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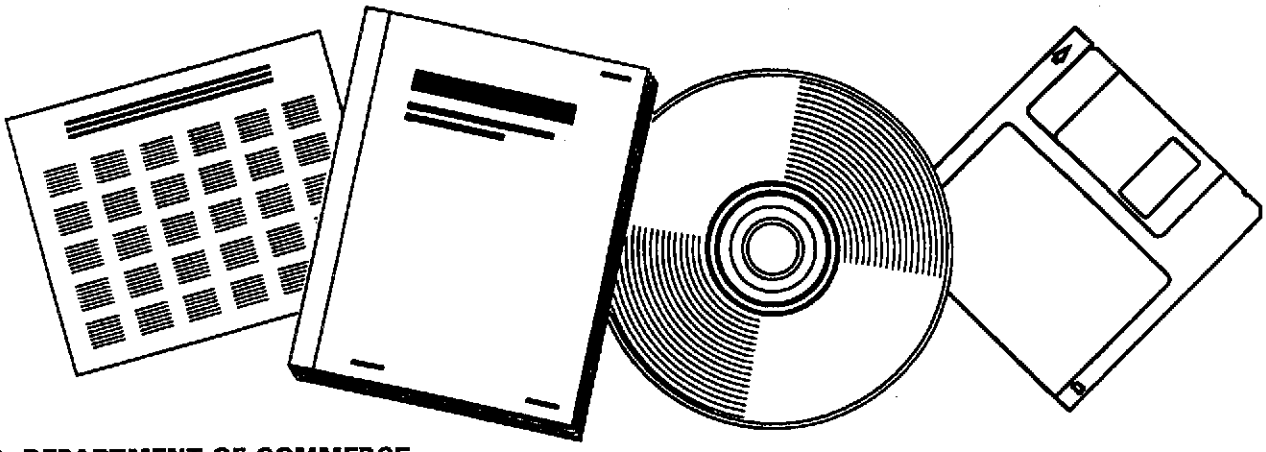
AVAILABILITY OF MINING WASTES AND THEIR POTENTIAL FOR USE AS HIGHWAY MATERIAL -- VOLUME III: ANNOTATED BIBLIOGRAPHY - FINAL REPORT

VALLEY FORGE LABORATORIES, INC.
DEVON, PA

MAY 76



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AVAILABILITY OF MINING WASTES AND THEIR POTENTIAL FOR USE AS HIGHWAY MATERIAL

Vol. III. Annotated Bibliography

May 1976

Final Report

Prepared for

FEDERAL HIGHWAY ADMINISTRATION

Offices of Research & Development

Washington, D. C. 20590

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16. Abstract

This study was performed to determine the availability of mining and metallurgical wastes and to assess their potential for use in various aspects of highway construction. A review was made of domestic and foreign literature pertaining to the production and use of these waste materials. This review covered references on the quantities, locations, characteristics, and utilization efforts associated with various types of mining and metallurgical wastes. Particular emphasis was given to those references which present the findings of research concerned with the engineering properties and the field performance of specific waste materials. A total of 80 of the most pertinent references on the subject of mineral waste utilization are cited in this volume.

This is the third of three volumes. Volume I, published as FHWA-RD-76-106, is subtitled "Classification and Technical and Environmental Analysis." Volume II, published as FHWA-RD-76-107, is subtitled "Location of Mining and Metallurgical Wastes and Mining Industry Trends."

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PREFACE

This is the third volume of a three-volume report. This report presents the findings of an investigation funded by the Department of Transportation, Federal Highway Administration (FHWA), under Contract Number DOT-FH-11-8784. The Contract Manager was Dr. W. Clayton Ormsby, Materials Division, FHWA.

The work was conducted during the period July, 1975 through June, 1976 by Valley Forge Laboratories, Inc. This volume of the report was prepared by Mr. Robert J. Collins, who was the Principal Investigator for the study.

Assistance in the collection and review of the literature was provided by Drs. Stanley K. Ciesielski, William B. Fergusson, and Edward M. Wallo and Messrs. George T. Kraus and Richard H. Miller.

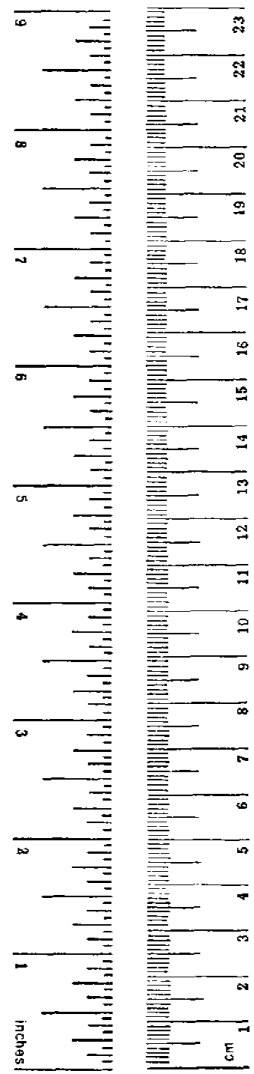
Typing of the draft was performed by Mrs. Vicki Thompson. Editorial corrections were made by Mrs. Mildred Staley.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

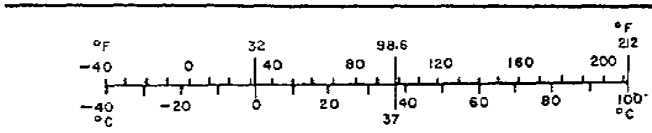
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FOREWORD

It is estimated that between 1.6 and 2 billion tons of mineral wastes are produced each year in the United States from the mining and processing of fossil fuels and ores. Over the past thirty years, approximately 20 billion tons of these waste materials have accumulated in waste dumps and tailing ponds across the country.

Some of these wastes are responsible for varying degrees of environmental degradation. Many occupy land which is potentially valuable for other purposes. Because some of these wastes are derived from normally acceptable rock formations, they are promising sources of construction materials. All of those factors serve to make utilization of such wastes attractive in certain areas.

The mining industry has successfully used its own wastes as construction material for many years. A number of mining and metallurgical wastes have also been used in the construction of public highway facilities. Some of these materials have developed a favorable performance record in a variety of highway related applications. A great deal of research work has also been performed in order to evaluate the potential usefulness of certain mining and metallurgical wastes as construction material.

Because of the increasing scarcity of conventional materials in some areas and the overall abundance of mining wastes, the Federal Highway Administration has sponsored a research program to survey the types, locations, quantities, and general nature of mining and metallurgical wastes and to assess their potential for possible use as highway construction material.

The initial step in conducting this research is to survey all literature pertaining to mining and metallurgical wastes. A large number of references have been collected and reviewed on all aspects of this particular subject. The purpose of this report is to present an annotated bibliography of those publications which are most pertinent to the utilization of mining and metallurgical wastes in highway construction.

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ANNOTATED BIBLIOGRAPHY

The following annotated bibliography covers references on the production, characteristics, and uses of mining and metallurgical wastes, with particular emphasis placed on those references concerned with the engineering properties and highway-related uses of specific waste materials.

ANNOTATED BIBLIOGRAPHY ON THE USE OF MINING AND METALLURGICAL WASTES

1. Aiken, H. B. "Mascot Zinc Tailings as an Aggregate in Cement Concrete." University of Tennessee Engineering Experiment Station, Bulletin No. 8, Knoxville, Tennessee, May, 1925. 23p.

   Tailings from the concentration of zinc from the American Zinc Company at Mascot, Tennessee, were evaluated for possible use in Portland cement concrete. A study was made of the gradation of these tailing materials, commonly called chat, and the uniformity of random samples taken over a period of several months. Field investigations were made of existing concrete structures using the tailings as aggregate. Laboratory studies were conducted of compressive strength development using various trial mixes with different combinations of cement, sand, and tailings. The relative costs of these trial mixes were also determined.

   Observations of the gradation of tailing samples taken during a three-month period indicate that the jig tailings are a uniformly graded product, with a maximum variation between ten and fifteen percent. No defects were found in any of the existing concrete structures in which the Mascot tailings were used. Results of a laboratory investigation of trial mixes using the tailings confirm that, if mixtures are properly designed and proportioned, concrete can be made

with the tailings that will be just as serviceable as that produced with conventional aggregates. The use of some sand in the mixes resulted in improved workability.

2. Aleshin, E. and Schwartz, M. A. "Techno-Economic Analysis of Mining and Milling Wastes." Illinois Institute of Technology Research Institute, Project No. G6027 for U. S. Department of Interior, Bureau of Mines, May 29, 1969. 88p.

