

Evaluation of Domestic Incinerator Ash for Use as Aggregate in Asphalt Concrete

NORMAN W. GARRICK AND KUO-LIANG CHAN

The potential use of incinerator ash in asphalt concrete paving was evaluated. Laboratory tests were conducted on ash from a waste-to-energy incinerator. Tests were conducted to assess whether asphalt concrete mix with ash was suitable both in terms of physical performance and environmental safety. It was determined that a mix with acceptable parameters on the Marshall tests could be produced with an aggregate consisting of up to 32 percent incinerator ash. This mix requires a higher asphalt content than a normal mix and appears to be prone to stripping. The results of the toxicity tests on the leachate were inconclusive; however, they suggest that there might be a problem since a significant amount of lead was detected in the leachate. It was concluded that an asphalt concrete mix with ash might be suitable for use in base course or for low-quality surface applications. However, a significant quantity of undesirable material must first be removed to get an aggregate of acceptable quality. Only about one-third of the material in the bottom ash is suitable for use in an asphalt concrete mix.

The northeastern United States is in danger of being buried under a mountain of discarded paper, wood, metal, plastic, and other detritus of modern life. Incineration is one of many strategies being used to deal with the refuse disposal problem. As can be expected, there are problems associated with burning trash on a large scale. Foremost among these is the question of how best to dispose of the potentially toxic residue that is generated by incineration. Many people have suggested that this material might be suitable for use in construction as a structural fill, an aggregate for asphalt concrete and portland cement concrete, or a replacement for some of the cement in concrete. Various facets of this idea have been studied since at least the 1940s.

In Connecticut, this issue is particularly topical since the use of waste-to-energy incinerators is an important component of the state's solid waste management plan (1). This project was conducted to investigate the feasibility of using incinerator ash from a refuse-derived fuel (RDF) incinerator in asphalt concrete paving. The project was conducted in two parts: a literature review of work that has been done to date and a laboratory study of incinerator ash from one local RDF incinerator. Unlike most previous studies, the laboratory tests in this project were conducted to evaluate not only the physical properties of the asphalt concrete mix but also the potential toxicity of leachate from the mix.

LITERATURE REVIEW

Commercial incineration of domestic refuse in the United States dates back to the turn of the century; however, the first significant wave of construction of incinerators did not come about until the 1940s. To get around war-related shortages, residues from some of these plants were used for embankment and subbase construction at various sites in Pennsylvania and New York during the war years (2).

In the 1960s and 1970s, with the push to construct large, centrally located incinerators, interest in the technology of residue utilization was revived as an answer to the problem of ash disposal. Many projects were conducted to study the issue, but the most comprehensive review was given in a series of reports published by FHWA in the mid-1970s (2-4).

FHWA described the different types of incinerator plants and the properties of the incinerator ash that are likely to affect the performance of the ash as a construction material (3). FHWA classified incinerator residue as well burned out, intermediately burned out, or poorly burned out depending on the amount of volume reduction and the organic content of the material remaining after ignition. The criteria used for this method of classification are summarized in Table 1.

The degree of burnout is affected by the composition and moisture content of the incoming refuse and the overall efficiency of the plant. If the refuse is relatively dry, most modern plants can be operated to give a well-burned-out residue with about 90 percent reduction in volume and 70 to 80 percent reduction in weight. FHWA found that only the well-burned-out residue is a likely candidate for use in asphalt concrete.

FHWA's laboratory evaluation showed that it was necessary to mix the incinerator residue with conventional aggregate. The best results were obtained when the incinerator residue made up no more than 40 to 55 percent of the total aggregate (5). Asphalt concrete mixes made with incinerator residue were found to require a higher asphalt content than conventional mixes (up to 10 percent compared with the usual 4 to 6 percent).

