USE OF ZINC SMELTER WASTE AS HIGHWAY CONSTRUCTION MATERIAL

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Oklahoma has large quantities of smelter waste, resulting from zinc and lead mining operations, located principally in the north central, northeast, and eastern portions of the state. In their current condition and location, these waste piles are extremely unsightly, and they kill or damage adjacent vegetation and contribute significantly to both surface and groundwater pollution. Before any solid waste material may be accepted for use as construction aggregate, it must possess acceptable physical properties. These properties, determined from standard tests, include mechanical strength, surface texture, particle shape, resistance to polishing or skid resistance, specific gravity, water absorption, chemical stability, particle size distribution, resistance to abrasion, and resistance to frost action (1). The most economical aggregate is often the one closest to the construction site. However, even with modern aerial survey techniques, nearby materials cannot always be located, thus expenses incurred by aggregate transportation increase overall construction costs. An often overlooked method of lowering aggregate material cost is the use of synthetic or artificial aggregates, which are generally considered to be aggregates produced by some chemical and/or physical process. Highway engineers are always hesitant to use artificial aggregates unless they are of proven field quality. However, several types of artificial aggregates have been utilized with reasonable success under limiting conditions.

•TO satisfy a rapidly growing population, the highway engineer is building more and more roads, using naturally occurring aggregates that are being both depleted and covered by expanding cities. Also, one of the hardest environmental pollution problems to solve is the disposal of solid mineral wastes. However, if our economy demands that these mineral wastes be produced, then disposal methods must be developed in order for man to live with them. A common solution for the two problems might be utilization of mineral wastes as aggregates for road construction, especially in many areas of the United States where natural aggregates are being depleted and therefore expensively transported from other regions.

Extensive use has been made of ground or pulverized reef shell as a flexible pavement aggregate for road and airfield construction in the Gulf-states region of the United States. Problems in evaluating laboratory mix design results stem from the reef shell particle size and shape and the inadequacy of the Marshall method of design to predict field behavior (2, 3, 4).

Another widely used source of artificial aggregate is the waste product in the production of iron, called slag. Asphaltic concrete mix designs utilizing "blast furnace slag" are characterized by optimum asphalt contents, which are not indicative of their field performance. Use of unslaked "open hearth slag" can result in volumetric expansion of the aggregate, producing failures in portland cement concrete (PCC) and heaving of slabs overlying the waste if used as a base material (5, 6, 7, 8).

Expanded clay and shale aggregates manufactured from shale aggregates commonly not considered suitable for highway pavements are currently being used in portland cement and asphaltic concretes. The aggregates exhibit desirable features such as low weight and high strength, but the raw material must be located in sufficient quantities and quality to warrant the establishment of a multimillion dollar thermal treatment plant (9, 10).

Research work is currently being conducted at the University of Missouri at Rolla concerning the use of ground waste glass as an aggregate in asphalt paving mixtures. Although at this time no published information concerning field test results is available, problems arising from stripping and public response to driving on broken glass will undoubtedly occur (11).

With added attention toward solid waste disposal, the use of compacted sewage ash as a fine aggregate is being studied. The compacted ash does not swell, slake, or lose its strength on soaking, but it is quite corrosive to metals and should not be compacted by a sheepsfoot roller (12).

Additional information regarding the use of these and other aggregates is summarized elsewhere (13).

WASTE MATERIALS TESTED IN THIS STUDY

Four types of Oklahoma zinc smelter waste and a very fine "blow sand" were studied during the investigation.

Two types of smelter waste were obtained from the Eagle Pitcher Co. smelter located at Henryetta, Oklahoma. One of the samples from the Henryetta smelter was reddish in color and was given the name Henryetta Red Tailings (HRT). Visual observation of individual grains revealed a very porous and cohesionless material, cubical in shape and having a sharp angular texture, as shown in Figure 1. The larger particles of the material were brittle in nature, but grain sizes passing the No. 10 sieve were very durable. Specific gravity, percentage of water absorption, and grain size distribution for HRT are given in Table 1. The other cohesionless smelter waste from the Eagle Pitcher plant was similar in surface texture, particle shape, and porosity but was black in color. This material was called Henryetta Black Tailings (HBT) and is shown in Figure 2. HBT also exhibited the same brittleness of large particles and durability in smaller grain sizes as was found for HRT. Specific gravity, percentage of water absorption, and grain size distribution for HBT are also given in Table 1.

