

Incinerator Residue as Aggregate for Hot-Mix Asphalt Base Course

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A laboratory and field evaluation of the use of municipal incinerator residue as aggregate in bituminous pavement construction is reported. A test installation that consisted of a 114.3-mm (4.5-in) thick bituminous pavement composed largely of incinerator residue was placed in Washington, D.C. The base was placed in two lifts, finished over compacted subgrade, and covered with 38.1 mm (1.5 in) of a conventional bituminous surface-course mixture. Details of the production of the residue, laboratory evaluation, asphalt plant operation, and placement and finishing of the test installation as well as recommendations and precautions for future projects in which incinerator residue is used are given. Preliminary results indicate that, with proper precautions, incinerator residue can be used as an aggregate substitute or extender in the construction of bituminous base. Its use, however, will be determined by the interplay of economic, environmental, and energy factors.

This paper describes the production and placement in Washington, D.C., of approximately 363 Mg (400 tons) of bituminous-treated street base in which municipal incinerator residue was used as the major aggregate component. This is the fourth experimental section to use incinerator residue as a component of a bituminous road pavement. Previous projects have been constructed and evaluated at locations near Houston, Texas, and Philadelphia and Harrisburg, Pennsylvania.

INCINERATOR RESIDUE

The approximately 140 municipal incinerators in operation in the United States produce approximately 4.54 million Mg (5 million tons) of residue annually. Incineration of municipal solid waste (household trash and garbage) reduces the volume of waste by about 90 percent and the weight by about 70 percent. This remaining unburned residue presents a severe disposal problem. For instance, the District of Columbia is faced with disposing of a residue stockpile of approximately 272 160 Mg (300 000 tons) that is accumulating at the rate of about 181 440 Mg/year (200 000 tons/year). This annual accumulation amounts to approximately 0.4 hm² (1 acre) of ground covered by about 24 m (80 ft) of residue. There are several potential uses for this material: for embankments (fill) and for structural layers in pavements in combination with binders such as asphalt. This paper deals with the use of residue with paving-grade asphalt cement as a binder.

Residues consist of materials that were not burned during incineration and may sometimes include fly ash that is recovered from stack effluents. Unburned materials consist of metals, ceramics and stone, and organic matter. The amount of unburned organic material is the result of incinerator operation and management as well as the variability of incoming waste and changing weather conditions, which may not permit adequate, off-setting adjustments of the incinerator operation to ensure complete combustion.

The approximate composition of a typical residue is (in percentages by weight) 50 percent glass, 30 percent metals, 15 percent ash, and 5 percent stone, porcelain, organics, etc. The residue is generally odorless, chemically inert, nonpolluting, and essentially structurally sound according to most standard criteria for natural aggregates used in bituminous-base construction.

The metallic components of incinerator residue are made up, as one should expect, of a rather large variety of objects—e.g., wire, cans, metal pipe, and shock absorbers. Some operations recover these objects for sale to scrap outlets. Removal is done by a trommel, which is a rotating slotted drum. Gradation of the trommeled residue complies with many specifications for bituminous bases; in cases in which the material does not comply, blending with small amounts of natural aggregate will usually produce a specification aggregate.

In summary, the use of incinerator residue in pavements should be considered as a means of disposing of the increasing accumulation of residues as well as the possible augmentation of aggregate supplies in some areas where inventories of quality and economical aggregates are low.

PROJECT LOCATION AND STRUCTURAL DETAILS

The site of the experimental section is the full width of 14th Street, S.E., from W Street to Cedar Street, in the Anacostia area of Washington, D.C. The location is a residential area that has medium residential traffic and on-street parking. The street is approximately 122 m (400 ft) in length and 9.1 m (30 ft) wide. The reconstructed section includes curb and gutter on both sides.

The subgrade soils were not tested and classified, but they were reported to be wet clay, probably classification A-6, with poor drainage. The structural section consisted of 152.4 mm (6 in) of bank run gravel subbase on the prepared subgrade. The 114.3 mm (4.5 in) of incinerator-residue asphalt base will be surfaced with 38.1 mm (1.5 in) of District of Columbia class C surface mix.

PRODUCTION OF RESIDUE FOR THE PROJECT

Residue was produced at District of Columbia Solid Waste Reduction Center No. 1. Fly-ash stack effluent is combined with the residue at this plant, and the residue is trucked to the District's Blue Plains facility and stockpiled for further processing and disposal.

