.74	0.68	0.66	0.69	0.7	0.69
Moisture: Initial,%		0.4	0.5	0.5	0.3	0.4	0.3	0.4	0.5	0.5
Final,%		1.2	1.3	1.2	1.1	1.2	1.1	1.3	1.2	1.2
Specific Gravity			2.661						2.681	

			SP,F	Vis,P,140F
Asphalt A	F/A	0.2	127.0	6376.0
		0.4	143.5	27840.0
Asphalt B	F/A	0.2	127.5	5159.0
		0.4	144.5	24160.0

Air Perm:	Surface Area,m2/g	1.94
	Avg Size,microns	1.2
	Density,g/cm3	1.49
Mixing:	Ball Point,g	38
	Crumble Point,g	48

* - Sample used in limited testing

Plant no. 15

Sample	S	1	2	3	4-A	4-B	4-C*	4-D	4-E	5
Mix Type										
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	100.	100.	100.	100.	100.	100.	100.	100.	100.	99.
200	100.	100.	100.	100.	100.	100.	100.	100.	100.	78.
Microns 50	100.	99.	100.	100.	100.	100.	99.	100.	99.	96.
30	100.	99.	100.	99.	99.	99.	98.	99.	99.	80.
20	98.	97.	98.	92.	97.	97.	96.	97.	97.	60.
10	83.	81.	82.	77.	78.	76.	76.	75.	78.	33.
5	54.	54.	51.	44.	46.	46.	45.	42.	45.	17.
3	35.	36.	32.	26.	28.	28.	28.	22.	27.	11.
1	12.	12.	10.	8.	7.	8.	8.	5.	7.	5.
0.8	9.	9.	7.	6.	5.	6.	6.	3.	5.	4.
0.6	6.	7.	5.	4.	3.	4.	4.	0	2.	3.
Plasticity: PL,%		31.	27.	30.	27.	28.	31.	27.	29.	29.
LL,%		34.	29.	33.	31.	32.	33.	32.	33.	31.
PI,%		3.	2.	3.	3.	4.	2.	5.	4.	4.
pH		11.7	12.	12.1	12.4	12.3	12.4	12.4	12.2	12.
Density: Dry-Vib,g/cm3		0.85	0.89	0.98	0.97	0.94	0.92	1.07	0.95	0.96
Polar,g/cm3		0.94	0.95	1.02	1.07	0.96	0.96	1.07	0.98	1.34
Non-Polar,g/cm3		0.78	0.79	0.85	0.88	0.85	0.69	0.92	0.88	1.23
Moisture: Initial,%		0.4	0.5	0.3	0.3	0.5	0.3	0.1	0.3	0.3
Final,%		1.2	1.1	1.1	1.2	1.6	1.1	1.3	1.1	0.5
Specific Gravity			2.634							2.672

		SP,F	Vis,P,140F
Asphalt A F/A	0.2	125.0	5449.0
	0.4	137.5	19460.0
Asphalt B F/A	0.2	127.0	4586.0
	0.4	139.0	17350.0

Air Perm:	Surface Area,m2/g	1.57
	Avg Size,microns	1.4
	Density,g/cm3	1.47
Mixing:	Ball Point,g	28
	Crumble Point,g	36

* - Sample used in limited testing

Plant no. 17

Sample	S	1	2	3*	4	5-A	5-B	5-C	5-D	5-E
Mix Type	WEAR1	BIND1	WEAR1	WEAR1	WEAR2	BIND2	BIND2	BIND2	BIND2	BIND2
% Passing:										
No. 30	99.	100.	100.	99.	95.	100.	99.	100.	99.	100.
50	90.	99.	93.	94.	90.	96.	92.	94.	94.	96.
200	22.	20.	23.	22.	21.	33.	19.	27.	32.	41.
Microns 50	87.	97.	95.	95.	86.	91.	86.	93.	93.	95.
30	52.	82.	71.	67.	49.	56.	42.	65.	68.	71.
20	32.	65.	50.	43.	30.	30.	20.	42.	45.	47.
10	18.	39.	27.	24.	15.	14.	9.	20.	22.	23.
5	8.	16.	17.	10.	8.	6.	4.	8.	8.	9.
3	5.	7.	7.	7.	6.	4.	3.	4.	4.	4.
1	4.	0	1.	4.	4.	3.	3.	2.	2.	2.
0.8	4.	0	0	2.	4.	3.	3.	2.	2.	2.
0.6	4.	0	0	2.	4.	3.	3.	2.	2.	2.
Plasticity: PL,%										
LL,%										
PI,%	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
pH		12.2	12.2	12.6	12.4	12.6	12.8	12.6	12.6	12.5
Density: Dry-Vib,g/cm3		1.14	1.63	1.64	1.65	1.72	1.75	1.85	1.76	1.75
Polar,g/cm3		1.39	1.47	1.48	1.45	1.52	1.52	1.44	1.49	1.52
Non-Polar,g/cm3		1.53	1.48	1.48	1.46	1.49	1.47	1.52	1.53	1.5
Moisture: Initial,%		0.6	0.2	0.2	0.7	0.3	0.2	0.2	0.3	0.3
Final,%		0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.3	0.2
Specific Gravity				2.719					2.810	