Two additional smelter wastes were obtained from the Blackwell Zinc Co., located at Blackwell, Oklahoma. One cohesionless material, shown in Figure 3 and called Blackwell Tailings (BT), was black in color. The material oxidized in the presence of water and turned a reddish-yellow color. BT was also porous in nature and sharp and angular in texture, and particles retained on the No. 10 sieve appeared shiny or glassy. Smaller particles of BT were not as durable as those found in HBT or HRT. Percentage of water absorption, specific gravity, and grain size distribution data for BT are given in Table 1.

BT is currently sold to other commercial smelting firms for removal of trace metals other than zinc. The economic feasibility of using BT as a road construction aggregate as opposed to its utilization for additional smelting was not considered in this study.

The remaining Blackwell Zinc Co. waste material to be studied was called Blackwell Condenser Tailings (BCT). BCT, as shown in Figure 4, was also cohesionless, white in color, and relatively fine-grained (Table 1). BCT, like the other waste materials studied, has a cubical shape and sharp angular texture; however, it is nonporous. The smelting processes undergone by the waste materials are not described because they were considered privileged information by both companies providing smelter waste for analysis.

Another cohesionless aggregate utilized during the investigation was a naturally occurring very fine, poorly graded sand, locally called "blow sand" but here called Sapulpa sand (SS), obtained from a site located 4 miles west of Sapulpa, Oklahoma. SS was substituted for fine aggregate not naturally occurring in the smelter waste. The grain size distribution for SS is given in Table 1. This sand is typical of the fine to very fine sands that are relatively abundant in most parts of Oklahoma.

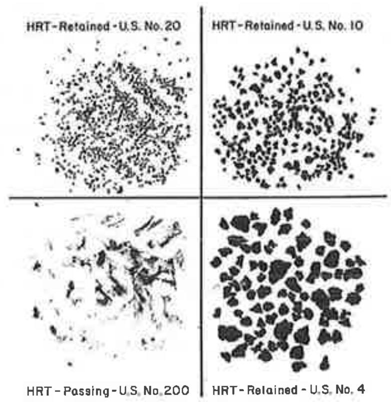


Figure 1. Sized particles of HRT.

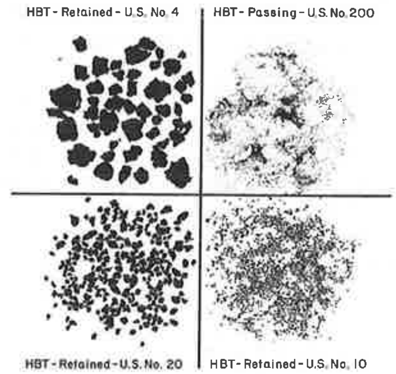


Figure 2. Sized particles of HBT.

Table 1. Physical properties of test materials.

Test Material	Grain Size Distribution, Total Percent Passing U. S. Standard Sieve									Bulk Specific Gravity	Water Absorption (percent)
	½ In.	⅜ In.	No. 4	No. 10	No. 20	No. 40	No. 80	No. 100	No. 200		
HRT	99.7	95.3	90.2	59.6	24.5	10.9	4.0	3.0	1.6	2.86	3.78
HBT	99.1	96.2	69.8	31.9	11.5	4.4	1.6	1.2	0.7	2.37	4.87
BT	100.0	99.7	90.4	64.2	29.7	10.1	2.4	1.7	0.8	3.14	5.00
BCT	100.0	100.0	98.7	85.6	41.1	23.9	12.5	9.4	4.9	2.18	3.41
SS	100.0	100.0	100.0	100.0	100.0	100.0	87.0	35.4	13.1	2.66	—

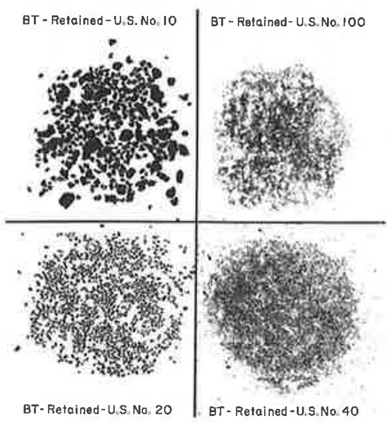


Figure 3. Sized particles of BT.