The material was then trommeled to recover metals. Most, but not all, metallic objects larger than about 50.8 mm (2 in) were removed from the residue.

For this project, the material that remained after trommeling was transported to yet another location at Blue Plains for final processing and stockpiling to await later transportation to the asphalt hot-mix plant. Final processing consisted of mixing the residue with a front-end loader and dumping it onto a bar grizzly to remove particles and objects larger than approximately 25.4 mm (1 in). Finished material was graded uniformly and ready for incorporation into the final mixture. Samples were taken from this stockpile for testing at the Federal Highway Administration's Fairbank Highway Research Station laboratories.

PROPERTIES AND MATERIALS OF PROJECT RESIDUE

Gradation and Blended Aggregates

The gradation of the residue, particularly the minus-0.075-mm (minus no. 200) wash fraction, would not meet the District of Columbia specification for asphalt concrete. It was thus decided to permit the blending of as much as 30 percent natural aggregate (by weight of total aggregate) with the residue to lower the fines content. The natural aggregate was a 50:50 blend of sand and stone. The sand was Charles County concrete sand from a Waldorf, Maryland, source, and the stone was Shenandoah No. 67 dolomitic limestone, from a Millville, West Virginia, source. The aggregate data are given in Tables 1 and 2.

Asphalt

Asphalt was supplied by the Chevron Asphalt Company. The material was an AC-20 grade asphalt, steam-reduced at the company's Baltimore refinery. The crude source is unknown. The material is certified to meet AASHTO M-226-73.

MIXTURE DESIGN

Tables 3 and 4 give Marshall method data for mixes A and B. Figures 1 and 2 show the design curves for both mixtures. The job-mix formula (mix B) was as follows: 68.5 percent residue, 1.5 percent hydrated lime, 15.0 percent concrete sand, 15.0 percent dolomitic limestone, and 9.0 percent AC-20 asphalt cement (by weight of total mixture). The recommended temperature ranges are (a) for mixing, 146°C-152°C (295°F-305°F) and (b) for compaction, 138°C-143°C (280°F-290°F).

In reviewing the data in Table 3 for mix B, it is recognized that the above job-mix formula at 9.0 percent asphalt is less than optimal, primarily because of the low air voids value of 1.8 percent, which is below the lower limit of the generally accepted range of 3-8 percent. More desirable levels of air voids can be noted for 8.0 and 8.5 percent asphalt; however, at these asphalt contents, complete coating of the aggregate particles could not be achieved. Coatability was considered extremely important.

In light of the absorptive nature of the residue and the poor drainage of the wet-clay subgrade, it was desired that the mixture be as impermeable as possible to mitigate any stripping problems. Therefore, despite the low air voids obtained in the laboratory, 9.0 percent asphalt was selected for the job-mix formula. Other combinations of residue and natural aggregate—for example, a higher percentage of natural aggregate—that could have provided optimal mixture properties were not investigated.

Since field compaction is generally less than laboratory compaction [the District of Columbia Department of Transportation (DOT) specifies a minimum of 94 percent of laboratory density], it is expected that the air voids in the finished pavement would be more acceptable (higher than 1.8 percent). Further, considering the relatively low traffic volume involved and that the mixture is an underlying layer and not a surfacing, no significant increase in density above that provided by the rollers should be expected.

PLANT MIXING OPERATIONS

Asphalt Construction, Inc., of Washington, D.C., provided central plant mixing at its Brentwood, Maryland,

facility, a central batch plant with a capacity of 1.81 Mg/batch (2 tons/batch). The plant was manually controlled and equipped with a bag house for air quality control. No major plant modifications were required to accommodate the incinerator residue. A small bar grizzly with openings of approximately 50.8 mm (2 in) was placed above the conveyor belt at the cold feed to remove occasional pieces of wire and stray metal. Very few pieces of metal were removed during the course of this project.

Hydrated lime was added dry to the pug mill from bag storage. To facilitate production, the lime content was slightly adjusted from 1.5 to 1.37 percent (by weight of total aggregate) to allow the use of a single 22.68-kg (50-lb) bag of lime per batch and thus eliminate weighing. The residue content was increased to compensate for the reduced lime.

After it was mixed, the material was conveyed to a heated surge silo and later trucked to the pavement location. Inert gas was not used in the silo. The maximum time of storage in the silo was approximately 7 h.