   The techniques for beneficiating copper, taconite, and lead-zinc ores are described. A list of major copper, taconite, and lead-zinc mines is included, along with estimated waste quantities and mineralogy of tailing discharges. A marketing survey was made to determine the potential market for foamed building materials in six (6) selected geographical regions. The authors recommend that taconite tailings be considered for further study as a possible source of raw material for lightweight building products in the Great Lakes region.

3. Baker, Michael, Jr. "Investigation of Mining Related Pollution Reduction Activities and Economic Incentives in the Monongahela River Basin." Report to the Appalachian Regional Commission. April, 1975.

   This study is part of a series of reports prepared for the Appalachian Regional Commission for development of a pollution abatement plan for the eighteen-county Monongahela River Basin, which encompasses parts of West Virginia, Maryland, and Pennsylvania. The objective of the study was to develop feasible economic incentives which would encourage the private sector to undertake environmental improvement activities at active or abandoned coal mining operations. The report concludes that utilization of coal mining and preparation waste should be emphasized, since this is an area where environmental improvement activities can be undertaken at a profit.

   Recommended means of utilizing coal waste are:

   1. Processing of coal refuse piles to recover coal.

   2. Use as landfill or embankment material.

   3. Use of raw coal waste combined with fly ash in the manufacture of bricks, blocks, lightweight aggregate and other products.

4. Production of high grade aluminum sulfate for the potential extraction of alumina.

A section of this report discusses the history, research, and current developments associated with the utilization of coal waste in Pennsylvania. Results of a laboratory investigation of the engineering properties of bituminous coal mine refuse are also presented. Tests were conducted to determine soil index properties, moisture-density relationships, compaction and strength characteristics, degradation, permeability, and chemical parameters.

4. Bingham, E. R. "Waste Utilization in the Copper Industry." In Proceedings; First Mineral Waste Utilization Symposium. Chicago, Illinois, March 27 - 28, 1968. p. 73 - 79.

The current status of mining and extracting copper from low grade ores and the resultant waste disposal problems associated with these processes are discussed. The problem of waste disposal in the copper industry is two-fold. Copper companies try to find a use for their waste or convert it to a by-product. Failing this, they dispose of the waste as efficiently and safely as possible.

Because of the low grade ores being mined, extremely high tonnages of wastes are produced. The wastes occur in the form of waste rock, mill tailings, and slag from smelters. At open pit mines, two (2) tons of waste rock are produced for every ton of ore. Much of the waste rock is leached to recover additional copper, but some is used for construction purposes, such as aggregate, ballast, or rip-rap.

The quantities of tailings are so great that total utilization is almost impossible. However, the tailings are used to construct impoundments, dikes, and roadbeds. Smelter slag, high in silica and iron, has been utilized as fill, railroad ballast, and aggregate. Unfortunately, these materials are located great distances from market areas and transportation costs deter significant utilization.

5. Blanco, R. E.; Godbee, H. W.; and Frederick, E. J., "Incorporating Industrial Wastes in Insoluble Media." Chemical Engineering Progress. Volume 66, No. 2, February, 1970. p. 51 - 56.

A process for incorporating radioactive wastes in asphalt or polyethylene was developed at Oak Ridge National Laboratory. The process has been successfully demonstrated in both continuous and batch mixing operations. The initial steps involve mixing the waste solution, slurry, or solids with commercial emulsified asphalt, molten-base asphalt or molten polyethylene and raising the temperature to evaporate the waste fluid. The solids remain intimately dispersed in the medium and the product flows out of the evaporator into a receiving vessel.

The typical flowsheet is presented for incorporation of waste sands and slimes from the uranium mining and milling industry into asphalt. The wastes would be neutralized with lime to precipitate radium and sulfates and only the concentrated slurry would be evaporated. Possible uses would be for road surfacing, roofing materials, or impervious building blocks. The cost of incorporating the sludge and liquid waste from a 1,000 ton-per-day uranium ore mill is estimated.

6. Busch, Richard A.; Backer, Ronald R.; and Atkins, Lynn A. "Physical Property Data on Coal Waste Embankment Materials." U. S. Bureau of Mines, RI No. 7964, 1974.

Approximately 3.5 tons of material were collected from eight (8) coal refuse embankment sites in southern West Virginia. Photographs and scale drawings of sampling locations at each site are included. In all, thirty-two grab samples and twenty-one undisturbed Shelby tube samples were obtained.

Maximum and minimum laboratory densities, grain size distribution, and specific gravities were determined for the grab samples. Composite coarse samples were also tested for permeability and shear strength. Four (4) composite samples were sent to the Bureau of Reclamation soils laboratory for large-scale triaxial shear tests. One grab sample from each site and one Shelby tube were sent to the University of Idaho, College of Mines for petrographic and chemical analysis.

Permeability, direct shear, grain size distribution, specific gravity, and Proctor compaction tests were performed on Shelby tube samples. A description of test procedures is included. The report presents and discusses the test results in detail. A considerable number of tables and charts are contained in the Appendix.

7. Butler, Philip E. "Utilization of Coal Mine Refuse in the Construction of Highway Embankments." In Proceedings; First Symposium on Mine and Preparation Plant Refuse Disposal. Louisville, Kentucky, October 22 - 24, 1974. p. 237 - 255.

A discussion of the sampling and laboratory testing of coal refuse materials from the anthracite and bituminous coal regions of Pennsylvania is presented. Physical tests conducted included grain size distribution, moisture-density, shear strength, and loss on ignition (L.O.I.) testing to estimate coal percentage. Chemical tests included a determination of sulfate (SO_3) and pH levels in accordance with British National Coal Board Standards. It is of the utmost importance to compact coal refuse to its most dense state in order to eliminate the possibility of spontaneous combustion and acid drainage.

This report also discusses the construction procedures and field monitoring of a highway embankment containing 1.5 million cubic yards of anthracite breaker refuse. This embankment is part of the western approach of a bridge across the Susquehanna River between Forty Fort and Kingston in northeast Pennsylvania near Wilkes-Barre and is believed to be the first major project in the United States in which coal refuse was used. Shear strength and moisture-density design parameters are noted. Construction methods and equipment used in the placement of the embankment are explained, as is the instrumentation used in monitoring foundation response and ambient temperatures at locations within the embankment. Planned utilization of coal mine refuse in future Pennsylvania highway construction projects is also discussed.

8. Charmbury, H. B. and Chubb, W. R. "Operation Anthracite Refuse." Pennsylvania State University Special Research Report No. SR-94, January 15, 1973. 48p.

"Operation Anthracite Refuse" is the title of a four-year research study performed for the U. S. Bureau of Mines and Pennsylvania Department of Environmental Resources aimed at developing new ways to use anthracite refuse. The work was divided into three phases. The first phase was a complete literature survey to determine previous efforts made to utilize anthracite refuse. The second phase consisted of laboratory or small scale testing of possible uses. The third phase was field or large scale testing of promising uses determined from the laboratory tests.

Three (3) new uses were developed. All three involve the use of incinerated refuse. It was found that if this material was crushed and properly sized, it could be used as anti-skid material on snow-covered or icy roads, as a substitute for aggregate in bituminous wearing surfaces, and as a soil-less medium for the growth of plants and flowers.

9. Charmbury, H. B. and Maneval, D. R. "The Utilization of Incinerated Anthracite Mine Refuse as Anti-Skid Highway Material." In Proceedings; Third Mineral Waste Utilization Symposium. Chicago, Illinois, March 14 - 16, 1972. p. 123 - 128.

   During 1969, the Pennsylvania Department of Transportation evaluated incinerated anthracite refuse ("red dog") for possible use as an anti-skid material. Previous attempts to use unburned refuse were largely unsuccessful due to the presence of coal particles and the acid-forming nature of the material. A number of experiments were conducted with prepared incinerated refuse. These experiments confirmed that the material, when crushed and graded from one-half inch to one-eighth inch, is suitable for use as anti-skid material for highways.

10. Clark, Don A. "State-of-the-Art: Uranium Mining, Milling, and Refining Industry." Final Report, U. S. Environmental Protection Agency, Project No. 21-AGF-02, June, 1974. 113p.

    This report presents an overview of the uranium producing industry in the United States. Locations and capacities of uranium mines and mills are presented, along with a description of the mining and milling processes used to extract uranium from the ore. Characteristics of various types of uranium wastes and their environmental effects are discussed, including the problem of radium removal from mill effluents and tailings solids. The report is useful as background information on the generation of mill tailings and problems inherent in considering their possible use.

11. Collings, R. K.; Winer, A. A.: Feasby, D. G.; and Zoldners, N. G. "Mineral Waste Utilization Studies." In Proceedings; Fourth Mineral Waste Utilization Symposium. Chicago, Illinois, May 7 - 8, 1974. p. 2 - 12.