		SP,F	Vis,P,140F
Asphalt A F/A	0.2		
	0.4		
Asphalt B F/A	0.2		
	0.4		

Air Perm:	Surface Area,m2/g	0.06
	Avg Size,microns	34.5
	Density,g/cm3	
Mixing:	Ball Point,g	67
	Crumble Point,g	>280

* - Sample used in limited testing

Plant no. 19

Sample	S	1	2	3-A	3-B	3-C*	3-D	3-E	4	5
Mix Type	BASE3	BASE1	WEAR1	BASE2	BASE2	BASE2	BASE2	BASE2	BASE3	BASE2
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	100.	99.	99.	99.	99.	99.	99.	99.	99.	99.
200	99.	95.	96.	97.	96.	96.	96.	96.	96.	96.
Microns 50	98.	99.	98.	99.	100.	99.	99.	99.	98.	99.
30	93.	95.	93.	93.	93.	93.	92.	95.	92.	93.
20	80.	83.	81.	78.	79.	79.	77.	82.	77.	78.
10	49.	53.	49.	46.	46.	46.	45.	49.	45.	45.
5	24.	27.	24.	22.	23.	22.	21.	25.	26.	21.
3	14.	16.	15.	14.	14.	14.	12.	14.	18.	13.
1	7.	7.	6.	6.	6.	6.	5.	7.	7.	5.
0.8	6.	5.	5.	5.	4.	5.	3.	5.	5.	4.
0.6	5.	4.	4.	4.	3.	4.	2.	3.	4.	3.
Plasticity: PL,%		31.	32.	33.	31.	33.	33.	31.	33.	34.
LL,%		35.	35.	35.	31.	35.	33.	34.	33.	35.
PI,%		3.	3.	2.	0.	2.	0.	2.	0.	1.
pH		8.7	8.9	8.5	8.4	8.7	8.4	8.3	8.3	8.7
Density: Dry-Vib,g/cm3		1.01	1.12	1.12	1.13	1.14	1.14	1.11	1.15	1.15
Polar,g/cm3		0.95	1.06	0.96	0.98	0.98	1.02	0.94	0.98	0.99
Non-Polar,g/cm3		0.82	0.88	0.79	0.82	0.84	0.77	0.82	0.81	0.82
Moisture: Initial,%		0.4	0.2	0.1	0.1	0.1	0.1	0.	0.2	0.2
Final,%		0.4	0.6	0.6	0.2	0.6	0.6	0.5	0.6	0.6
Specific Gravity		2.771	2.802	2.771						

			SP,F	Vis,P,140F
Asphalt A	F/A	0.2		
		0.4		
Asphalt B	F/A	0.2		
		0.4		

Air Perm:	Surface Area,m2/g	1.21
	Avg Size,microns	1.8
	Density,g/cm3	1.47
Mixing:	Ball Point,g	33
	Crumble Point,g	42