Before this experiment, two pilot runs were made at the plant. In the first run, residue from which metal had not been removed by trommeling was used. The results showed the untrommeled residue to be unacceptable because of screen blockage by some of the metal and because the mixed material contained wire and other metal objects that would prevent an acceptable finished surface.

The second pilot run used trommeled residue and provided an orientation exercise for plant personnel. This run pointed up two areas of concern that require consideration in future residue projects:

1. An unacceptable amount of dust was generated during plant operations.
2. Organic matter included in the residue burned in the dryer, which allowed a reduction in the burner fuel requirements of the plant but changed the gradation of the residue from that measured in the stockpile.

This situation and recommendations for corrections are considered more fully later in this paper.

Another problem that was encountered at the Brentwood plant was that the residue had a tendency to "hang up" and clog gates in the cold bins. The hot bins appeared to function normally, probably because the sand reduced the internal friction of the residue. This problem can be eliminated by using bin vibrators or by manually hammering on the bin when necessary. This aspect required considerable attention because the residue had a relatively high asphalt requirement and reduction of the residue will produce batches that are highly over-asphalted. Several batches in the project were over-asphalted and produced mixes that would ordinarily be considered unacceptable.

One characteristic of residue mixtures that should be kept in mind is that they are very sensitive to asphalt content. Anything that changes the proportions of binder to fines will produce mixtures that are overasphalted, with consequent loss in stability, or mixtures that are harsh and difficult to place and finish. If residue clogs the gates of the cold-feed bins and sand is not proportionately reduced, fines will be reduced and, if asphalt content remains constant, an overasphalted mixture will be produced.

PLACEMENT AND FINISHING

The base was placed by the Troxler Asphalt Company of Washington, D.C., on June 14, 1977. Haul time from the hot-mix plant to the job site was approximately half an

hour. Use of a Blaw-Knox paver was followed by use of a steel-wheeled breakdown roller that also provided intermediate compaction. Finish rolling was done by a three-axle tandem roller according to District of Columbia specifications. The 114.3-mm (4.5-in) base

was placed in two lifts. The project was held up for several days because of rain, and the subgrade was partially saturated when the residue base was placed.

Mixture appearance and workability were noticeably affected by temperature. At temperatures above approx-

Table 1. Gradation of aggregate.

Sieve Size (mm)	Percentage Passing					Mix		D.C. Specification
	D.C. Residue	Sand	Stone	Hydrated Lime	A ^a	B ^b		
25.0	100		100		100	100	100	
19.0	98		91		98	97	90-100	
12.5	91		50		91	86	71-91	
9.5	80	100	26		80	75	60-85	
4.75	53	98	3		54	53	45-65	
2.36	39	90	2		40	42	33-52	
1.18	30	79	0		31	34	22-40	
0.60	24	53			25	26	14-30	
0.30	19	12			20	16	6-21	
0.15	15	5			16	12	3-31	
0.075	11.7	0		100	13.0	9.5	2-8	

Note: 1 mm = 0.039 in.

Gradation according to AASHTO T-27, washed analysis.

^aContains 98.5 percent residue and 1.5 percent lime (calculated).

^bContains 68.5 percent residue, 15 percent sand, 15 percent stone, and 1.5 percent lime (calculated).

Table 2. Specific gravity and absorption of aggregate.

Item	D.C. Residue	Sand	Stone	Hydrated Lime	Mix		D.C. Specification
					A ^a	B ^b	
Bulk specific gravity ^c							
Dry	2.174	2.601	2.821	-	2.176	2.313	-
Saturated surface dry	2.318	2.621	2.833	-	2.318	2.427	-
Apparent specific gravity	2.541	2.654	2.856	2.343	2.538	2.597	-
Absorption ^d (%)	6.9	0.8	0.4	-	6.8	4.9	-
Calculated surface area ^e (m ² /kg)	8.9	-	-	-	9.6	7.9	-

Note: 1 m²/kg = 4.88 ft²/lb.

^aContains 98.5 percent residue and 1.5 percent lime (calculated).

^bContains 68.5 percent residue, 15 percent sand, 15 percent stone, and 1.5 percent lime (calculated).

^cAASHTO T-84.

^dAASHTO T-85.

^eAsphalt Institute, Manual Series 2.

Table 3. Marshall mix design data for mix A.