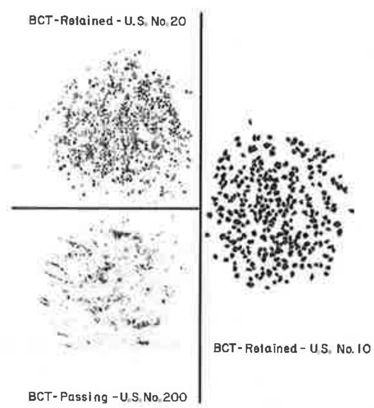


Figure 4. Sized particles of BCT.

Asphaltic cement utilized during the study was furnished by the Allied Material Corporation, Inc., of Stroud, Oklahoma. This material had a standard penetration of 85 to 100 at 77 F and specific gravity of 1.02.

USE OF SMELTER WASTE IN ASPHALTIC MIXTURES

Testing Procedures

The objective part of the study was to determine the feasibility of using zinc smelter waste as an aggregate in sand-asphalt mixtures. Hot-mix/hot-laid sand-asphalt mixtures are generally used in base course construction but can be used as a surface course for pavements carrying limited light loads.

Gradation requirements for sand-asphalt base courses (hot-mix/hot-laid) conforming to Section 708A of the Standard Specifications for Highway Construction of the Oklahoma Highway Commission are shown in Figure 5a. No type of smelter waste tested had a natural gradation within specification limits. Therefore, it was necessary to either crush or sort and recombine the smelter waste or add additional fines in the form of SS (fine sand).

In the process of combining the tailings and SS, a maximum amount of smelter waste was used, and a midpoint gradation was not achieved. Table 2 gives the percentage used of each smelter waste and SS; Figure 5b shows the resulting gradations of each combination of smelter waste and SS.

The Hveem gyratory method of mix design was used during the study, and mix design procedures were followed using percentages of smelter waste and SS, then repeated using 100 percent smelter waste. Smelter wastes were both crushed and sorted and recombined to yield the same gradation produced by the addition of fine sand.

Evaluation of Test Results

A summary of the results of laboratory mix designs for all test mixes (smelter waste-fine sand and 100 percent smelter waste) is given in Table 3. Figure 6 shows the relation between Hveem stability and asphalt content for the mixes, as computed by a total mix weight basis. Figure 7 shows relations between asphalt content and percentage of total voids. Figure 8 shows obtained relations between asphalt content and compacted unit weight of the mixes.

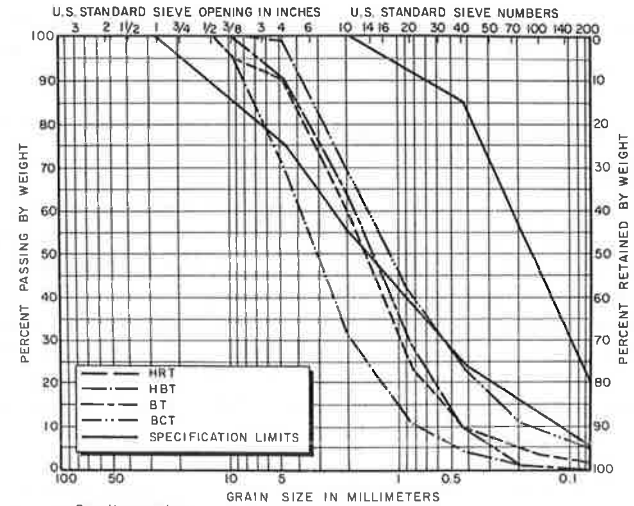
Figure 6 shows a very interesting phenomenon. A small difference of only 3 to 5 percent in Hveem stability can be observed for an increase of 1 percent asphalt content. This is somewhat unusual because a percentage difference in Hveem stability of as much as 10 percent would be expected with conventional aggregates. Meredith (2) reports a lack of response to density, stability, and flow in shell-asphalt mix designs as determined by using the Marshall method. Because of this problem, much emphasis is placed on the percentage of voids for the total mix. Earle (14) also mentions problems in determining asphalt contents using the Marshall tests with blast furnace slag. Engineering judgment coupled with a proven field mix is generally used in slag-asphalt mix designs in Great Britain.