    Solid mineral wastes in Canada were classified in four (4) general categories: overburden, waste rock, mine and mill tailings, and metallurgical and chemical resi-

dues.

A laboratory study was conducted on tailing samples from Canadian metal mining operations. A number of the more promising samples were evaluated for possible uses, such as construction material, ceramic products, and mineral filler applications.

It was found that tailings samples from base metal mines were of little or no value due to high metallic sulphide contents. Tailings from gold and uranium mining contained relatively high percentages of quartz and showed some promise for use in glass and brick manufacture. Phosphogypsum showed considerable potential as a substitute for natural gypsum in the manufacture of gypsum products. High strength, low density concrete was made using expanded blast furnace slag pellets as lightweight aggregate. Tailings from an ilmenite processing plant are being investigated for use as aggregate in concrete and asphalt.

12. Cox, J. L. "Phosphate Wastes." In Proceedings; First Mineral Waste Utilization Symposium. Chicago, Illinois, March 27 - 28, 1968. p. 50 - 61.

This report discusses the waste disposal problem in the Florida phosphate industry. The biggest problem of phosphate mining in Florida is the handling and disposal of large quantities of colloidal clay wastes called slimes. The slimes constitute over half of all plant wastes and represent approximately one-third of the total matrix mined.

These slimes are deposited as a slurry having a solids content of four or five percent. Even after years of settling, they are still only thirty-five (35) to forty (40) percent solids. The particle size is very small with seventy-five (75) percent of the particles being less than three (3) microns. The chemical and mineralogical composition of these slimes is quite variable. A number of approaches has been attempted to utilize phosphate slimes, but to date there have been no significant breakthroughs. It is estimated that between twenty (20) and thirty (30) million tons of these slimes are produced annually in Florida.

13. Culbertson, William J., Jr., and Nevens, Thomas D. "Uses of Spent Oil Shale Ash." Denver Research Institute, University of Denver. Prepared for Colony Development Operation, August 21, 1972. 35p.

A marketing study was conducted to determine the possible uses of retorted or spent oil shale ash. The oil shale ash itself resembles a rather friable, black, silty material with an average particle size of 200 mesh. A number of potential markets were investigated for the rather sparsely populated northwestern Colorado area. At the present time, there do not appear to be any major markets within a 200-mile radius for any raw material that might be produced from spent oil shale ash. The potential amounts of this waste, which may be generated from a single medium-sized oil shale retorting plant, are so large (approximately 50,000 tons per day) that it will probably be economical to utilize only a small fraction of the available spent shale.

In the future, depletion of natural building materials in western Colorado will open up some potential markets for spent oil shale ash. The most promising of these potential markets are lightweight aggregate for use in structural concrete and cement production. It is possible that by 1980, approximately 500,000 tons per year of this material could be consumed. However, any possible use of this material will require some research and development work prior to marketing.

14. Dean, Karl C. "Utilization of Mine, Mill, and Smelter Wastes." In Proceedings; First Mineral Waste Utilization Symposium. Chicago, Illinois, March 27 - 28, 1968. p. 138 - 141.

The U. S. Bureau of Mines is conducting research on possible mineral waste uses at a number of its Metallurgy Research Centers. Among the work being done at the Salt Lake City research facility are studies of the utilization of by-products from the processing of phosphate rock, utilization of copper mill tailings, removal of vanadium and uranium from uranium mill tailings, and the conversion of mill tailings to simulated soil material.

Phosphate slimes were found to have limited use as fertilizer in citrus groves. Phosphogypsum is impure gypsum which presently has little commercial value. Calcium silicate slag, produced from the roasting of phosphate ores in electric furnaces, has been used as highway aggregate. Copper mill tailings have been successfully used in the manufacture of building brick. High percentages of vanadium and uranium have been leached from uranium mill tailings using sulfuric acid. It has been found that sewage sludge or compost, when added to fine mill tailings, provides sufficient bac-

teria to produce soils which support plant growth.

15. Eggleston, Howard K. "The Successful Utilization of Iron and Steel Slags." In Proceedings; Second Mineral Waste Utilization Symposium. Chicago, Illinois, March 18 - 19, 1970. p. 15 - 22.

The early history of the production and first uses of blast furnace slag are described. Even though a number of uses were developed for the slag by the early part of the twentieth century, only a small percentage of the slag was actually utilized before World War II. The techniques used in the successful transformation of slag from a waste product to an all-purpose aggregate with complete utilization are chronologically documented. Greater marketing efforts are needed in order to more fully utilize steel slags.

16. Emery, John J. "New Uses of Metallurgical Slags." Canadian Mining and Metallurgical Bulletin (CIM), Montreal, Canada, December, 1975. p. 60 - 68.

This paper discusses the present disposal and use trends of metallurgical slags in Canada. With the exception of blast furnace slag and some steel slag, much of the metallurgical slag in Canada is disposed rather than utilized. Although blast furnace slag is widely consumed, not enough advantage is taken of the cementitious nature of granulated or pelletized blast furnace slags, which are glassy products. The author recommends more energy-intensive uses of these slags in cement production and base stabilization. The use of glassy slags as binding medium in stabilized base construction is gaining momentum in Western Europe.

Because of the varying chemical composition and expansive nature of steel slags, their uses are more limited than blast furnace slags. These slags are first processed for recovery of ferrous metal. Principal uses of steel slag at the present time are for highway base and shoulder aggregate, railroad ballast, and miscellaneous fill. Because of high stability and skid resistance characteristics, the author recommends greater use of steel slag in asphalt concrete and slurry seal mixes.

Unfortunately, other slags produced in Canada are utilized minimally. These slags include by-products of copper, lead, zinc, and nickel production. It is recommended that any utilization consider material and energy values in order to attain full resources potential.

17. Emery, John J. and Kim, Chang S. "Trends in the Utilization of Wastes for Highway Construction." In Proceedings; Fourth Mineral Waste Utilization Symposium. Chicago, Illinois, May 7 - 8, 1974. p. 22 - 32.

The report describes the formation of a computerized waste utilization data bank, the Civil Engineering Reference Program Utilization (CERPU), developed by the Highway Materials Laboratory at McMaster University in Hamilton, Ontario, Canada. A study involving characterization and potential utilization of mining and metallurgical wastes was initiated in 1972 to develop an annotated bibliography on waste utilization. Research into the use of steel slags and taconite tailings in highway construction are discussed.

Steel slags have been found to be expansive due to hydration of chemically uncombined calcium or magnesium oxides. Unless allowances are made for these volume changes, steel slags must not be used in confined applications or as aggregate in Portland cement concrete. Steel slag use in bituminous concrete produces mixtures with very high Marshall stabilities and excellent skid resistance. Research is continuing into use of steel slag in precoated chippings and as aggregate for slurry seals.

Taconite tailings also produce bituminous concrete mixtures with high Marshall stabilities.

The skid resistance characteristics of these mixtures will be studied in future research. The steel slag and taconite tailings bituminous mixtures both exhibit extremely high densities (180 pounds per cubic foot), resulting in increased asphalt use and high transportation costs.

18. Fine, M. M. and Heising, L. F. "Iron Ore Waste-Occurrence, Beneficiation, and Utilization." In Proceedings; First Mineral Waste Utilization Symposium, Chicago, Illinois, March 27 - 28, 1968. p. 67 - 72.

The authors trace the development of this country's iron ore industry from the mining of high grade natural hematite ores to present benefication of low grade taconite ores, in which nearly four tons of waste are deposited for every ton of iron ore produced. As of 1964, more than 550 million tons of iron ore tailings had accumulated from iron mining, with nearly eighty percent of this total deposited in Minnesota and Michigan. An increasingly large amount of tailings are

being added to the dumps each year.

Most iron ore tailings are fine material in the form of a mineral slime, containing an average of twenty percent iron content. Although several tailings ponds have been reworked to reclaim the iron, lack of knowledge of the mineral content of the wastes and uncertainties regarding fee ownership of old stockpiles and tailings ponds act as deterrents to the use of iron ore wastes.

19. Fondriest, F. F. and Snyder, M. J. "Synthetic Aggregates for Highway Construction." National Cooperative Highway Research Program, Report No. 8, 1964. 13p.

As shortages of conventional aggregates become more acute and material demands increase, the manufacture of synthetic aggregates from a number of industrial waste products, as well as natural soils, will become more economically feasible. Existing synthetic aggregate sources, such as slags and clinkers, demolition waste, and lightweight aggregates produced by heat treatment of suitable clays and shales, are discussed. In addition, the authors note potential new aggregate sources, which include the heat treatment of finely divided by-product or waste materials, such as phosphate slimes, coal mine refuse, and steel furnace dusts. The possible uses of certain materials as synthetic aggregate in highway construction are presented in tabular form. It is recommended that planning and developmental work begin to make synthetic aggregates from widely available materials.