Property or Material	Avg of Three Specimens		Single-Specimen Determination			Criterion
	8.5 and 9.3% Asphalt ^a	9.5 and 10.5% Asphalt ^a	10.0 and 11.1% Asphalt ^a	12.0 and 13.6% Asphalt ^a	14.0 and 16.3% Asphalt ^a	
Appearance of mix	Dry	Dry	Dry	Good	Rich	
Specific gravity						
Bulk	2.018	2.057	2.065	2.076	2.050	
Maximum ^b	2.209	2.182	2.169	2.117	2.067	
Air voids (%)	8.6	5.7	4.8	1.9	0.8	3-8 ^c
Voids in mineral aggregate (%)	15.1	14.4	14.6	16.0	19.0	Min, 14 ^a
Voids filled with asphalt (%)	43.0	60.4	67.1	88.1	95.8	65-75 ^d
Unit weight (kg/m ³)	203	207.1	207.9	208.8	206.3	-
Absorbed asphalt (%)	5.7	5.7	5.7	5.7	5.7	-
Effective asphalt (%)	3.3	4.3	4.9	7.0	9.1	-
Film thickness (μm)	3.4	4.4	5.1	7.2	9.4	Min, 6.0 ^e
Dust/asphalt ratio	1.40	1.24	1.17	0.95	0.80	Max, 1.2 ^f
Stability at 60°C (kN)	13.1	13.16	-	7.65	4.59	Min, 2.22 ^{g,h}
Flow (mm)	4	4	-	5.6	7.2	2-4.6 ^{g,h}
Effect of water on stability ⁱ (24 h at 60°C)						
Stability (kN)	-	10.51	9.72	-	-	Min, 2.22 ^g
Flow	-	5	5	-	-	2-4.6 ^g
Retained stability (%)	-	79.8	-	-	-	Min, 7.0 ⁱ

Notes: 1 kg/m³ = 0.062 lb/ft³; 1 μm = 0.000 04 in; t°C = (t°F - 32)/1.8; 1 kN = 224.8 lb; 1 mm = 0.039 in.

Mix containing 98.5 percent residue and 1.5 percent hydrated lime; compacted according to AASHTO T-245, 50 blows each side; mixed at 146°C-152°C and compacted at 138°C-143°C.

^aAsphalt percentages for mix basis and aggregate basis, respectively.

^bBased on an effective aggregate specific gravity of 2.471 measured by AASHTO T-209, bowl determination.

^cAsphalt Institute, Manual Series 2, March 1974 [range of 3-11 percent voids is specified by AASHTO (1)].

^dAASHTO (1).

^eCampan and others (2).

^fGoode (3) for AASHTO T-165 test.

^gNot required by AASHTO T-245 but considered desirable.

Table 4. Marshall mix design data for mix B (average of three specimens).

Property or Material	8.0 and 8.7% Asphalt ^a	8.5 and 9.3% Asphalt ^a	9.0 and 9.9% Asphalt ^a	9.5 and 10.5% Asphalt ^a	10.0 and 11.1% Asphalt ^a	Criterion
Appearance of mix	Dry	Slightly dry	Good	Good	Rich	
Specific gravity						
Bulk	2.186	2.195	2.201	2.198	2.194	
Maximum ^b	2.270	2.256	2.241	2.227	2.213	
Air voids (%)	3.7	2.7	1.8	1.3	0.9	3-8 ^c
Voids in mineral aggregate (%)	13.1	13.2	13.4	14.0	14.6	Min, 14 ^c
Voids filled with asphalt (%)	71.8	79.5	86.6	90.7	93.8	65-75 ^d
Unit weight (kg/m ³)	136.4	137.0	137.3	137.2	136.9	-
Absorbed asphalt (%)	3.9	3.9	3.9	3.9	3.9	-
Effective asphalt (%)	4.4	4.9	5.5	6.0	6.5	-
Film thickness (μm)	5.5	6.1	6.9	7.5	8.1	Min, 6.0 ^e
Dust/asphalt ratio	1.09	1.02	0.96	0.90	0.86	Max, 1.2 ^f
Stability at 60°C (kN)	12.8	11.5	11.16	9.53	8.17	Min, 2.22 ^g
Flow (mm)	3.6	3.6	4	4.36	4.67	2-4.6 ^{g,h}
Effect of water on stability ⁱ						
24 h at 60°C						
Stability at 60°C (kN)	-	9.66	9.38	-	-	Min, 2.22 ^g
Flow (mm)	-	4.36	4.36	-	-	2-4.6 ^g
Retained stability (%)	-	84.0	84.0	-	-	Min, 70 ^f
Four days at 48.9°C ^{g,h}						
Stability at 60°C (kN)	-	7.93	7.8	-	-	Min, 2.22 ^g
Flow (mm)	-	4.8	4.8	-	-	2-4.6 ^g
Retained stability (%)	-	68.9	69.9	-	-	Min, 70 ^f