* - Sample used in limited testing

Plant no. 20

Sample	S	1	2-A	2-B	2-C*	2-D	2-E	3	4	5
Mix Type	WEAR3	WEAR1	WEAR2	WEAR2	WEAR3	WEAR3	WEAR3	WEAR3	WEAR4	WEAR5
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
200	92.	91.	93.	95.	92.	95.	94.	92.	94.	93.
Microns 50	98.	98.	98.	99.	99.	99.	99.	98.	98.	99.
30	90.	92.	92.	92.	92.	93.	91.	92.	91.	92.
20	79.	81.	81.	80.	80.	82.	81.	81.	81.	79.
10	56.	57.	57.	56.	56.	59.	57.	57.	54.	52.
5	31.	30.	31.	28.	29.	31.	30.	30.	27.	27.
3	18.	16.	17.	14.	14.	17.	16.	17.	14.	13.
1	6.	3.	4.	4.	3.	6.		5.	4.	3.
0.8	5.		3.			5.			3.	
0.6	3.		2.			4.				
Plasticity: PL,%		31.	36.	36.	36.	32.	31.	34.	37.	39.
LL,%		32.	36.	36.	36.	32.	33.	34.	37.	40.
PI,%		1.	1.	0.	0.	1.	2.	0.	0.	1.
pH		7.5	7.2	7.9	8.7	9.5	9.4	8.5	8.2	9.2
Density: Dry-Vib,g/cm3		0.94	0.9	0.92	1.05	0.97	1.08	1.06	0.99	0.97
Polar,g/cm3		0.91	0.86	0.84	0.88	0.91	0.93	0.84	0.91	0.88
Non-Polar,g/cm3		0.70	0.69	0.64	0.69	0.72	0.75	0.61	0.72	0.68
Moisture: Initial,%		0.2	0.6	0.5	0.5	0.3	0.5	0.3	0.4	0.5
Final,%		0.2	0.4	0.8	0.8	0.7	1.	1.	0.8	0.6
Specific Gravity						2.859				

			SP,F	Vis,P,140F
Asphalt A	F/A	0.2	126.0	5806.0
		0.4	143.0	25140.0
Asphalt B	F/A	0.2	127.0	4798.0
		0.4	143.0	21330.0

Air Perm:	Surface Area,m2/g	1.20
	Avg Size,microns	1.8
	Density,g/cm3	1.43
Mixing:	Ball Point,g	32
	Crumble Point,g	42

* - Sample used in limited testing

Plant no. 22

Sample	S	1	2	3	4-A	4-B	4-C*	4-D	4-E	5
Mix Type	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1	WEAR1
% Passing:										
No. 30	99.	99.	100.	99.	99.	99.	99.	99.	99.	99.
50	94.	94.	95.	96.	95.	93.	95.	92.	93.	94.
200	46.	47.	57.	57.	55.	47.	54.	47.	46.	45.
Microns 50	95.	95.	97.	94.	96.	95.	93.	94.	95.	92.
30	74.	73.	79.	73.	76.	75.	73.	72.	77.	68.
20	55.	52.	60.	54.	56.	55.	55.	53.	58.	50.
10	28.	27.	32.	28.	30.	28.	29.	28.	31.	26.
5	12.	10.	15.	12.	13.	11.	12.	12.	13.	10.
3	6.	4.	7.	6.	6.	6.	6.	6.	7.	6.
1	0.	0.			2.				2.	
0.8	0	0			1.				1.	
0.6	0	0			1.				1.	
Plasticity: PL,%										
LL,%										
PI,%	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
pH		8.7	8.6	8.2	8.6	9.	8.6	8.4	8.8	8.8
Density: Dry-Vib,g/cm3		1.56	1.5	1.49	1.5	1.59	1.51	1.56	1.54	1.58
Polar,g/cm3		1.22	1.16	1.21	1.19	1.25	1.17	1.27	1.22	1.25
Non-Polar,g/cm3		1.19	1.15	1.17	1.15	1.19	1.18	1.17	1.16	1.23
Moisture: Initial,%		0.2	1.	0.3	0.4	0.4	0.2	0.3	0.3	0.2
Final,%		0.5	0.3	0.4	0.4	0.4	0.3	0.2	0.4	0.3
Specific Gravity		2.661				2.662			2.657	

		SP,F	Vis,P,140F		
Asphalt A	F/A 0.2			Air Perm: Surface Area,m2/g	0.32
	0.4			Avg Size,microns	7.1
Asphalt B	F/A 0.2			Density,g/cm3	1.60
	0.4			Mixing: Ball Point,g	43
				Crumble Point,g	59