Since 1970 test sections made from asphalt concrete mix with incinerator residue have been constructed at various sites, including Houston (1974); Harrisburg, Pennsylvania (1975); Washington, D.C. (1977); and Lynn, Massachusetts (1980) (5). Mix with residue was used for both surface and base course in Harrisburg and Lynn but was used only in the base course of the Houston and Washington projects. In all cases the test sections were reported to be in good condition after many years of service. However, some surface raveling was reported in Harrisburg despite the fact that lime had been

TABLE 1 FHWA's Classification of Incinerator Ash (3)

Category	Description
WELL BURNED-OUT	Usually produced by continuous fed incinerators with high degree of grate agitation. Residue is about <u>10 % by volume</u> and <u>20 to 30 % by weight</u> of the refuse input.
INTERMEDIATE BURNED-OUT	Usually produced by continuous fed incinerators with little or no agitation or breaking down of the burning refuse. Residue is about <u>20 % by volume</u> and <u>25 to 35 % by weight</u> of the refuse input.
POORLY BURNED-OUT	Produced by batch fed incinerator or poorly operated continuous fed incinerators. Residue is about <u>30 to 40 % by volume</u> and <u>30 to 40 % by weight</u> of the refuse input.

added to inhibit asphalt stripping. It was also reported that the large quantity of dust generated by the residue during mixing with asphalt slowed down the rate of production at the hot mix plant.

Collins reports on one project in which incinerator residue was processed before being used as an aggregate (5). The process consists of first grinding the residue to a particle size of 1/4 in. or less. The ground material is heated at 1,600°F to remove combustibles and is fused at 2,000°F. After air cooling, the fused mass is crushed to give the desired gradation. In 1976, this Eco-rock, as it is called, was used in asphalt concrete mix for paving a road in Harrisburg, Pennsylvania. This road was still reported to be in good condition after 10 years of service. Furthermore, its skid resistance was found to be better than average. A large-scale Eco-rock plant, built in 1984 by the Environmental Protection Agency and the city of Philadelphia, was never activated.

THE CONNECTICUT STUDY

Description of Residue

The residue used in this study was from an RDF incinerator in Hartford, Connecticut. Depending on the operating condition of the plant, the residue produced was 12 to 15 percent by weight of the incoming refuse. This represents a very high degree of combustion. The residue can be collected in four separate streams in this plant: bottom ash, grate shiftings, economizer ash, and fabric filter ash. The bottom ash was about 85 percent of the residue, the fabric filter about 14 percent, and the grate shiftings and economizer ash was less than 1 percent. Only the bottom ash was used in this study. The other streams were unsuitable as aggregates in asphalt concrete because of their small particle size.

The bottom ash arrived at the laboratory as a wet sludge that had to be oven dried. After drying, all particles larger than 1 in. and all unburnt paper were removed from the sample. Particles larger than 1 in. constituted about 21 percent by weight of the bottom ash, whereas the paper made up only about 1.5 percent. Thus the material that was actually used in this project consisted of only about 78 percent of all the bottom ash generated.

Description of Project

The first stage of this project was the evaluation of the physical properties of the residue. Properties evaluated include gradation, specific gravity, water absorption, and particle toughness (by the Los Angeles abrasion test). The second stage of the project was the determination of an asphalt mix composition that would meet conventional specifications for road paving. The major objective of this process was to select the mix with as large a proportion of residue as was feasible; therefore, the first trial was a mix with the aggregate being 100 percent residue. In subsequent mixes, the residue was gradually replaced with a local aggregate (traprock) until a mix was obtained that met the specifications.

In the third stage of the project, the indirect tensile strength and the moisture susceptibility of the selected asphalt concrete mix were determined. Finally, leachate tests were conducted on samples of this mix to assess the likelihood of any potential hazard to the environment.

Properties of Residue

The data in Table 2 indicate that the largest fraction of the residue (after the removal of oversized particles and large pieces of paper) consists of mineral matter such as sand, stone, brick, and fused ash. Many particles in this fraction appear to be quite porous. Aside from the mineral matter, much of the rest of the residue is either glass or metal. Glass and, to some extent, metal could pose some problem in an asphalt mix because they are likely to be prone to stripping. The organic matter is present as fairly fine particles (minus No. 16 sieve).