Notes: 1 kg/m³ = 0.062 lb/ft³; 1 μm = 0.000 04 in; t°C = (t°F - 32)/1.8; 1 kN = 224.8 lbf; 1 mm = 0.039 in.
 Mix containing 68.5 percent residue, 1.5 percent hydrated lime, 15 percent sand, 15 percent stone; compacted according to AASHTO T-245, 50 blows for each side; mixed at 146°C-152°C and compacted at 138°C-143°C.
^aAsphalt percentages for mix basis and aggregate basis, respectively.
^bBased on effective specific gravity of 2.545 measured by AASHTO T-209, bowl determination.
^cAsphalt Institute, Manual Series 2, March 1974 [range of 3-11 percent voids is specified by AASHO (1)].
^dAASHO (1).
^eCampan and others (2).
^fGoode (3) for AASHTO T-165 test.
^gNot required by AASHTO T-245 but considered desirable.
^hAfter immersion period, specimens were conditioned for 1 h in 60°C water bath.

Figure 1. Design curves for mix A, with 98.5 percent residue.

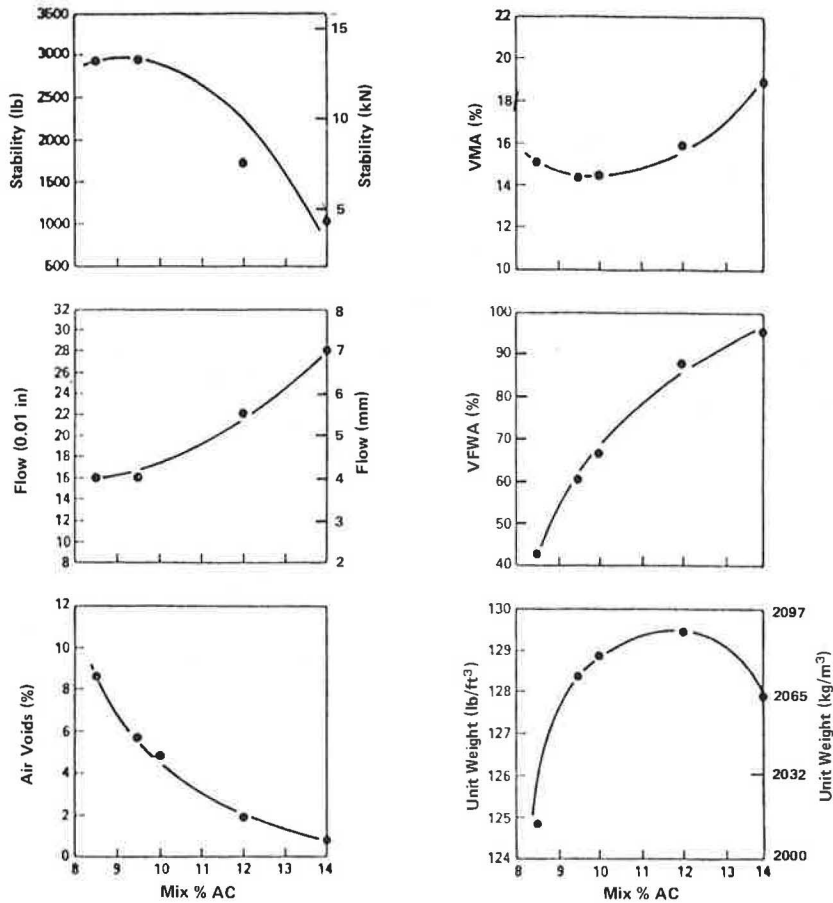
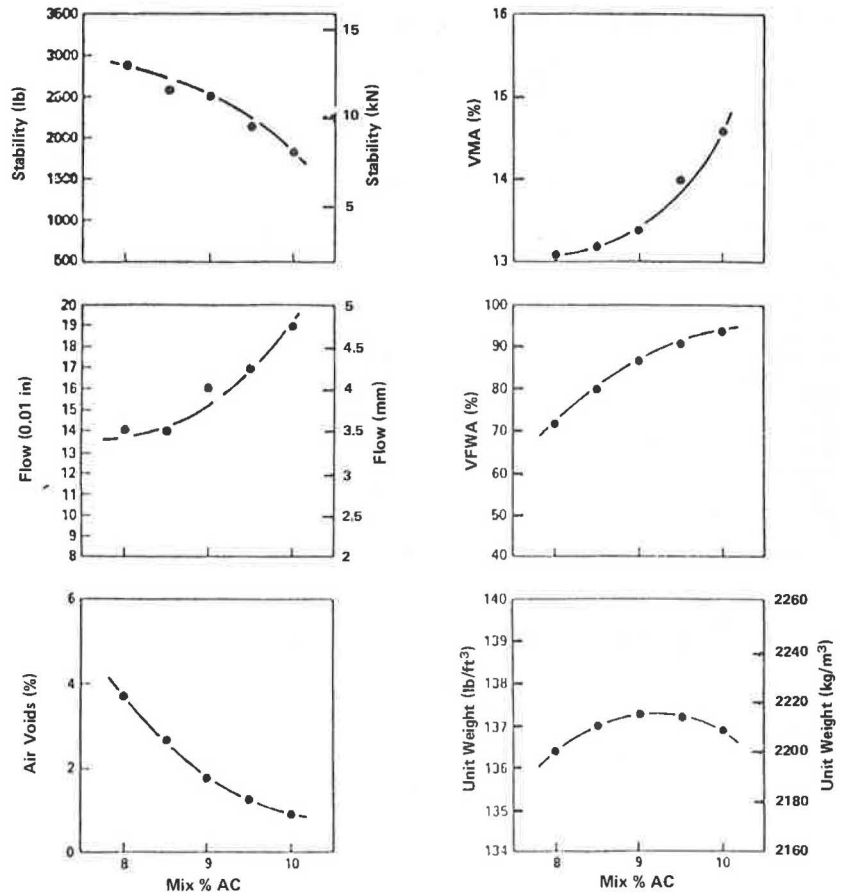