20. Gallup, George H. "White Pine Copper Company's Reverberatory Furnace Slag for Highway Aggregates." Michigan Department of State Highways and Transportation, Soils and Materials Section, Testing and Research Division, October, 1974. 25p.

Reverberatory furnace slag from the White Pine Copper Company in Ontonangon County, Michigan, has been tested by the Michigan Department of Highways and Transportation to evaluate the material for highway use. The slag particles are dense, hard, and glassy, have a vesicular pore structure, low absorption, and come in various colors. The coarse fraction meets requirements for soundness, abrasion, deleterious particle content, and has a high freeze-thaw durability factor. The fine fraction (minus No. 4 sieve size) fails to meet the mortar tensile strength test. The reverberatory furnace slag is approved for all highway aggre-

gate uses, except as fine aggregate for Portland cement concrete.

21. Gary, James H.; Feld, I. L.; and Davis, Edward G. "Chemical and Physical Beneficiation of Florida Phosphate Slimes." U. S. Bureau of Mines, Report of Investigations 6163, 1963. 35p.

Data is presented regarding the composition and physical properties of Florida phosphate waste slimes. Phosphate slimes are usually discarded from the washer at two to three percent solids. Even after years of settling in impoundments, the slimes rarely contain more than thirty percent solids. The feasibility of de-watering and beneficiating these slimes by several different methods is discussed.

The slimes generally contain from twelve to fourteen percent phosphorus. Physical beneficiation techniques, such as pressure filtration, flotation, cyclone sizing, and selective flocculation were used in an attempt to concentrate and recover these values. Acid leaching and ion exchange methods were also studied. None of the above methods of de-watering and beneficiating the slimes proved to be economical.

22. George, Harry D. "The Handling, Processing, and Marketing of Steel-Making Slag." In Proceedings; First Mineral Waste Utilization Symposium. Chicago, Illinois, March 27 - 28, 1968. p. 80 - 83.

The production, handling, processing, and utilization of open hearth, electric furnace, and basic oxygen furnace steel slags are discussed. Methods used for tapping each of these slags are described. The magnetic portion of steel slags must be removed prior to crushing and sizing. There is also a brief discussion of various uses of steel slags, including several highway uses.

23. Gromko, Gerald J. "A Preliminary Investigation of the Feasibility of Spent Oil Shale as Road Construction Material." Fifty-Fourth Annual Meeting of the Transportation Research Board. January 13 - 17, 1975.

This paper presents the findings of a laboratory investigation into the engineering properties of spent oil shale for use in bituminous paving mixtures. A number of physical tests were performed, including sieve analysis, specific gravity, Los Angeles abrasion, and the Hveem design method for asphalt mix design. Test

findings indicate that spent oil shale is a dense, well-graded material composed of flat, angular particles with a rough surface texture. Asphalt paving mixtures studied possessed high stability and resistance to stripping. Further evaluation of durability under the effects of weather and traffic is needed before recommending the use of spent oil shale mixtures for surface courses of high-type roads.

24. Guerra, Fabian. "Characteristics of Tailings from a Soils Engineer's Viewpoint." In Proceedings; First International Tailing Symposium. Tucson, Arizona, October 31 - November 3, 1974. p. 102 - 137.

The geotechnical and mineralogical characteristics of two (2) iron ore tailings sources from the Labrador Peninsula are presented. The grain size distribution, moisture-density, plasticity, permeability, shear strength, and consolidation of these tailings are discussed. The possible use of these materials for various engineering purposes is examined. It is concluded that sand-type tailings have a wide application as an engineering construction material for such uses as tailings dams, pipe bedding, fill material, and as a component of soil-cement mixtures. On the other hand, silt-type tailings are difficult to compact and are susceptible to frost action and severe erosion; therefore, they are not recommended for construction use, but should only be considered as sealants of pervious sands.

25. Gutt, W. "Aggregates from Waste Materials." Chemistry and Industry, 1972. p. 439 - 447.

This paper reviews the present state-of-the-art of waste material use as construction aggregate in Great Britain and discusses future prospects for increased utilization. A table is presented which shows the location and quantities of principal solid wastes produced, methods of disposal, and current uses. Materials discussed in detail as existing aggregate sources include blast furnace slag, steel slag, pulverized fuel ash (fly ash), colliery wastes (coal refuse), slate waste, and various metallurgical slags.

Future prospects include increased use of blast furnace and steel slags as polish-resistant roadstone, continued bulk fill and sub-base uses for colliery shales, use of incinerator residue as sub-base and fine aggregate, and local utilization of slate waste. Successful application of wastes has been more achiev-

able when the by-product is offered as a dense aggregate rather than a lightweight aggregate, primarily because of economics. Innovations are needed in the transport of suitable wastes to areas where aggregate demand is great.

26. Hansen, Torben C.; Richard, Cedric W.; and Mindess, Sidney. "Production of High-Pressure Steam-Cured Calcium Silicate Building Materials from Mining Industry Waste Products. Part I: Program for Investigation and Report of Field Survey of Siliceous Mine Wastes in California." U. S. Bureau of Mines, Technical Report No. 86, January, 1968. 83p.

    Although this investigation is directed toward an evaluation of siliceous mine waste for possible use as calcium silicate building units, this report is of value because it describes in detail the locations and descriptions of lode tailings and placer deposits in the California gold mining districts.

27. Hollinger, R. H. "Utilization of Coal Dust Slurries." Final Report, U. S. Bureau of Mines, Contract No. 14-09-0070-380. June, 1969. 54p.

    A series of laboratory experiments was conducted at the Franklin Institute Research Laboratory to determine the feasibility of using coal washing fines in construction materials, particularly concrete masonry building units. A large number of cube specimens were prepared and tested for compressive strength and freeze-thaw resistance using various sources, gradations, and quantities of coal washing fines. Water permeability tests were conducted to determine the effect of adding coal washing fines on the rate of water penetration in concrete masonry units. It was found that the use of minus 100 mesh coal washing fines in concrete block improved the resistance of the block to water penetration while maintaining adequate compressive strength.

    An economic analysis of the production of block containing coal washing fines was also carried out. It was determined that production and shipping costs restrict the distance such products could be shipped to a maximum of forty-five miles from the washing plant.

28. Howard, Gary Grant. "A Laboratory Investigation of the Properties of Coal-Bitumen Paving Mixtures." University of Kentucky, College of Engineering, Bulletin No. 71, March, 1964. 46p.

The principal objective of this study was to investigate the feasibility of using coal and, to a lesser extent, coal mining waste, as an aggregate in bituminous paving mixtures. Materials evaluated were coal, coal refuse, and "red dog." A locally available crushed limestone was used in control mixes. Bituminous binders used were a rapid-curing asphalt cement cutback, a road tar, and a slow-setting asphalt emulsion. These binders were selected so that heating the aggregates and bitumens prior to mixing would not be necessary.

All bitumen-aggregate mixtures were evaluated by the immersion-compression test at optimum binder content. For "red dog" and refuse mixtures, the optimum binder content was selected as that which produced mixtures having the highest compressive strength corresponding to at least six percent voids in the compacted specimens.

Bitumen-aggregate mixtures containing coal refuse or "red dog" as aggregate have sufficient unconfined compressive strength, but insufficient retained strength, to meet recommended criteria. It was concluded that mixtures containing these aggregates may fail when exposed to water. Low air voids contents and degradation of aggregate are also problems associated with these mixes.

29. Hughes, Michael L. and Halliburton, T. Allan. "Use of Zinc Smelter Waste as Highway Construction Material." Highway Research Record No. 430, 1973. p. 16 - 25.

Slag wastes from zinc smelters, located at Blackwell and Henryetta, Oklahoma, were evaluated for possible use in sand-asphalt paving mixtures, Portland cement concrete mixtures, and stabilized base course mixtures. The smelter wastes were essentially cohesionless materials having sharp, angular particles graded from ½-inch top size down to 200 mesh and varying in color from black to red to reddish-yellow. Since none of the smelter wastes had a natural gradation within specification limits for sand-asphalt mixtures, additional fines were added in the form of fine naturally occurring sand. The Hveem-Gyratory method of mix design was used during the study. Minimum values of stability were exceeded. Addition of smelter waste to asphalt concrete wearing surface mixtures should increase the skid resistance of the mix.

Because of cement-aggregate reactivity, zinc smelter

wastes should not be used in Portland cement concrete mixtures. However, they appear satisfactory for use as fine aggregate in stabilized base courses.

30. Huttl, John B. "Germans Succeed in Making Building Stones from Mill Tailings and Flyash." Engineering and Mining Journal, November, 1960. p. 94 - 96.