The gradation of the residue is given in Table 3. The values in this table indicate that the residue meets the specifications for the Connecticut mix (Class 1), which is used on high-type facilities. Results of the specific gravity and absorption determination are given in Table 4. The residue was determined to have lower specific gravity and a higher degree of water absorption than most conventional aggregates (values for the traprock are given for comparison).

It is also of interest to compare the coarse (retained on No. 4 sieve) and fine (passing No. 4 sieve) fractions of the residue

TABLE 2 Composition of the RDF Incinerator Residue Versus Typical FHWA Well-Burned Residue

Components	Hartford RDF Residue (by weight)	FHWA Well- burned Residue (by weight)
Metal	23.0%	17.1%
Glass	35.0%	39.9%
Mineral Matter (sand, brick etc)	40.0%	39.5%
Organic Matter (wood, paper etc)	2.0%	3.5%

itself. The fine fraction is less dense and more absorbent—reflecting the fact that it contains a large amount of unburned organics (mostly paper), which could not easily be removed. The composition of the coarse fraction is very different, consisting mostly of metal, glass, and ceramics particles.

The percentage loss on the Los Angeles abrasion test for the coarse fraction of the residue was 44.7 percent, higher than the 40 percent maximum specified by the Connecticut Department of Transportation (ConnDOT) for its highest quality aggregate. This result is indicative of a material that is not as tough as one would desire in an aggregate to be used in a paving mix, but it is not unexpected given the large number of glass particles in the residue.

Mix Design

The purpose of this procedure was to obtain a mix that met conventional asphalt mix specifications but contained as high a proportion of residue as possible. The first trial was a mix in which the aggregate consisted totally of incinerator residue. This mix proved to be unsuitable because the Marshall stability value was low (650 lb) and the air void content was excessively high (23.5 percent) (see Table 5). (These results are for the mix with optimum asphalt content in the Marshall mix procedure.)

In the second trial the aggregate was 60 percent traprock and 40 percent residue. This proportion was used for all sieve

sizes. The Marshall results were virtually unchanged from those for the first trial. The Marshall stability value actually decreased slightly to 600 lb, and the air voids improved to 21.5 percent.

It was felt that the undesirable results of these two trials were most likely attributable to the presence of unburnt organic matter of fine particle size. Thus, in the third trial, residue particles finer than the No. 8 sieve were excluded. For this trial, the incinerator ash was used as the coarse fraction (retained on the No. 8 sieve), and the traprock was used as the fine fraction. The residue made up 48 percent of the total aggregate weight—a larger proportion than in the mix for the second trial. Nonetheless, this change resulted in a significant improvement in the Marshall properties of the mix. The Marshall stability increased to 1,050 lb, a value greater than the minimum specified for ConnDOT Class 1 mix. The air voids improved significantly to 13.5 percent; however, this value was still significantly higher than that allowed by the specifications.

To obtain a lower air voids content, the amount of residue of fine particle size was further reduced for the fourth trial. This was achieved by changing the cutoff point from the No. 8 to the No. 4 sieve. As before, the coarse fraction (in this case, the fraction retained on the No. 4 sieve) was incinerator residue only, whereas the fine fraction was traprock. The residue portion of the total aggregate weight was reduced to 32 percent by this change.

TABLE 3 Average Gradation of the RDF Incinerator Residues (Chunks Larger than 1 in. Not Included)

Sieve Size	Residue % Passing Sieve	CONNDOT SPEC LIMITS (Class 1)
1 in (25.4 mm)	100	100
1/2 in (12.7 mm)	85	70-100
3/8 in (9.51 mm)	72	60-82
#4 (4.76 mm)	46	40-65
#8 (2.38 mm)	30	28-50
#16 (1.19 mm)	18	-
#30 (0.60 mm)	12	-
#50 (0.30 mm)	7	6-26
#100 (0.15 mm)	4	-
#200 (0.075 mm)	3	3-8