As may be seen in Figure 6, the largest differences in stability among the various smelter wastes were obtained in mixes with larger percentages of SS. The stability values occurring at the optimum asphalt content for smelter waste/sand-asphalt and 100 percent smelter waste-asphalt exceed the minimum 20 percent stability required by the Oklahoma Department of Highways specifications for sand-asphalt mixtures, as obtained values ranged from 25.5 to 43.7 percent (Table 3). Use of either 100 percent smelter waste or smelter waste-sand did not greatly affect obtained stability for a given smelter waste.

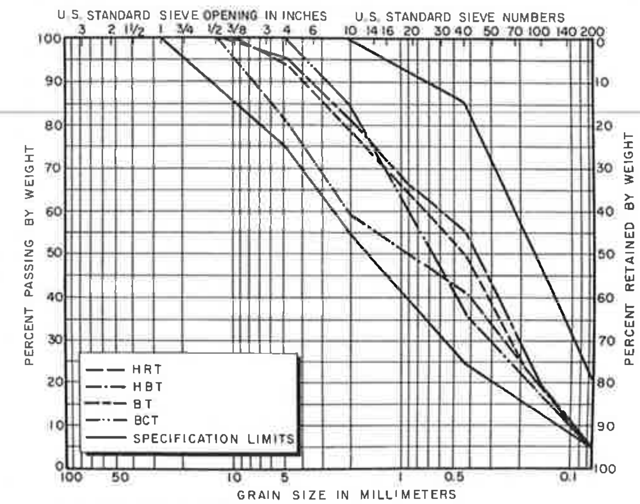
The unit weights of the compacted samples (110 to 130 pcf for all except BT) tend to be lower than usual for conventional aggregates, primarily because of low zinc waste specific gravities and/or high aggregate angularity. Unit weights of approximately 140 lb/ft^3 can be expected from samples containing aggregate with a specific gravity of 2.65.

Optimum asphalt contents for the mixtures were within the allowable range of 3.0 to 8.0 percent required by the Oklahoma Highway Commission. For all samples at

Figure 5. Grain size distribution curves for smelter wastes with and without fine sand.



a. Smelter wastes.



b. Smelter wastes and sand.

Table 2. Percentages of smelter waste and Sapulpa sand used for sand-asphalt.

Smelter Waste	Smelter Waste Utilized (percent)	Sapulpa Sand Utilized (percent)
HRT	55	45
HBT	60	40
BT	50	50
BCT	80	20

Table 3. Hveem gyratory mix design results.

Test Material	Optimum Asphalt Content (percent)	Stability (percent)	Unit Weight (lb/ft^3)	Voids of Total Mix (percent)
60 percent HBT and 40 percent SS	8	34.5	128.7	11.0
100 percent HBT	8	39.5	126.0	6.8
55 percent HRT and 45 percent SS	7	26.4	122.0	14.7
100 percent HRT	7	25.5	114.3	19.0
80 percent BCT and 20 percent SS	4	43.7	117.9	14.8
100 percent BCT	4	43.4	114.8	16.6
50 percent BT and 50 percent SS	6	37.7	139.4	16.5
100 percent BT	6	43.0	158.7	11.0

Figure 6. Hveem stability versus asphalt content for zinc smelter waste mixes.