Flotation tailings from a 1,000 ton-per-day lead-zinc concentrator are combined with fly ash from a coal-burning power plant to produce steam-hardened building bricks at the Gewerkschaft Auguste Victoria in Marl, Westphalia, Germany. The flotation tailings are filtered to separate filter sands for use while disposing of the finer slimes in a dewatering pond. The bricks meet the specification requirements for conventional bricks, but when the portion of fly ash exceeds thirty percent, the bricks are not frost-resistant.

Because of changes in the operation of the power plant boilers, molten boiler slag is now utilized instead of fly ash. Therefore, fifteen percent filter sands are now combined with twenty-five percent granulated boiler slag, and sixty percent natural sand to produce 270,000 bricks per day. The company has also investigated the possibility of using flotation slimes with fly ash and cement in the production of porous concrete.

31. Illinois Institute of Technology Research Institute. "Utilization of Foundry Waste By-Products." Report to American Foundrymen's Society, IITRI Project. No. G8020, February 25, 1969.

This report classifies and describes the principal types of solid waste by-products generated by the casting of metals in the foundry industry. An evaluation is made of various possible uses for these by-products and they are ranked in order of greatest potential. A study was also made of the probable cost of transporting these materials by rail and barge. A detailed explanation is made in this report of the rationale for determining freight rates for each mode of transport.

32. Illinois Institute of Technology Research Institute. "Utilization of Red Mud Wastes for Lightweight Structural Building Products." Final Report to U. S. Bureau of Mines, Contract No. 14-09-0070-386, August 23, 1968. 41p.

A survey was made of the aluminum processing plants which are producing red mud wastes in the extraction

of alumina from bauxite ore. Characterization studies were performed on a typical red mud sample by chemical analysis and X-ray diffraction methods. An experimental program was conducted to determine the feasibility of producing a lightweight building material by foaming and sintering compositions containing red mud, clay, and various additives. It was concluded that lightweight materials can be produced from these compositions, although these materials do not have the strength of competitive building materials.

33. Illinois Institute of Technology Research Institute. "Waste Utilization Project for Florida Phosphate Slime." Final Report, U. S. Environmental Protection Agency, Water Quality Office, Grant No. 14050EPU, January 15, 1971. 37p.

Several possible uses for phosphate slime were investigated. The production of lightweight aggregate was found to be technically feasible by pelletizing in a rotary disc agglomerator and firing in a rotary kiln at 1050° to 1150° C. Tests were run on concrete mixtures using these lightweight aggregates with the proper proportioning, the lightweight concrete mixtures were found to generally conform to the strength and density requirements of ASTM Designation C-330. Economic evaluations of different potential uses indicated that lightweight aggregate showed the most marketing potential. A characterization of dried and slurried phosphate slimes is also presented.

34. Jimerson, G. David and Wyatt, William V. "The Location and Potential Use of By-Products in Arkansas." National Technical Information Service, Catalog No. PB 230 953, August, 1973. 107p.

A survey was made of industries in rural Arkansas to determine the types and quantities of solid wastes which are produced in these areas. The by-products were classified as wood, paper, metals, agricultural, leather and cloth, glass, minerals, and polymeric waste. Total monthly amounts of these wastes are summarized and indicated on maps according to highway districts in the state. A list is included of all companies supplying information and their respective locations.

Some laboratory testing was performed. The results of these tests are presented. By-products recommended for direct use by the Arkansas Highway Department include slag, used concrete, cement kiln stack dust, glass, barite tailings, and classifier sand. A comprehensive

list of wastes that have been used by other state highway departments is also included.

35. Josephson, G. W.; Sillers, F., Jr.; and Runner, D. G. "Iron Blast Furnace Slag: Production, Processing, Properties, and Uses." U. S. Bureau of Mines, Bulletin No. 479, 1949. 304p.

This publication contains more information about blast furnace slag than any other work on the subject. The methods of producing and processing blast furnace slag are described with the aid of photographs. Principal producers of blast furnace slag are shown on a map of the United States. A detailed description is given of the properties of blast furnace slag and the methods used to determine and evaluate these properties. Several sections of the report are devoted to documenting the uses which have been made of blast furnace slag, including specifications and recommended mix design and construction procedures for using blast furnace slag as aggregate in Portland cement concrete and asphalt base and surface mixtures.

36. Kandahl, P. S.; Wenger, M. E.; and Schmidt, G. H. "Expansive Characteristics of Open Hearth Slag." Pennsylvania Department of Transportation, Bureau of Materials, Testing, and Research, Project No. 69-11, October, 1970. 39p.

An investigation was conducted by the Pennsylvania Department of Transportation during 1969 to determine the degree of expansion of slag produced in open hearth steel furnaces and the time required for proper seasoning of the slag. Specimens of open hearth slag were subjected to normal and accelerated curing conditions and their expansive characteristics were measured. The expansive characteristics of bituminous concrete mixtures using open hearth slag as aggregate were also determined.

The report concludes that open hearth slag has expansive characteristics when exposed to moisture, even in bituminous concrete mixtures. A twelve-month curing period in a controlled stockpile is recommended for open hearth slag prior to its intended use. This will allow sufficient expansion to cover variable seasoning rates caused by non-uniform chemical composition and gradation.

37. Lake, J. R.; Fraser, C. K.; and Burns, J. "Laboratory Investigation of the Physical and Chemical Properties

of Spent Oil Shale." Roads and Road Construction, June, 1966. p. 155 - 159.

An investigation was made by the Road Research Laboratory into the variability and physical and chemical properties of spent oil shale to determine the suitability of this material for use in road construction. Samples of five (5) different sources of spent oil shale from Uphall, West Lothian, Scotland, were obtained for testing. Laboratory tests included natural moisture content, gradation, specific gravity, water absorption, permeability, compaction, California bearing ratio, and frost susceptibility.

Results of these tests are presented and discussed. The materials were found to be similar in gradation and compaction characteristics. Addition of five (5) percent cement was sufficient to reduce frost heave in all specimens to acceptable values. The report concludes that the shales tested were suitable for road fills and sub-bases, but it is necessary to examine individual material sources prior to road-building use.

38. LaRosa, Paul J.; Karnavas, James A.; and Pelczarski, Eugene, A. "Carbonate Bonding of Coal Refuse." Black, Sivalls, and Bryson, Inc., Environmental Protection Agency, Water Quality Office, Grant 14010 FOA, February, 1971. 44p.

A laboratory study was made of the variables which affect the properties of carbonate bonded coal refuse. The carbonate bonding process consists of mixing coal refuse with water and lime hydrate, compacting the mixture, and reacting it with a carbon dioxide-rich gas to form a coherent structure bonded by a matrix of calcite crystals. The resulting carbonate bonded refuse can be used to seal coal refuse piles or to construct a stabilized road base material.

Four (4) types of coal refuse were investigated. They included relatively unoxidized and highly oxidized anthracite and bituminous coal refuse. Compressive strengths from 2200 to 4400 psi were obtained by bonding these types of refuse using up to twelve percent lime hydrate and nine to fifteen percent moisture content. Compressive strength was found to increase with increases in lime hydrate content, reaction time, and carbon dioxide concentration.

A cost comparison was made between carbonate bonding of coal refuse and the use of other construction mate-

rials and techniques. Findings of this comparison indicate that the carbonate bonding process is the least costly means available for coal refuse pile sealing and road building.

39. LaRosa, Paul J.; Ricciardella, K. A.; and McGarvey, R. J. "Carbonate Bonding of Taconite Tailings." Report No. EPA-670/2-74-001, Office of Research and Development, U. S. Environmental Protection Agency, Washington, January, 1974.

    This study parallels an earlier investigation using the carbonate bonding technique with coal refuse. In the laboratory, compressive strengths of 4000 psi were obtained from briquette specimens of taconite tailings (three to five percent moisture content) mixed with twenty percent lime hydrate and reacted with carbon dioxide-rich gas. The highest compressive strengths were obtained using dolomitic lime hydrates with high carbonate bonding reaction times.

    Five test plots (each 1.2 meters square) were placed to demonstrate carbonate bonding of taconite tailings under actual field conditions. Due to inclement weather and limitations of plot sizes, sufficient field compaction could not be attained. Additional work is required to develop parameters for field application of carbonate bonding of taconite tailings. Approximate cost comparisons indicate that the cost of carbonate bonding is comparable to that of conventional road construction materials and represents a cost saving in the construction of high class roads.

40. Lenhart, Walter, B. "Aggregates from Mine Waste." Rock Projects, May, 1950. p. 94 - 95.

    Waste rock from Bethlehem Steel Company's iron ore mine at Cornwall, Pennsylvania, was processed and used as commercial aggregate to supply requirements for the extension of the Pennsylvania Turnpike eastward from Carlisle to King of Prussia. The material is a limestone intermixed with some magnetics. A detailed description is given of the equipment used in the loading, crushing, and screening operations at the processing plant.