* - Sample used in limited testing

Plant no. 23

Sample	P1-A	P1-B	P1-C	P1-D	P1-E	S	2	3	4	5
Mix Type	--	--	--	--	--	--	1	--	--	--
% Passing:										
No. 30	91.	93.	92.	92.	92.	99.	100.	98.	100.	100.
50	76.	75.	78.	87.	87.	98.	100.	97.	99.	99.
200	16.	12.	17.	29.	30.	86.	97.	84.	89.	88.
Microns 50	92.	82.	86.	93.	93.	98.	98.	99.	99.	98.
30	70.	38.	49.	71.	67.	90.	92.	92.	91.	90.
20	50.	20.	27.	51.	41.	79.	83.	81.	80.	78.
10	30.	9.	12.	29.	25.	55.	61.	58.	55.	52.
5	18.	3.	4.	16.	12.	32.	36.	34.	32.	29.
3	13.	2.	3.	11.	10.	20.	24.	20.	19.	20.
1	8.	0	2.	6.	5.	9.	11.	7.	8.	10.
0.8	7.	0	2.	5.	4.	8.	8.	6.	7.	9.
0.6	5.	0	2.	4.	4.	6.	7.	5.	5.	7.
Plasticity: PL,%							26.	26.	27.	28.
LL,%							28.	28.	28.	28.
PI,%	NP	NP	NP	NP	NP	NP	2.	2.	1.	1.
pH	8.9	8.7	8.8	9.0	8.9		8.7	9.	8.8	8.9
Density: Dry-Vib,g/cm3	1.75	1.67	1.75	1.73	1.74		1.05	1.2	1.15	1.18
Polar,g/cm3	1.52	1.43	1.47	1.42	1.41		1.12	1.	1.	1.12
Non-Polar,g/cm3	1.47	1.43	1.43	1.4	1.39		0.80	0.91	0.81	0.84
Moisture: Initial,%	0.3	0.3	0.2	0.3	0.4		0.7	0.5	0.4	0.6
Final,%	0.3	0.3	0.3	0.3	0.4		0.8	0.6	0.7	0.8
Specific Gravity				2.669				2.767		

		SP,F	Vis,P,140F		
Asphalt A	F/A 0.2			Air Perm: Surface Area,m2/g	
	0.4			Avg Size,microns	
Asphalt B	F/A 0.2			Density,g/cm3	
	0.4			Mixing: Ball Point,g	
				Crumble Point,g	

* - Sample used in limited testing

Plant no. 23T

Sample	1-A	1-B	1-C*	1-D	1-E	F1=A	F1-B	F1-C	F1-D	F1-E
Mix Type	1	--	--	--	--	--	--	--	--	--
% Passing:										
No. 30	99.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	98.	98.	99.	99.	99.	99.	99.	99.	99.	99.
200	89.	85.	87.	91.	92.	92.	91.	92.	91.	92.
Microns 50	98.	96.	97.	98.	99.	98.	99.	98.	98.	99.
30	90.	86.	88.	91.	92.	92.	92.	92.	92.	92.
20	79.	74.	75.	79.	80.	81.	80.	80.	81.	80.
10	54.	48.	50.	55.	55.	56.	57.	57.	57.	55.
5	31.	27.	29.	31.	32.	33.	33.	32.	33.	31.
3	20.	16.	18.	20.	22.	22.	22.	22.	22.	20.
1	8.	8.	8.	10.	11.	10.	12.	10.	10.	10.
0.8	6.	6.	7.	8.	9.	9.	9.	9.	8.	8.
0.6	5.	5.	6.	7.	8.	8.	8.	8.	7.	6.
Plasticity: PL,%	28.	26.	26.	26.	25.					
LL,%	29.	28.	29.	29.	29.					
PI,%	2.	2.	3.	3.	3.					
pH	8.3	8.4	8.5	8.6	8.6					
Density: Dry-Vib,g/cm3	1.1	1.2	1.18	1.12	1.1					
Polar,g/cm3	0.96	1.02	0.97	0.92	0.89					
Non-Polar,g/cm3	0.77	0.84	0.81	0.73	0.71					
Moisture: Initial,%	0.6	0.5	0.5	0.5	0.7					
Final,%	0.9	0.7	0.7	0.8	0.8					
Specific Gravity				2.828						

		SP,F	Vis,P,140F
Asphalt A	F/A 0.2		
	0.4		
Asphalt B	F/A 0.2		
	0.4		

Air Perm:	Surface Area,m2/g	0.86
	Avg Size,microns	2.5
	Density,g/cm3	
Mixing:	Ball Point,g	40
	Crumble Point,g	49