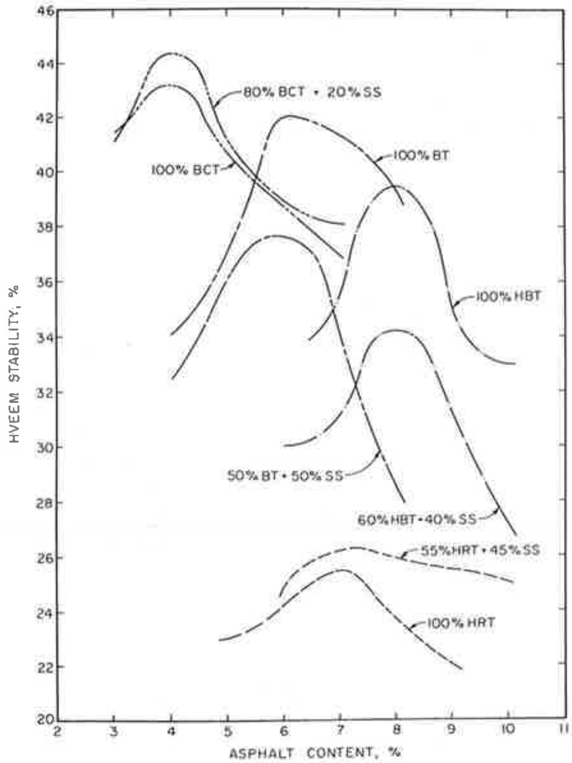


Figure 7. Relation between asphalt content and percentage of total voids for zinc smelter waste mixes.

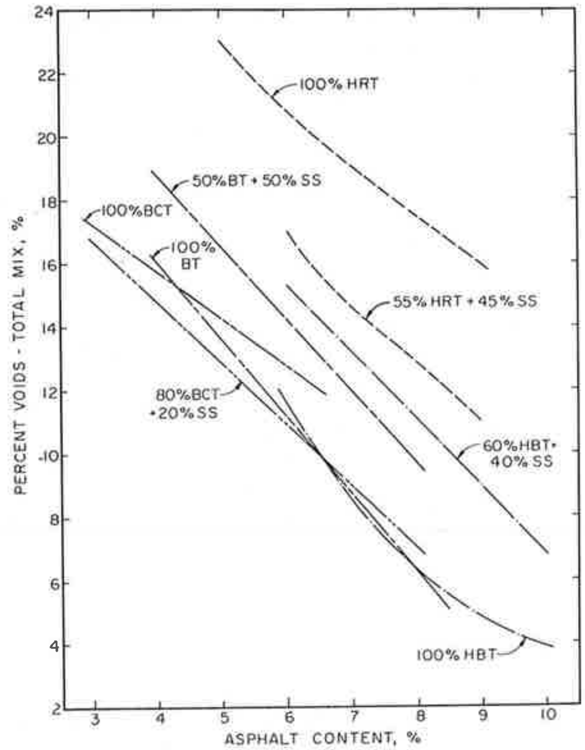
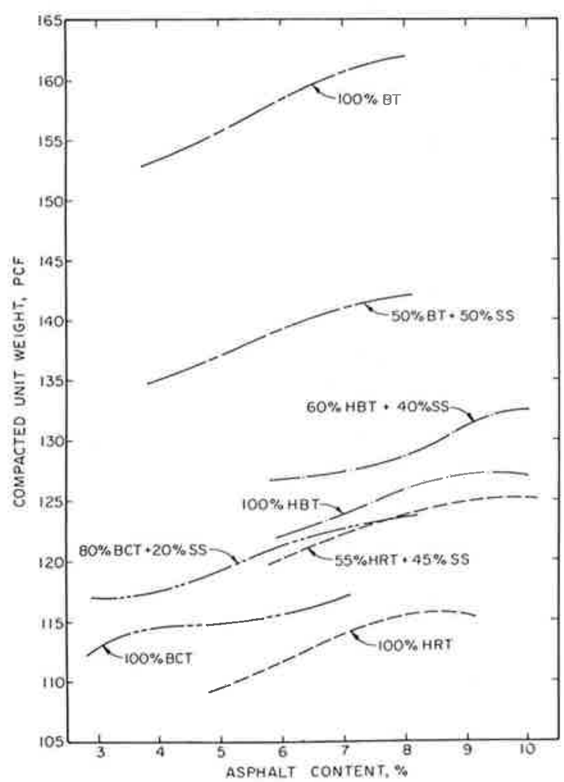


Figure 8. Compacted unit weight versus asphalt content for zinc smelter waste mixes.



optimum asphalt content, the compacted unit weight is less than 82 percent of the maximum theoretical density. The probable cause of this behavior was the high angle of internal friction of the zinc tailings. Direct shear tests on the four zinc smelter wastes produced friction angles Φ ranging from 47 to 54 deg; these very high values are attributed to the effects of interlock and angularity of the waste particles.