41. Little, Arthur D., Inc. "Analysis and Markets of Taconite Waste Products." Report to Reserve Mining Company, June 19, 1970. 59p.

    This report presents the findings of a study involving

the possibility of utilizing tailings from taconite processing at Silver Bay, Minnesota, either in their entirety or in part as a raw material for the building and construction industry. An economic and marketing analysis was made of the sand and gravel market in the Great Lakes region. Major population centers surveyed included Chicago, Cleveland, Detroit, Milwaukee, Minneapolis-St. Paul, Toledo, Toronto, Erie, and Buffalo. The cost of moving the taconite tailings was studied for barge and rail transportation. A detailed economic analysis was made of the cost of equipment and operations necessary to reclaim and produce specification material from taconite tailings.

Sand and gravel products cannot be marketed at Great Lakes ports for prices exceeding $2.15 per ton. The total break-even costs for producing sand and fine aggregate from tailings at Silver Bay and delivering to docks at lower lake ports are estimated to be $2.45 per ton. The report concluded that sand and gravel products from taconite tailings cannot be sold in the Great Lakes market area at prices high enough to cover operating, transportation, and unloading costs.

42. Little, A. D., Inc. "Economic Analysis of Proposed Effluent Guidelines. The Industrial Phosphate Industry." Final Report, U. S. Environmental Protection Agency, Contract No. 69-01-1541, November, 1974. 49p.

This report is primarily a discussion of the economic impact of proposed waste effluent guidelines upon certain products in the industrial phosphate industry. However, it is useful insofar as it describes the production of phosphorus and phosphate slag and lists the major phosphorus producers and the locations of operating phosphorus furnaces.

43. Luckie, P. T.; Peters, J. W.; and Spicer, T. S. "The Evaluation of Anthracite Refuse as a Highway Construction Material." Pennsylvania State University, Special Reserach Report No. SR-57, July 30, 1966. 66p.

One (1) raw refuse sample and two (2) beneficiated refuse samples, all from the same source of anthracite refuse, were submitted to the Pennsylvania Department of Transportation. The two (2) beneficiated samples represented the removal of coal and pyrites. Although some physical properties, such as the Los Angeles abrasion, were satisfactory, high percent weight losses in the sodium sulfate soundness test justified rejection of the material as aggregate in base or sub-base pave-

ment layers. Possible suggested highway uses are in shoulders and embankments. The study concluded that beneficiated refuse improves its quality, but makes it more costly than regular aggregates. Therefore, the material should not be extensively used in highway construction.

44. MacCartney, John C. and Whaite, Ralph H. "Pennsylvania Anthracite Refuse: A Survey of Solid Waste from Mining and Preparation." U. S. Bureau of Mines Information Circular No. 8409, 1969. 77p.

This report presents the findings of a survey of anthracite refuse bank locations and characteristics conducted in 1966 by the Bureau of Mines in northeastern Pennsylvania. A total of 863 refuse banks were identified from this survey. These banks occupy a total area of approximately nineteen square miles and contain over 910 million cubic yards of material. The majority of the refuse is located within two miles of populated areas. All refuse banks are plotted on location maps and pertinent information on each bank is presented in tabular form.

45. Maneval, David R. "Recent Foreign and Domestic Experience in Coal Refuse Utilization." In Proceedings; First Symposium on Mine and Preparation Plant Refuse Disposal, Louisville, Kentucky, October 22 - 24, 1974. p. 256 - 262.

Coal mine refuse has been used in a number of applications in Europe, especially in the past ten years. In Germany, cement-stabilized coal refuse bases are used to prevent frost heave. Lightweight aggregate from fired coal refuse is currently being used in Poland as fill for building construction panels. The Dutch have used coal refuse as fill material in large open pit excavations and are considering its application for future dike construction.

So far, the greatest use of coal refuse has been in Great Britain. The British have developed extensive information on the engineering properties and compactive techniques needed for the construction of properly designed embankments using coal refuse. The key to utilizing coal refuse in such applications is proper compaction of the refuse. Coal refuse is also used in cement-stabilized base courses and in the manufacture of cement, brick, and lightweight aggregate.

Coal refuse use in the United States has been limited

to date. Future efforts by government and industry should be directed toward construction programs where coal refuse can be utilized on a much greater scale.

46. Maneval, David R. "Utilization of Coal Refuse for Highway Base or Sub-Base Material." In Proceedings; Fourth Mineral Waste Utilization Symposium. Chicago, Illinois, May 7 - 8, 1974. p. 222 - 228.

Considerable experience has been developed since 1966 in Great Britain for analyzing and utilizing coal refuse in highway construction. Although burnt colliery spoil has been used for many years in the United Kingdom, a great deal of concern existed regarding the use of unburnt colliery spoil. The primary objections to its use were the potential for spontaneous combustion and the generation of acid-bearing leachate.

Research has indicated that unburnt refuse can be used as fill material for highways in large quantities, provided it has been satisfactorily compacted. Data on Proctor moisture-density, combustion potential, leaching and swelling indexes, and freeze-thaw and wet-dry tests are required by the British for all refuse being considered for highway use. Criteria have been developed for soluble sulfate content and residual air voids.

Aside from the use of coal refuse as highway embankment material in Northeast Pennsylvania and some past instances where it has been used to construct work roads at mining areas, there has been little or no use of coal refuse for highway construction in the United States.

47. Marek, Charles R.; Herrin, Moreland; Kesler, Clyde E.; and Barenburg, Ernest J. "Promising Replacements for Conventional Aggregates for Highway Use." National Cooperative Highway Research Program, Report No. 135, 1972.

A number of options are discussed to provide supplementary sources of construction aggregate, including the utilization of wastes. Areas are identified where shortages of conventional aggregate are now occurring and the capability of projected aggregate supplies to meet future demands is analyzed. Desirable aggregate properties are discussed in detail. Recommendations are made for needed research of promising aggregate replacements, beneficiation techniques, or means of otherwise alleviating aggregate shortages.

48. McNay, Lewis M. "Coal Refuse Fires, An Environmental Hazard." U.S. Bureau of Mines Information Circular No. 8515, 1971. p. 50.

In 1968 the Bureau of Mines located and examined a total of 292 burning coal refuse banks throughout the coal-producing regions of the United States. The locations of these burning refuse banks are presented by individual state maps in areas of occurrence and pertinent data relative to location and size of each bank is tabulated on an individual state basis. The nature and origin of coal refuse, causes and environmental impacts of coal refuse fires, and techniques to control such fires are also discussed.

49. McNay, Lewis M. "Mining and Milling Waste Disposal Problems - Where Are We Today?" In Proceedings; Second Mineral Waste Utilization Symposium. Chicago, Illinois, March 18 - 19, 1970. p. 125 - 130.

This report presents a good overview of the technical and economic factors that influence the handling of mining and milling wastes. The generation of these wastes is continually increasing. Degrading environmental effects of these waste accumulations are noted. In all probability, these waste materials will never be totally utilized; the amounts generated are far too great.

Several alternatives are available. The materials can be intelligently disposed, made to blend into the surrounding landscape, and the land put to a useful purpose. It may be economically feasible to dispose of the waste underground for use as mine support. More preferable is the recovery of mineral value or development of useful products from these materials.

50. Mellot, Dale B. "Anthracite Refuse in ID-2A Bituminous Concrete." Pennsylvania Department of Transportation, Bureau of Materials, Testing, and Research, Project No. 70 - 8, July 23, 1970. 10p.

Burned-out anthracite refuse ("red dog") was investigated for possible use as an aggregate in bituminous concrete mixes. Nearly 1400 tons of shale refuse from the Huber colliery near Ashley, Pennsylvania was used as aggregate in four experimental resurfacing projects in Luzerne County, involving approximately 30,000 square yards of paving. All mixes were within gradation limits for ID-2A wearing surface mixtures.

Asphalt contents averaged 8 percent for these mixes.

Marshall stability values all exceeded 2200 pounds; however, flow values were often found to be in excess of specification limits. Some problems were encountered in the field due to wet conditions and improper rolling procedures. Coverage was increased more than thirty percent due to the low specific gravity of the mixes. Initial skid resistance values were found to be equal to the control material.

51. Miller, Richard H. and Collins, Robert J. "Waste Materials as Potential Replacements for Highway Aggregates." National Cooperative Highway Research Program, Final Draft Report, Project Number 4-10/A, November, 1973.