* - Sample used in limited testing

Plant no. 24

Sample	P4-A	P4-B	P4-C	4-D	4-E	4-A	4-B	4-C*	P4-D	P4-E
Mix Type	1	1	1	1	1	1	1	1	1	1
% Passing:										
No. 30	87.	93.	92.	100.	100.	100.	100.	100.	89.	90.
50	76.	76.	78.	100.	100.	100.	100.	100.	73.	72.
200	18.	17.	24.	99.	99.	99.	99.	99.	18.	18.
Microns 50	88.	89.	88.	98.	98.	99.	99.	98.	90.	90.
30	40.	40.	45.	94.	93.	95.	97.	94.	46.	46.
20	15.	14.	18.	82.	81.	87.	86.	83.	21.	20.
10	4.	6.	6.	54.	51.	55.	56.	51.	11.	11.
5	2.	2.	2.	30.	26.	31.	30.	27.	4.	5.
3	1.	1.	2.	18.	15.	19.	18.	15.	3.	3.
1	0	0	2.	7.	6.	6.	8.	6.	2.	2.
0.8	0	0	2.	6.	5.	4.	6.	5.	2.	2.
0.6	0	0	2.	5.	5.	3.	5.	3.	1.	2.
Plasticity: PL,%				33.	35.	33.	33.	34.		
LL,%				35.	35.	35.	34.	36.		
PI,%	NP	NP	NP	2.	0.	2.	1.	2.	NP	NP
pH	8.6	8.8	9.	8.7	9.8	8.4	9.3	9.7	8.6	9.3
Density: Dry-Vib,g/cm3	1.76	1.74	1.76	0.81	0.86	0.81	0.85	0.85	1.72	1.73
Polar,g/cm3	1.53	1.54	1.52	0.81	0.83	0.81	0.85	0.81	1.47	1.48
Non-Polar,g/cm3	1.45	1.43	1.41	0.72	0.74	0.72	0.73	0.7	1.43	1.48
Moisture: Initial,%	0.2	0.3	2.	1.1	1.2	1.1	0.9	0.9	0.4	0.4
Final,%	0.3	0.4	0.5	1.	1.	0.9	0.6	0.8	0.2	0.4
Specific Gravity			2.716				2.667		2.716	

		SP,F	Vis,P,140F
Asphalt A	F/A 0.2	128.0	6252.0
	0.4	148.5	38860.0
Asphalt B	F/A 0.2	128.5	5206.0
	0.4	149.0	32740.0

Air Perm:	Surface Area,m2/g	1.14
	Avg Size,microns	2.0
	Density,g/cm3	
Mixing:	Ball Point,g	35
	Crumble Point,g	39

* - Sample used in limited testing

Plant no. 25

Sample	S	1-A	1-B	1-C	1-D	1-E	2	3*	4	5
Mix Type	BASE1	BASE1	BASE1	BASE1	BASE1	BASE1	BASE1	WEAR1	BASE1	BASE1
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	100.	100.	100.	99.	100.	100.	100.	100.	100.	100.
200	100.	100.	100.	96.	98.	100.	100.	100.	99.	99.
Microns 50	100.	99.	100.	99.	99.	100.	100.	100.	100.	100.
30	98.	97.	96.	95.	96.	98.	97.	97.	96.	96.
20	88.	87.	86.	82.	83.	92.	88.	88.	84.	86.
10	49.	49.	47.	40.	39.	61.	49.	51.	44.	45.
5	19.	20.	18.	13.	14.	27.	19.	21.	17.	11.
3	10.	11.	8.	5.	6.	13.	9.	9.	10.	8.
1	3.	4.	3.	0.	2.	5.	4.	3.	6.	4.
0.8	2.	3.	2.		2.	3.	2.	2.	5.	3.
0.6	2.	2.	2.		1.	2.	2.	1.	4.	1.
Plasticity: PL,%		31.	32.	30.	34.	32.	33.	32.	33.	34.
LL,%		34.	33.	33.	35.	35.	33.	33.	35.	35.
PI,%		3.	1.	3.	1.	2.	1.	1.	2.	1.
pH		9.	9.	9.8	9.8	9.7	9.9	10.	9.1	10.
Density: Dry-Vib,g/cm3		1.04	1.06	1.09	1.13	0.99	1.08	1.05	1.12	1.16
Polar,g/cm3		1.01	1.14	1.17	1.14	1.01	1.01	0.86	1.02	1.02
Non-Polar,g/cm3		0.86	0.98	1.	0.97	0.87	0.84	0.78	0.87	0.89
Moisture: Initial,%		1.	0.6	0.6	0.9	0.6	0.7	0.5	0.5	0.4
Final,%		1.2	0.9	1.	0.9	0.7	0.9	1.	1.1	1.1
Specific Gravity		2.816						2.735	2.816	

		SP,F	Vis,P,140F
Asphalt A	F/A 0.2		
	0.4		
Asphalt B	F/A 0.2		
	0.4		

Air Perm:	Surface Area,m2/g	0.74
	Avg Size,microns	3.0
	Density,g/cm3	1.42
Mixing:	Ball Point,g	35
	Crumble Point,g	42