Figure 2. Design curves for mix B, with 68.5 percent residue.



imately 135°C (275°F), the mixture in truckbeds appeared "fat" (overasphalted) and very fluid and finished very easily. The finished surface at these higher temperatures was fat possibly because of the combination of high temperature and reduced fines. In any event, at elevated temperatures the roller had to be held back for at least 30 min to preclude the same sort of problems with shoving and lateral movement that are observed to occur with tender mixes. At temperatures below approximately 135°C, the mixture appeared harsh and stiff, and it required some effort to dump it from the truck to the paver hopper. In fact, one man could not move the material with a hand rake. In spite of this apparent harshness, the material finished quite well when paver speeds were slow enough to prevent tearing by the screed. Except in handworking, lower temperatures were desirable for this residue mixture.

On June 15, 1977, the day after placement, overasphalted (fat) sections were removed by scraping away approximately 6.35 mm (0.25 in) with a front-end loader over an approximate length of 30.48 m (100 ft) and a 1.83- to 2.44-m (6- to 8-ft) width.

PLANT MIX AND PAVEMENT CORE EXTRACTION

Pavement cores were taken by personnel of the District of Columbia DOT on June 23, 1977, from a section that appeared to be overasphalted as well as from a section that appeared to be normal (not overasphalted). Cores identified by a C suffix were from overasphalted sections, and those identified by a W suffix were from normal sections. Cores 2C, 3C, and 4C and 1W, 2W, and

4W were from station 5+50, and cores 5W, 7W, and 8W were from station 7+75. The analysis of extracted asphalt is based on the extract from a truck sample of the mixture.

Data indicate that, for the overasphalted section (cores 2C, 3C, and 4C), the average minus 0.075 mm (no. 200) (9.5 percent) is lower than the 13.2 and 11.9 percent shown for the normal sections (cores 1W-8W). In addition, the total of plus-0.6-mm (no. 30) natural aggregate for the overasphalted section (53.9 percent) is much higher than that for the normal sections (about 37 percent) and for the original gradation and an original laboratory Marshall design specimen (about 30 percent). Because a sufficient number of cores were not taken to permit testing for maximum specific gravity, air voids could not be computed. Cores will be taken from the same locations at a later date, and air voids will then be assessed.