An inventory was made of the types, sources, and quantities of solid wastes which are potentially suitable for the production of aggregate. The technical, economic, and environmental aspects of using such wastes as replacements for aggregates in highways were evaluated. A classification system was developed for determining the most suitable waste materials for this purpose. A number of materials are specifically recommended for further developmental work and utilization as aggregate in highway construction. In addition, an analysis of conventional aggregate supply and demand is also presented.

52. Moulton, L. K.; Anderson, D. A.; Seals, R. K.; and Hussain, S. M. "Coal Mine Refuse: An Engineering Material." In Proceedings; First Symposium on Mine and Preparation Plant Refuse Disposal. Louisville, Kentucky, October 22 - 24, 1974. p. 1 - 25.

Results of laboratory and field investigations of the engineering properties of coal mine refuse are summarized in this report. Fresh and aged samples of coal refuse used for the laboratory studies were obtained from four mines in northern West Virginia. Physical tests included grain size distribution, specific gravity, Atterburg limits, loss on ignition, Los Angeles abrasion, standard Proctor compaction, degradation on compaction, permeability, shear strength, slaking, relative density, and compressive strength development after stabilization with flyash, lime and/or Portland cement.

A wide range of variability was found in the basic physical properties of coal mine refuse, not only from different refuse sources or degrees of weathering,

but also from sample to sample from the same source.

The findings of this investigation essentially confirm the results of similar testing conducted on colliery spoils by the British. The report concludes that much additional research on coal refuse is needed and the coordinated efforts of government, industry, and universities are required.

53. Myers, J. W.; Pfeiffer, J. J.; and Orning, A. A. "Production of Lightweight Aggregate from Washery Refuse." U. S. Bureau of Mines, Report of Investigations No. 6449, 1964. 19p.

The Bureau of Mines, in cooperation with Truax-Traer Coal Company of Ceredo, West Virginia, investigated the feasibility of using coal washery refuse in the manufacture of lightweight aggregate for building materials. A plant capable of handling 120 tons of coal refuse per day was placed into operation during 1955. A chain-grate stoker with an updraft air system was used for combustion rather than a downdraft sintering system or rotary kiln, so that the combustible matter in the refuse would supply the heat of reaction.

The refuse was crushed to passing 1/4 inch size. Pelletizing was used to prepare the refuse for the stoker. Although refuse samples from different sources have widely varying combustion and sintering characteristics, coal refuse can be converted into satisfactory aggregate for use in the manufacture of lightweight concrete blocks by burning on a chain-grate stoker. The product was found to meet the requirements of ASTM Designation C 130 for lightweight aggregate.

54. Nakamura, H. H.; Bortz, S. A.; and Schwartz, M. A. "Use of Bauxite Wastes for Lightweight Building Products." American Ceramic Society Bulletin, Vol. 50, No. 3, March, 1971. p. 248 - 250.

Red mud from Jamaican bauxite was characterized for composition, particle size distribution, pyrometric cone equivalent, and specific gravity. The red mud is found either as a slurry (containing 20 to 25 percent solids) or as a dry residue. Experimental studies confirm that lightweight material can be produced from these residues by mechanical foaming and the use of clay binders and foaming agents. The density of the foamed compositions can be controlled by varying the mixing time. The strength of the foamed compositions

was found to be comparable to that of foamed concrete, foamed fly ash, and other lightweight foamed products.

55. Nakamura, H. Henry; Aleshin, Eugene; and Schwartz, M. A. "Utilization of Copper, Lead, Zinc, and Iron Ore Tailings." In Proceedings; Second Mineral Waste Utilization Symposium. Chicago, Illinois, March 18 - 19, 1970. p. 139 - 148.

The location and available quantities of the most significant accumulations of copper, lead, zinc, and iron ore tailings are noted and various current uses for these materials are discussed. An analysis of the grain size distribution and chemical composition of these materials is presented in this report. An analysis was made of the potential for producing foamed, fired lightweight aggregates from these materials. A techno-economic survey was also made of the marketing potential of each of these tailings as a lightweight building material. Taconite tailings were most highly recommended for this purpose.

56. National Academy of Sciences. "Underground Disposal of Coal Mine Wastes." Report to the National Science Foundation, Washington, D.C., 1975. 172p.

This report assesses the technical and economic feasibility of various methods of underground backfilling of mine voids using coal refuse. Trends of coal waste production and properties of coal waste are discussed. The feasibility of alternatives to disposal of underground coal wastes is considered, including the use of coal refuse as construction fill, lightweight aggregate, cement-stabilized base material, aggregate in asphaltic highway mixes and as anti-skid material.

The report concludes that underground waste disposal of coal refuse is technologically feasible in most instances, but not economically feasible in many operations, especially in currently operating mines. More consideration should be given to coal mine waste as a potential resource. However, at the present time, the only prospect for utilizing large quantities of coal mine waste appears to be for construction fill. Although technically promising, the use of coal waste for lightweight aggregate or anti-skid material would involve relatively small quantities.

57. National Commission on Materials Policy. "Material Needs and the Environment-Today and Tomorrow."

U.S. Government Printing Office, Washington, D.C., June, 1973.

This report presents the recommendations of the National Commission on Materials Policy made to the President and Congress of the United States regarding the interrelationships between materials, energy, and the natural environment. The role of minerals in the American economy is detailed, including supplies and uses of mineral and energy resources and their flow through the production and consumption system. A number of interesting and provocative chapters are included in this report, covering items such as land use; supply, use, and recovery of materials; environmental factors in materials policy; and energy and materials.

The most pertinent chapter in this report concerns the disposition of wastes. Sources of solid wastes are identified and quantified. The origin and nature of various mineral wastes are noted. The Commission recommends that industry dispose of wastes, including mine tailings, in a manner to facilitate eventual recovery of valuable resources.

58. Paone, James; Morning, John L.; and Giorgetti, Leo. "Land Utilization and Reclamation in the Mining Industry, 1930 - 71." U.S. Bureau of Mines, IC 842, 1974.

Detailed summaries are provided of the acreage of land utilized for mining and land reclamation in each state over a forty year period. The amount of land used by principal mineral industries in each state over the same time period is also presented. Land utilization and reclamation in the principal mining states is discussed in detail. Comparisons are also made of the principal mineral industries.

59. Peters, James W.; Spicer, T. S.; and Lovell, H. L. "A Survey of the Location, Magnitude, Characteristics and Potential Uses of Pennsylvania Refuse." Pennsylvania State University, Special Research Report No. SR-67, January 25, 1968.

The history of anthracite mining and preparation in Pennsylvania is discussed, along with known attempts to make use of anthracite refuse. A total of 157 culm banks and 113 silt banks are tabulated and mapped. Considerable data was developed from a sizing

and washability evaluation of samples collected from the four anthracite coal fields in Northeast Pennsylvania. Based on a study of past use of anthracite refuse, the report recommends the following:

1. Anthracite refuse be considered as a source of low-grade coal for producing electric power.

2. Consideration should also be given to using the material in underground stowage to prevent mine subsidence.

3. Some intermediate gravity fractions could be considered for use as lightweight aggregate.

An earlier report by Luckie, Peters, and Spicer concluded that anthracite refuse would probably be acceptable for highway use only as embankment material.

60. Pettibone, Howard C. and Kealy, C. Dan. "Engineering Properties and Utilization Examples of Mine Tailings." In Proceedings; Third Mineral Waste Utilization Symposium. Chicago, Illinois, March 14 - 16, 1972. p. 161 - 169.

Engineering properties of tailings samples from nine mines are summarized. Gradation, specific gravity, relative density, and triaxial shear test results are presented. The utilization of mine tailings in the construction of an earth dam and an interstate highway embankment are discussed.

61. Pincus, A. G. "Wastes from the Processing of Aluminum Ores." In Proceedings; First Mineral Waste Utilization Symposium. Chicago, Illinois, March 27 - 28, 1968. p. 40 - 49.

This paper describes the production of red muds and brown muds resulting from the processing of alumina from bauxite. These muds are essentially clay-like slimes of high pH, high in iron and trace elements, and deposited at 20 percent solids content. Several uses have been attempted for the material, but none have been sustained in sizeable volume.

Research was conducted on producing foamed building units directly from these slurries. The foaming of these wastes was done successfully on a laboratory scale. Minor proportions of additives can be used to

control porosities and produce structural blocks with comparable strengths to existing competitive materials. These units exhibit superior thermal insulation and acoustical properties at low densities.

62. Ramsey, D. E. and Davis, R. F. "Fabrication of Ceramic Articles from Mining Waste Materials." Ceramic Bulletin, Vol. 54, No. 3, 1975. p. 312 - 313.