TABLE 4 Specific Gravity and Absorption: RDF Incinerator Residue Versus Traprock

Property	Traprock		RDF Residue	
	Coarse	Fine	Coarse	Fine
Bulk Spec. Gravity	2.89	2.84	2.29	1.52
Apparent Spec. Gravity	2.97	3.03	2.52	1.75
Absorption, %	1.0	2.3	3.9	8.6

TABLE 5 Marshall Results for Four Trial Ash Mixes and for Traprock Mixes (Optimum Asphalt Content Only)

Test	Trap	Trial 1 100% Residue	Trial 2 40% Residue	Trial 3 48% Residue	Trial 4 32% Residue
Asphalt Content, %	4.9	7.0	7.0	6.5	6.2
Stability lb, 60 C	2200	650	600	1050	1150
Unit Wgt lb/cu. ft.	157.8	102.3	103.4	139.2	141.6
Flow 0.01 in	11.0	11.5	13.0	11.0	12.0
Air Void %	5.0	23.5	21.5	13.4	7.2
VMA, %	16.3	28.5	27.5	19.5	18.6

The air voids for this mix decreased significantly to 7.2 percent; this value was slightly greater than the maximum specified for Class 1 mixes. However, all the other Marshall parameters for this mix met the minimum ConnDOT specification for Class 1 mixes. Thus it was decided to use this mix proportion as the basis for the comprehensive testing program.

Properties of Asphalt Concrete Mix

These tests were conducted on the Trial 4 mixes of optimum asphalt content. It was determined that the optimum asphalt content of these mixes was 6.2 percent. This value is substantially higher than the asphalt content of about 4.9 percent for a traprock mix. In other words, the use of incinerator residue increases asphalt demand by about 20 percent over that required by an all-traprock mix.

Results of the indirect tensile test (77°F) and of the stripping tests are given in Table 6. The results show that the indirect tensile strength of the residue mixes was about 20 percent

lower than that of the traprock mix. It is difficult to say how these results would compare with other aggregates since many factors affect the indirect tensile strength. Therefore, results from other studies cannot be used for comparison.

The residue mixes also performed poorly in the stripping test, which was conducted according to the Tunnicliff procedure (6). The tensile strength ratio (TSR) for these mixes suggests that they might be susceptible to water damage (TSR of 0.75 is generally considered to be acceptable). This result is attributable to the large amount of glass in the residue. It might be possible to solve this problem by adding lime to the asphalt concrete mix.

Leachate Tests

Both the extraction procedure toxicity (EP Tox) and the toxicity characteristic leaching procedure (TCLP) tests were run on samples of loose residue mix and traprock mix. In both procedures a leachate is extracted from the sample with a specified aqueous extraction fluid (7,8). The leachate is an-

TABLE 6 Properties of Trial 4 Residue Mixture

Mix Type	Indirect Tensile Strength (ITS), psi	Water Sensitivity Tensile Strength Ratio (TSR)
Trap	103	0.85
Residue	80	0.70

TABLE 7 Leachate Test Results (EP Tox and TCLP) for Trial 4 Residue Mix and Traprock Mix

Element	Maximum Value, ppm	Traprock Mix		Residue Mix	
		E.P Tox ppm	TCLP ppm	E.P Tox ppm	TCLP ppm
Ba	100.00	0.0490	0.2470	0.1540	0.2040
Cd	1.00	0.0030	0.0030	0.0040	0.0190
Cr	5.00	0.0060	0.0110	0.0040	0.0260
Pb	5.00	0.0082	0.0258	2.3750	10.5000
Ag	5.00	0.0000	0.0170	0.0000	0.0230
As	5.00	0.0004	0.0009	0.0016	0.0024
Se	0.99	0.0027	0.0017	0.0023	0.0018

alyzed to determine the concentration of eight toxic metals; the specimen is classified as being hazardous if the concentration of any of these eight metals exceeds established threshold levels. The TCLP test is considered to be slightly more severe than the EP Tox test.