Obviously, the possible occurrence of such variations in the gradation and material makeup of residue mixtures must be carefully considered, particularly when they are blended with natural aggregate, a process in which variations in proportioning can occur. Thus, variations from batch to batch in a hot-mix plant seem inevitable. Any air voids value reported on the basis of routine laboratory testing could probably be in error by at least 1 percent for conventional mixtures. This, together with the uncertainty of the composition of residue mixtures, suggests that air voids may vary, perhaps by 2-3 percent or more.

RECOMMENDATIONS FOR FUTURE PROJECTS

Two areas need additional consideration in future projects that use incinerator residue. These are residue production at the incinerator and mixing operations at the hot plant.

The properties of incinerator residue can vary considerably with time because of several conditions that have been mentioned, such as plant management, moisture content and composition of incoming solid wastes, and the method of metal recovery and later stockpiling of the residue. It is necessary to reduce this variability to reasonable limits if residue is to be used in the production of acceptable paving mixtures. The past philosophy of incinerator management has been to treat both the residue and the captured fines from the stack as a waste material that requires disposal. To realize the full potential of incinerator residue as a construction material, this concept should be changed and the residue considered not waste material but a commercial product.

One of the primary considerations is the uniformity of the product, which should be relatively easy to improve at the operational level. Of major concern is the amount of combustible matter remaining in the residue that will subsequently burn in the hot-plant drier. It is not necessary to remove this fraction, but it should be relatively constant to mitigate constant burner adjustment at the hot-mix plant. Uniformity is also necessary because burning of the material can change the gradation between the stockpile and the hot bins. Since mix design is usually based on stockpile gradations and since the characteristics of these mixtures are sensitive to fines and asphalt content, the amount of material that will be removed by burning should be predictable. In this connection, tests (such as loss on ignition) are being devised that can probably be correlated with loss through the drier.

The experiment reported here showed that dust at the hot-mix plant occurs in sufficient quantities to be rated as objectionable. Some of these fines can be eliminated by not including captured incinerator stack fines (fly ash) in the residue. This may or may not be difficult to do and will depend on the design and operation of the particular incinerator that is producing the residue. A secondary, but by no means insignificant, benefit of the removal of these fines is that they contribute heavily to the asphalt requirements of the mixture. Design asphalt content is quite high, and even a slight reduction of asphalt content, at present prices, will add to the economic advantages of using incinerator residue. Another aspect of dust removal and hot-mix-plant operation is that dust can block the photoelectric cell that controls the burner and either shut the burner off or prevent downward adjustment, which will produce overheated mixtures. Finally, the removal of dust will reduce the amount of natural aggregate that is necessary to meet gradation requirements, which will further improve the economics of using residue.

Another area that should receive consideration is a lime-slurry application at the stockpile. Because of the high glass content of the residue and the high probability of water stripping of asphalt from these glass particles, lime will be required as an antistripping agent unless an adequate agent is added to the asphalt. Experience has shown that slurried lime is more effective than dry lime as an antistripping agent. Since incorporating lime slurry at the hot-mix plant is not as practical as applying it at the stockpile, it is recommended that provisions be made for introducing slurried lime at the stockpile. Elaborate and complicated procedures and equipment are not necessary. After the amount of material to be

treated is determined, the slurried lime can be applied either by a simple pump-and-spray arrangement or by conventional highway distributors that are readily available.

With regard to hot-mix-plant operations, two areas need to be considered: cold-feed control and temperature control. Cold-feed control should include a vibrator to prevent bridging in the bin as well as clogging of the gate.

Vibrators are common and can be found at many plants. In view of the sensitivity of workability to temperature, particular attention should be given to its control. This problem should be mitigated by reducing the variability in the amount of fines by means of modified incinerator operations, but temperature control should, nonetheless, receive close attention.

Future experiments would also be more effective if the amounts of material involved were adequate to permit plant adjustments to compensate for material variability and plant trim. A minimum of 907.2 Mg (1000 tons) appears to be a reasonable figure to ensure a supply of material that has low enough variability to allow for adequate evaluation of the field performance of pavements that contain incinerator residue.

Laboratory Extraction and Recovery of Asphalt

The results of physical tests on the asphalt recovered from a truck sample of mixture, taken at the time of placement, show that a normal amount of hardening of the asphalt occurred during the plant mixing process.

Pavement Performance

The performance of this material will be described in a future paper, after sufficient time has elapsed to observe trends in behavior and performance.