* - Sample used in limited testing

Plant no. 26

Sample	S	1	2*	3-A	3-B	3-C	3-D	3-E	4	5
Mix Type	BASE2	BASE1	WEAR1	WEAR2	WEAR3	WEAR3	WEAR4	WEAR5	WEAR6	BASE3
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
200	100.	100.	99.	99.	100.	100.	100.	100.	100.	100.
Microns 50	100.	100.	100.	100.	100.	99.	100.	100.	100.	100.
30	99.	98.	100.	99.	99.	99.	98.	99.	99.	99.
20	96.	96.	97.	94.	96.	95.	96.	95.	96.	95.
10	77.	80.	78.	76.	78.	78.	79.	79.	78.	78.
5	46.	50.	48.	46.	49.	49.	54.	53.	50.	49.
3	29.	32.	28.	31.	31.	32.	36.	35.	36.	32.
1	9.	11.	8.	11.	11.	12.	16.	14.	17.	12.
0.8	6.	9.	6.	9.	9.	9.	13.	10.	14.	9.
0.6	4.	5.	4.	7.	6.	6.	9.	7.	11.	7.
Plasticity: PL,%		36.	37.	36.	38.	37.	36.	37.	37.	38.
LL,%		38.	41.	37.	40.	39.	37.	39.	39.	40.
PI,%		3.	3.	1.	2.	2.	1.	2.	2.	2.
pH		7.7	7.1	7.1	6.8	7.1	6.9	7.	7.4	7.5
Density: Dry-Vib,g/cm3		0.68	0.67	0.65	0.79	0.67	0.67	0.66	0.65	0.67
Polar,g/cm3		0.73	0.66	0.72	0.69	0.74	0.70	0.67	0.68	0.68
Non-Polar,g/cm3		0.65	0.61	0.6	0.57	0.6	0.54	0.54	0.58	0.6
Moisture: Initial,%		0.2	0.3	1.2	0.6	0.9	1.	0.8	0.9	0.8
Final,%		1.4	2.	1.8	2.	1.7	2.	2.	1.8	1.8
Specific Gravity	2.678	2.687	2.687				2.678		2.687	2.687

		SP,F	Vis,P,140F
Asphalt A	F/A 0.2	131.0	8402.0
	0.4	171.0	165800.0
Asphalt B	F/A 0.2	131.0	6451.0
	0.4	175.0	201400.0

Air Perm:	Surface Area,m2/g	1.94
	Avg Size,microns	1.2
	Density,g/cm3	1.22
Mixing:	Ball Point,g	26
	Crumble Point,g	33

* - Sample used in limited testing

Plant no. 28

Sample	S	1	2-A	2-B	2-C*	2-D	2-E	3	4	5
Mix Type	WEAR1	WEAR1	WEAR2	WEAR2	WEAR2	WEAR2	WEAR2	WEAR3	WEAR3	WEAR3
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
200	94.	93.	93.	95.	94.	89.	91.	97.	95.	96.
Microns 50	99.	98.	98.	98.	99.	98.	98.	99.	99.	99.
30	88.	88.	89.	90.	90.	89.	89.	93.	91.	91.
20	72.	73.	77.	78.	76.	74.	75.	82.	79.	78.
10	45.	47.	51.	50.	47.	46.	46.	56.	51.	50.
5	25.	27.	28.	29.	26.	26.	25.	33.	28.	28.
3	18.	19.	20.	20.	19.	19.	17.	24.	20.	19.
1	11.	10.	11.	11.	10.	11.	11.	13.	11.	11.
0.8	9.	9.	10.	9.	9.	10.	10.	12.	10.	10.
0.6	8.	8.	9.	8.	8.	9.	9.	11.	9.	9.
Plasticity: PL,%		30.	32.	30.	30.	32.	32.	32.	30.	29.
LL,%		31.	31.	32.	31.	32.	32.	32.	31.	31.
PI,%		1.	0.	1.	1.	0.	0.	0.	1.	2.
pH		7.9	7.8	8.	7.9	7.9	8.2	8.3	8.1	8.2
Density: Dry-Vib,g/cm3		0.91	0.88	0.88	0.93	0.98	1.	0.89	0.96	0.92
Polar,g/cm3		0.91	0.86	0.84	0.88	0.91	0.93	0.84	0.91	0.88
Non-Polar,g/cm3		0.7	0.69	0.64	0.69	0.72	0.75	0.61	0.72	0.68
Moisture: Initial,%		0.8	0.9	0.5	0.5	0.6	0.6	0.4	0.9	0.5
Final,%		1.3	1.3	1.2	1.3	1.1	1.1	1.2	1.4	1.1
Specific Gravity		2.660			2.730					2.677