The results of the leachate tests in Table 7 show that lead is the only metal present in any appreciable amount in the leachate of the residue mix. The level of lead exceeds the threshold limit in the TCLP test but not in the EP Tox test.

It is difficult to draw firm conclusions about the potential toxicity of compacted pavements from these results, since the tests were not specifically designed for that purpose. Nevertheless, the results raise some concern, because many states severely restrict the use of substances such as these, which, in essence, fail the EP Tox or TCLP tests.

SUMMARY AND CONCLUSION

The results of the study indicate that an aggregate of marginal quality can be obtained from the bottom ash portion of the residue from this RDF plant. However, a large quantity of unsuitable material must first be removed from the residue. The components that must be removed include (a) oversized objects (larger than 1 in.), (b) unburned paper particles larger than the No. 4 sieve, and (c) fines passing the No. 4 sieve. Thus, only about 35 percent (by weight) of all the residue generated by the plant can be used as asphalt concrete aggregate.

An asphalt mix with acceptable Marshall parameters was made with an aggregate that is 32 percent residue and 68 percent traprock. As expected, the optimum asphalt content of this mix was higher (by 20 percent) than that of a corresponding traprock mix. In addition, the residue mix had lower tensile strength and showed a greater tendency to strip in the presence of water than did the traprock mix. A relatively high concentration of lead was detected by two separate procedures for analyzing the toxicity of the residue mix.

The results taken together do not provide a strong basis for recommending the use of the unprocessed residue in the wearing course of an asphalt concrete pavement. On the basis of the properties of the mix and of the residue itself, the performance of such a mix is likely to be marginal at best. This mix could possibly be suitable for use in the base course or in low-quality surface applications. However, the results of the leach-

ate tests raise the question whether a pavement from such a mix would be environmentally inert.

Very little attention has been paid to using processed residues as asphalt concrete aggregates. The undesirable properties of the residue that were identified in this report could conceivably be improved if the ash were stabilized by vitrification or some other process. Further research is required in this area.

ACKNOWLEDGMENT

This project was sponsored by the Environmental Research Institute at the University of Connecticut and the Connecticut Department of Environmental Protection. The environmental tests were conducted by Environmental Research Institute personnel.

REFERENCES

1. Weir, B. A., G. E. Hoag, K. J. Walsh, H. E. Klei, and A. J. Perna. Leachate Characterization of Ash from a Refuse Derived Fuel (RDF) Incinerator. Presented at AIChE National Meeting, Philadelphia, Pa., Aug. 1989.
2. Pindzola, D., and R. J. Collins. *Technology for Use of Incinerator Residue as Highway Material—Identification of Incinerator Practices and Residue Sources*. Report FHWA-RD-75-81 (Interim Report). FHWA, U.S. Department of Transportation, 1975.
3. Collins, R. J., R. H. Miller, and S. K. Ciesielski. *Guidelines for Use of Incinerator Residue as Highway Construction Material*. Report FHWA-RD-77-150. FHWA, U.S. Department of Transportation, 1977.
4. Teague, D. J., and W. B. Ledbetter. *Three Year Performance of Incinerator Residue in a Bituminous Base*. Report FHWA-RD-78-144 (Interim Report). FHWA, U.S. Department of Transportation, 1978.
5. Collins, R. J. Synthesis of Waste Utilization in Highway Construction. Presented at the 67th Annual Meeting of the Transportation Research Board, Washington, D.C., 1988.
6. Tunnicliff, D. G. *NCHRP Report 274: Use of Antistripping Additives in Asphaltic Concrete Mixtures—Laboratory Phase*. TRB, National Research Council, Washington, D.C., 1982.
7. *Test Method for Evaluating Solid Wastes. Physical/Chemical Methods* (2nd edition). SW-846. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1982.
8. *Methods for Chemical Analysis of Water and Wastes*. EPA-600/4-79-010. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1979.

Publication of this paper sponsored by Committee on Mineral Aggregates.