Use of Incinerator Residue in Surface Courses

Residential traffic was permitted on the base before the surface was applied, and this afforded the opportunity to observe the performance of incinerator residue as an aggregate in a surface course. Very soon after the surface was opened to traffic, the asphalt film began to strip away from glass particles in the mixture. Some time later, traffic started to pull the exposed glass particles away from the asphalt matrix that binds them into the mixture. Since the mechanism of this action has not been studied to determine whether tire action, water, or a combination of these forces is the main cause, preventive measures such as additives or increased film thickness cannot be recommended. Cores taken during the period of performance evaluation will be examined to determine to what extent the stripping can be attributed to water action.

Since the same stripping action was observed at a Harrisburg, Pennsylvania, installation where residue was used in a surface course, it is recommended that incinerator residue be used only for base-course construction and not be used in surface courses until solutions and preventive actions can be provided.

CONCLUSIONS

Based on this experiment and on the results of similar efforts at Houston, Texas, and Philadelphia and Harrisburg, Pennsylvania, and on the performance data being generated by the Houston experiment, it can be concluded that municipal incinerator residue should be considered

for use as an aggregate in the construction of bituminous bases. Although it is too early to completely evaluate performance, early indications are that the material should perform adequately under medium-level traffic.

The operations of the specific incinerator that produces the residue should be considered, and attention should be given to the removal of fines and the addition of slurrified lime to the stockpile. Acceptable mix-design procedures and hot-mix-plant control should, of course, be exercised in any future use of the material.

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Potential Use of Incinerator Residue as Aggregate for Portland Cement Concrete

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An evaluation, as a potential source of aggregate, of the residue that remains after the incineration of municipal refuse is described. The results of American Society of Testing and Materials acceptance tests indicate that incinerator residue can potentially be used as subbase and base-course material and aggregate for asphaltic concrete, portland cement concrete, and masonry units. Concrete strengths of approximately 27.6 MPa (4000 lbf/in²) are possible. Medium-weight concrete blocks that meet ASTM C 90 specifications have been manufactured. Alkali-aggregate reactions cause expansion, but it appears that this problem can be controlled.

A joint research project has been conducted by the Department of Civil Engineering, University of Notre Dame, and the Environmental Research Laboratory of Wheelabrator-Frye, Inc., of Mishawaka, Indiana, to develop profitable uses for incinerator residue produced by incineration of municipal refuse. The residue is discharged from grates at a temperature of about 815°C (1513°F) and passed through a grader. Residue smaller than 5.1 cm (2 in) passes through a water-sealed discharge and is quenched. Fly ash produced by the combustion of the refuse is collected in an electro-precipitator. It can be kept separate or combined with the residue in the quenching pit. In this research, the fly ash was combined with the residue. The wet-quenched material can then be dried, screened, and separated into magnetic and nonmagnetic fractions.

PROPERTIES OF NONMAGNETIC FRACTION

The nonmagnetic fraction can be described as a graded material made up of discrete particles >3.8 cm (>1.5 in) to <0.075 mm (<no. 200) in size. It is composed of glass, sand, slag, ash, and some metallic components. The coarse fraction can contain as much as 50 percent

glass (1,2). Some physical properties of the nonmagnetic fraction are given below (1 mm = 0.039 in):

Sieve Size (mm)	Percentage Retained	Specific Gravity	Percentage Absorption
25.4	5.0		
19.1	11.0		
12.7	17.8		
9.5	40.5	2.57	1.96
4.75	66.0	2.50	2.63
2.36	76.0	2.13	7.84
1.18	82.0	1.75	16.80
0.60	87.5	1.34	32.5
0.30	91.4		
0.15	94.3	2.42	
0.075	96.8		

Specific gravity was determined based on ASTM C 128, and percentage absorption was determined based on ASTM D 854.

The material was subjected to American Society of Testing and Materials (ASTM) acceptance tests to evaluate its potential as aggregate. The results were as follows (1 kg/m³ = 0.062 lb/ft³):

Test Property	Coarse Aggregate	Fine Aggregate
Clay lumps and friable materials (%)	0.5	
Los Angeles abrasion loss (%)	35.6	
Soundness loss (MgSO ₄ , five cycles) (%)	~5	~20
Organic impurities	OK	OK
Density (kg/m ³)	1280	960
Staining		Very light
Coating and stripping asphalt		OK
Loss on ignition (%)		