		SP,F	Vis,P,140F			
Asphalt A	F/A 0.2			Air Perm:	Surface Area,m2/g	1.20
	0.4				Avg Size,microns	1.8
Asphalt B	F/A 0.2				Density,g/cm3	1.41
	0.4			Mixing:	Ball Point,g	33
					Crumble Point,g	41

* - Sample used in limited testing

Plant no. 29

Sample	1-A	1-B	1-C*	1-D	1-E	2	3	4	5
Mix Type									
% Passing:									
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.
50									
200	93.	97.	93.	92.	92.	80.	88.	95.	89.
Microns 50	98.	99.	98.	98.	99.	93.	96.	100.	97.
30	90.	96.	90.	89.	94.	79.	88.	94.	88.
20	78.	88.	81.	76.	83.	66.	75.	84.	76.
10	50.	57.	54.	45.	53.	39.	44.	58.	49.
5	26.	30.	30.	23.	27.	19.	20.	31.	26.
3	15.	19.	19.	13.	18.	13.	11.	29.	17.
1	6.	9.	8.	4.	11.	6.	5.	8.	8.
0.8	5.	8.	7.	4.	10.	5.	3.	7.	7.
0.6	5.	6.	6.	4.	9.	4.	2.	5.	6.
Plasticity: PL,%	27.	28.	29.	28.	30.	27.	28.	29.	26.
LL,%	29.	31.	30.	31.	31.	28.	30.	31.	28.
PI,%	2.	3.	2.	2.	2.	1.	2.	3.	2.
pH	7.2	7.3	7.4	7.3	7.3	7.8	7.8	7.7	7.7
Density: Dry-Vib,g/cm3	1.00	0.90	0.92	1.03	0.95	1.10	1.10	0.91	0.96
Polar,g/cm3	0.88	0.82	0.84	0.98	0.88	0.96	0.95	0.81	0.88
Non-Polar,g/cm3	0.75	0.63	0.64	0.88	0.58	0.78	0.77	0.62	0.67
Moisture: Initial,%	0.2	0.3	0.4	0.4	0.7	0.6	0.5	0.4	0.6
Final,%	1.1	1.2	1.4	1.2	1.4	1.1	1.2	1.2	1.3
Specific Gravity			2.773						

		SP,F	Vis,P,140F			
Asphalt A	F/A 0.2			Air Perm:	Surface Area,m2/g	1.71
	0.4				Avg Size,microns	1.3
Asphalt B	F/A 0.2				Density,g/cm3	1.35
	0.4			Mixing:	Ball Point,g	
					Crumble Point,g	

* - Sample used in limited testing

Plant no. 31

Sample	S	2*	5
Mix Type	WEAR1	WEAR 1	WEAR1
% Passing:			
No. 30	99.	98.	97.
50	98.	90.	89.
200	70.	57.	45.
Microns 50	96.	95.	83.
30	81.	79.	59.
20	67.	65.	47.
10	48.	58.	33.
5	29.	30.	18.
3	17.	20.	10.
1	4.	6.	3.
0.8	3.	5.	2.
0.6	2.	4.	2.
Plasticity: PL,%			
LL,%			
PI,%	NP	NP	NP
pH		7.5	7.5
Density: Dry-Vib,g/cm3		1.14	1.36
Polar,g/cm3		1.20	1.17
Non-Polar,g/cm3		1.22	1.21
Moisture: Initial,%		0.6	0.8
Final,%		0.8	0.8
Specific Gravity		2.680	

		SP,F	Vis,P,140F
Asphalt A	F/A 0.2		
	0.4		
Asphalt B	F/A 0.2		
	0.4		

Air Perm:	Surface Area,m2/g	0.56
	Avg Size,microns	4.0
	Density,g/cm3	1.62
Mixing:	Ball Point,g	40
	Crumble Point,g	60