A current problem in Oklahoma is obtaining higher skid resistance of pavement surfacing, as many limestones and dolomites used in Oklahoma highway construction are susceptible to traffic polishing. The sharp angular texture of the four zinc smelter wastes indicated a potentially high skid resistance; thus the Oklahoma Department of Highways test for insoluble residue (OHD-L-25) was carried out on the smelter wastes. The test consists of soaking the aggregate in HCl until all reaction ceases and measuring the amount of treated sample retained on a No. 200 sieve. Aggregate used in the wearing course must contain at least 30 percent insoluble residue. All four zinc smelter wastes exceeded test requirements: HBT contained 70.1 percent insoluble residue, HRT contained 88.7 percent, BT contained 68.3 percent, and BCT contained 79.9 percent.

Although additional detailed testing and evaluation are perhaps needed to form a final opinion, nevertheless the test results imply that zinc smelter wastes can be substituted for conventional aggregates in sand-asphalt mixtures, by adding fine sand or crushing and/or sieving and recombining the smelter waste, to produce required gradation. Also, the smelter waste appears feasible for use in surface courses where improvement of skid resistance is needed, when blended with coarser grained limestones or dolomites.

USE OF SMELTER WASTE IN PORTLAND CEMENT CONCRETE MIXTURES

The four zinc smelter wastes were also used as fine aggregate in trial PCC mix designs, but all mixes would not "set" quickly, and obtained strengths were very low. Some samples could be crushed by hand after 28 days of curing.

Retardation of setting resembled that described by Schaeffer and Peyton. Schaeffer (15), in 1932, described problems experienced in England with efflorescence and scaling of concrete from release of water-soluble substances by aggregate. Peyton (16) reported that weathering of sphalerite (ZnS) contained in chert aggregate produces zinc carbonate (smithstone), which causes severe retardation of set if present in amounts greater than 0.3 percent by weight of cement.

To verify this possible cause of behavior, the alkali reactivity of all four smelter wastes was determined (using ASTM Designation C 289), and all were found to be highly reactive. Thus, use of these zinc smelter wastes in PCC mixes is not recommended.

USE OF SMELTER WASTE IN STABILIZED AGGREGATE

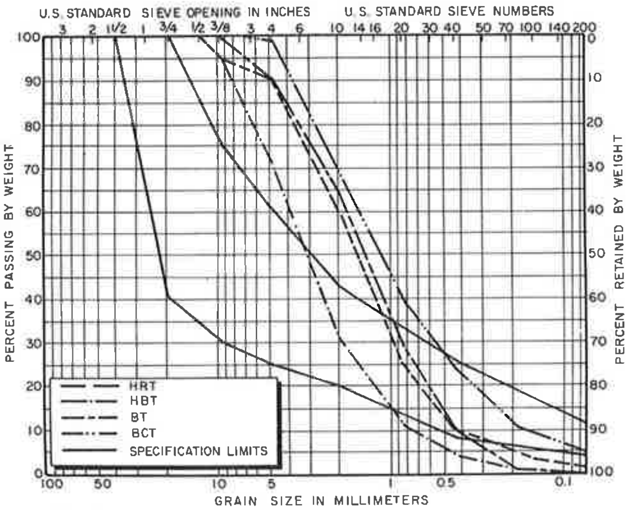
This phase of the investigation concerned the feasibility of using the zinc smelter wastes in the manufacture of mechanically stabilized aggregate mixtures for use as base material.

Stabilized aggregate base courses, as defined by Oklahoma Department of Highways specifications, should consist of blended coarse aggregate, sand, stone dust, or other inert finely divided mineral matter and a soil binder. At least 40 percent of the total mix retained on the No. 4 sieve should be uniformly graded. Material passing the No. 40 sieve is required to have a plasticity index of 6 or less and a liquid limit of 25 or less.