* - Sample used in limited testing

Plant no. 30

Sample	S	1-A	1-B	1-C*	1-D	1-E	2	3	4	5
Mix Type	W-B-C	W-B-C	W-B-C	W-B-C	W-B-C	W-B-C	W-B-C	W-B-C	W-B-C	W-B-C
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	99.	100.	99.	99.	99.	100.	99.	99.	99.	99.
200	94.	94.	95.	95.	95.	92.	94.	95.	95.	94.
Microns 50	98.	98.	97.	97.	98.	98.	98.	98.	98.	97.
30	90.	91.	87.	88.	89.	91.	88.	88.	90.	88.
20	77.	79.	73.	74.	76.	80.	73.	74.	77.	73.
10	49.	52.	45.	45.	48.	51.	46.	47.	49.	45.
5	25.	26.	23.	22.	25.	27.	22.	23.	26.	21.
3	15.	15.	12.	13.	13.	15.	12.	15.	14.	13.
1	6.	5.	4.	3.	4.	6.	6.	6.	5.	6.
0.8	5.	4.	0	0	2.	4.	5.	4.	3.	4.
0.6	3.	3.	0	0	1.	2.	4.	3.	2.	3.
Plasticity: PL,%		31.	32.	31.	30.	32.	30.	29.	30.	31.
LL,%		33.	33.	32.	31.	32.	31.	31.	32.	32.
PI,%		2.	1.	2.	1.	1.	1.	2.	2.	1.
pH		6.3	6.4	6.4	6.5	6.4	6.4	6.4	6.6	6.4
Density: Dry-Vib,g/cm3		1.13	1.16	1.18	1.18	1.24	1.3	1.18	1.2	1.2
Polar,g/cm3		1.06	1.1	1.09	1.14	1.3	1.09	1.11	1.09	1.14
Non-Polar,g/cm3		1.02	1.02	1.04	1.	0.76	1.02	1.02	0.98	1.
Moisture: Initial,%		0.5	0.6	0.6	0.7	0.6	0.8	0.6	0.3	0.8
Final,%		0.8	0.8	0.8	0.7	0.7	0.6	0.7	0.7	0.7
Specific Gravity					2.548		2.592			

		SP,F	Vis,P,140F
Asphalt A	F/A 0.2	125.0	4644.0
	0.4	132.0	9498.0
Asphalt B	F/A 0.2	124.0	3920.0
	0.4	133.5	9190.0

Air Perm:	Surface Area,m2/g	0.77
	Avg Size,microns	3.1
	Density,g/cm3	1.55
Mixing:	Ball Point,g	46
	Crumble Point,g	57

* - Sample used in limited testing

Plant no. 33

Sample	S	1	2	3	4*	5-A	5-B	5-C	5-D	5-E
Mix Type	BASE3	BASE1	BASE2	BASE3	WEAR1	BASE3	BASE3	BASE3	BASE3	BASE3
% Passing:										
No. 30	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.
50	99.	99.	100.	99.	99.	99.	99.	99.	100.	99.
200	63.	62.	77.	63.	86.	73.	67.	82.	87.	65.
Microns 50	93.	93.	95.	94.	96.	94.	94.	95.	97.	93.
30	76.	70.	78.	76.	85.	77.	75.	80.	84.	73.
20	63.	54.	64.	64.	73.	65.	63.	67.	72.	60.
10	46.	38.	44.	48.	56.	48.	48.	50.	55.	44.
5	32.	24.	28.	35.	41.	35.	35.	38.	40.	30.
3	23.	18.	21.	26.	31.	26.	27.	29.	31.	23.
1	7.	8.	8.	8.	12.	10.	11.	11.	13.	9.
0.8	4.	7.	6.	7.	10.	7.	9.	9.	11.	7.
0.6	3.	5.	4.	5.	8.	6.	6.	7.	8.	5.
Plasticity: PL,%					29.			26.	30.	
LL,%					33.			30.	33.	
PI,%	NP	NP	NP	NP	4.	NP	NP	4.	3.	NP
pH		8.8	8.4	7.3	7.5	7.3	7.3	7.3	7.4	7.5
Density: Dry-Vib,g/cm3		1.55	1.4	1.41	1.15	1.29	1.35	1.23	1.15	1.4
Polar,g/cm3		1.23	1.26	1.25	1.2	1.44	1.28	1.19	1.15	1.27
Non-Polar,g/cm3		1.25	1.09	1.16	0.96	1.08	1.11	1.	0.95	1.12
Moisture: Initial,%		0.4	0.6	0.4	0.5	0.6	0.4	0.6	0.6	0.5
Final,%		1.4	1.6	1.4	1.6	1.5	1.5	1.5	1.6	1.3
Specific Gravity								2.633		

		SP,F	Vis,P,140F
Asphalt A F/A	0.2	125.0	5043.0
	0.4	133.5	12630.0
Asphalt B F/A	0.2	125.5	4242.0
	0.4	134.0	10450.0

Air Perm:	Surface Area,m2/g	1.29
	Avg Size,microns	1.8
	Density,g/cm3	1.62
Mixing:	Ball Point,g	39
	Crumble Point,g	55

* - Sample used in limited testing

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