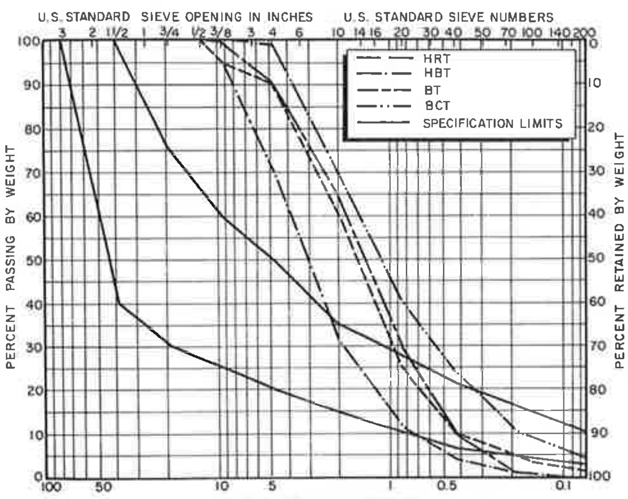
Stabilized aggregate is specified (by the Oklahoma Department of Highways) as either Type A or Type B, the difference being in acceptable gradation.

Figure 9a shows specification limits for Type A and grain size distributions for the four smelter wastes, while similar information for Type B stabilized aggregate is shown in Figure 9b. From Figure 9 it may be noted that all four types of smelter waste need additional coarse-grained material to meet requirements for either type of stabilized aggregate. However, it is a common procedure to blend aggregates and

Figure 9. Grain size distribution for zinc smelter waste compared to limits for stabilized aggregate.



a. Smelter waste and specification limits, Type A.



b. Smelter waste and specification limits, Type B.

produce the required gradation; thus the zinc smelter wastes appear feasible for consideration in manufacture of stabilized aggregate.

A lack of vegetative cover was observed near stockpiles of the tested smelter wastes. Soluble zinc leaches into the soil and may kill or damage vegetation. This may or may not be desirable when the tailings are used in stabilized aggregate but may not be of major importance when used under the center section of a road with wide surfaced shoulders. Conversely, this property may be an advantage if the smelter wastes are used in aggregate bases of low-traffic rural roads or under improved shoulders because they would retard growth of vegetation through the pavement structure.

It is therefore concluded that zinc smelter wastes may be an excellent potential source of fine aggregate for use in stabilized aggregate base courses.

CONCLUSIONS

Results of this study, although tentative, indicate that zinc smelter wastes may be used as aggregate in particular phases of highway construction. The following conclusions are made:

1. When natural gradation is modified by addition of fine sand or the material is either separated or crushed and recombined to meet particular gradation requirements, it may be used in sand-asphalt mixes. Resulting stability values are above minimums of the Oklahoma Department of Highways, and optimum asphalt contents are within specification limits.
2. The Hveem gyratory method appears adequate for mix design. However, the sharp angular texture of the aggregate, with resulting high angles of internal friction, causes unusual Hveem stability values.
3. Addition of zinc smelter waste to asphaltic concrete surface course mixes containing limestone aggregate susceptible to polishing should increase mix skid resistance.
4. Because of cement-aggregate reactivity, zinc smelter wastes should not be used in PCC mixtures.
5. All four of the zinc smelter wastes appear satisfactory for use in manufacture of mechanically stabilized aggregate mixtures.

It should be noted that three (HRT, HBT, and BCT) of the four smelter wastes are available at zero material cost. Although transportation costs may prevent economically feasible use of smelter wastes at some distance from their locations, this type of material should be especially attractive to small municipal and county road-building agencies that are forced to operate on extremely limited budgets. Further, use of these wastes would help to reduce the pollution problems that they present in their current condition and location.

RECOMMENDATIONS FOR FURTHER RESEARCH

Further research should be concerned with determining skid resistance of asphalt-zinc smelter waste mixtures; it should be quite high. Consideration should also be given to stripping, degradation, weathering, and validity of mix design procedures. A relation between field experience and laboratory mix design should be established. In addition, other types of zinc smelter waste (of which several exist in Oklahoma alone) should be investigated using the procedures described here. The wide variation in physical properties of the four samples used in this study indicates that generalization of results should not be attempted.

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