Research was conducted at North Carolina State University into the fabrication of potentially useful products from phosphate mine overburden and tailings consisting of 85 percent quartz and found primarily in the - 14 to + 100 mesh screen size range. A skid resistant highway aggregate was fabricated using 10 percent sodium carbonate addition fired at 920°C. for 1 hour to produce a water insoluble glass bond and controlled porosity. The sintered material was crushed, sized, and impregnated into 6 inch asphalt cylinders and evaluated for skid resistance and polishing. Comparisons were made with control samples of crushed stone and bloated shale aggregates having known wear and skid resistance properties. The experimental aggregate was found to be superior in frictional resistance to that of the commercial materials.

63. Smith, A. D. "Stabilized Unburnt Colliery Shale. An Investigation into the Feasibility of Using Stabilized Colliery Shale as a Road Base or Sub-Base Material." Kent County Council Materials Section, Report No. 11. AGW/S.7, March, 1972. 18p.

A large-scale field trial was undertaken during 1971 at the Chislet Colliery in Kent County, Great Britain to determine the properties of cement stabilized unburnt colliery shale for possible use as road base material. Two strips of three bays each were laid 6 inches thick within side forms on a hard and soft subgrade and subjected to varying compactive efforts. The trial mix selected was composed of 100 parts dry weight unburnt spoil material (passing a 2 inch sieve), 10 parts cement, at a 7 percent ($\pm$ 1 percent) moisture content.

Laboratory tests were conducted to determine particle size distribution, moisture content, bulk density, and seven day cube strength. Field data was obtained by in-place density tests, corings, and nuclear density readings. Six or eight passes using different rollers produced acceptable compaction on both soft and hard subgrades. All seven day cube strength

specimens exceeded the 500 psi minimum crushing strength specification requirement of the Ministry of Transport. Therefore, stabilized unburnt colliery shale is recommended for use as cement-bound granular material or as stabilized sub-base.

64. Smith, Joseph W. "Processing and Utilization of Steel-Making Slags." In Proceedings; Third Mineral Waste Utilization Symposium. Chicago, Illinois, March 14 - 16, 1972. p. 51 - 54.

A history of the development of techniques used for processing steel slags is described. The steps involved in a typical processing and scrap recovery operation are detailed, along with other tasks now being performed for steel companies by slag processors. The author mentions the physical and chemical properties of steel slag and their effect on the use of this material in road building. Problems with the disposal and recycling of steel furnace dusts are also noted.

65. Specht, R. C. and Herron, W. E., Jr. "Lightweight Aggregate From Phosphate Slimes." Rock Products, May, 1950. p. 96 - 97.

This paper summarizes the findings of an investigation conducted by the Engineering and Industrial Experiment Station of the University of Florida into the suitability of Florida phosphate slimes for the production of lightweight aggregate. Five slime samples from different plants were collected, dewatered, extruded into pellets, dried, and fired for approximately 10 minutes at bloating temperatures between 2000° and 2200°F. Four different techniques were used for dewatering the slimes prior to extrusion. The authors conclude that phosphate slimes will produce excellent lightweight aggregates, but cannot compete commercially with available clay deposits which will produce a product of equal quality and weight.

66. Spicer, T. S. "Pennsylvania Anthracite Refuse. A Summary of a Literature Survey on Utilization and Disposal." Pennsylvania State University, Special Research Report No. SR - 79, March 15, 1971. 43p.

A review was made of available literature pertaining to anthracite refuse to determine the most promising alternatives for using this material. Possible uses included landfill and backfill, low grade fuel recovery, filling mine voids, highway construction,

lightweight aggregate, mineral wool, gas production, and as a soil-less media for growing crops.

The only highway construction use recommended for anthracite refuse is as an embankment material. Coal refuse has been used in the construction of shoulders along the Northeast extension of the Pennsylvania Turnpike, and with some success as a stabilized sub-base material. When previously used as a concrete aggregate, the concrete weathered badly. Lightweight aggregate has been manufactured from anthracite and bituminous coal refuse in Pennsylvania and used in concrete blocks.

67. Spicer, T. S. and Luckie, P. T. "Operation Anthracite Refuse." In Proceedings; Second Mineral Waste Utilization Symposium, Chicago, Illinois, March 18 - 19, 1970.

This paper presents an overview of the problem of solid waste disposal in the anthracite region of Northeastern Pennsylvania. The history of coal mining in this area is traced. A description is made of the physical characteristics of "average" anthracite refuse. A summary is made of refuse bank locations according to size and type of material.

"Operation Anthracite Refuse" has as its objective to establish approaches for utilizing or better disposing of this material. A number of possible uses are outlined. These include highway construction and anti-skid material. "Red dog" has been approved for use as anti-skid material in Pennsylvania. Its use in bituminous paving appears promising. However, coal refuse will require thermal treatment or stabilization to be suitable for highway use.

68. Stoops, Robert F. and Redeker, Immo, H. "North Carolina Feldspar Tailings Utilization." In Proceedings; Second Mineral Waste Utilization Symposium, Chicago, Illinois, March 18 - 19, 1970. p. 177 - 180.

Approximately 250,000 tons of tailings are generated annually by feldspar producers in the Spruce Pine district of North Carolina. These tailings are composed mainly of feldspar and quartz. The tailings can be economically reworked to recover these minerals. An evaluation of the potential for use of these materials was made by North Carolina State University. This investigation indicated that the coarse tailings could be used in asphalt paving mixtures and the fine tail-

ings could be stabilized with Portland cement or a mixture of lime, fly ash, and Portland cement for use as stabilized base material.

69. Sullivan, G. D. "Coal Wastes." In Proceedings; The First Mineral Waste Utilization Symposium, Chicago, Illinois, March 27 - 28, 1968. p. 62 - 66.

The author discusses a number of different potential and actual uses for coal wastes. Some coal-associated clays and shales are acceptable for the manufacture of expanded aggregates. All shales do not lend themselves to the bloating process, so the shales must be carefully selected. Some examples are given of successful efforts to produce a lightweight aggregate from coal refuse. Other possible uses of coal refuse are mentioned in the report; however, none of the other uses are highway related.

70. Sweeney, John W. and Timmons, Bobby J. "Availability and Potential Utilization of By-Product Gypsum in Florida Phosphate Operations." State of Florida, Department of Natural Resources, Special Publication No. 18, Tallahassee, Florida, 1973. 9p.

The manufacture of wet-process phosphoric acid, the basic material needed to produce multi-nutrient fertilizer, results in the generation of large quantities of impure by-product gypsum. Over twenty million tons of by-product gypsum are generated annually by the phosphate-producing industry in central Florida and more than 150 million tons of this material are stacked on the ground and considered available. The annual production of by-product gypsum is nearly three times the domestic production of natural gypsum.

This material is physically and chemically unlike natural gypsum, due to the presence of deleterious fluorine and phosphoric acid. At the present time, very small amounts have been used for agricultural land plaster and as road base stabilization material in the Tampa area. The potential uses for by-product gypsum include road base stabilization and asphalt filler. Current foreign and domestic research efforts to utilize or extract mineral values from this material are summarized.

71. Tanfield, D. A. "Construction Uses for Colliery Spoil," Reprinted from Contract Journal, January 14 and 21, 1971. 5p.

Until 1968, only burnt colliery spoils were used to any great extent in the United Kingdom because it was widely believed that most unburnt spoils could be liable to spontaneous combustion. Because of the great amounts of unburnt spoil, the Ministry initiated a trial period for the use of unburnt and partially burnt colliery spoils as highway fill material. Early examples of successful use of this material in road projects are described.

It has been determined that unburnt colliery spoils are not subject to spontaneous combustion if sufficiently compacted. Furthermore, the material is quite workable in wet weather and, for the most part, is non-frost susceptible. As a result, unburnt spoils are now being handled commercially by the National Coal Board as minestones for the same applications previously reserved for burnt spoils. Examples of other promising uses, such as cement-stabilized subbases and manufacture of lightweight aggregates, are also cited.

72. Thornton, Sam I. and Welch, Robert C. "Arkansas Waste in Municipal Areas Suitable for Highway Construction or Maintenance." National Technical Information Service, Catalog No. PB 230-951, June, 1973. 85p.

The categories and quantities of solid wastes generated in municipal areas of Arkansas were determined. Principal waste products are chemical wastes, aggregates, wood products and paper, glass, rubber, textiles, sewage sludge, and incinerator residue. All industries which responded to the questionnaire are listed according to municipal area. Waste products are listed according to industrial classification and municipal area along with estimated quantities generated for each waste type.

A series of sieve analyses and Atterburg limits were performed on clay samples stabilized with various percentages of certain wastes determined from this study. Results of these tests are summarized. Based on a review of current uses, aggregates from mining and quarrying, brown muds, dried sewage sludge, incinerator residues, and hydrated lime are recommended for immediate application in highway construction in Arkansas.

73. U. S. Bureau of Mines. "The Florida Phosphate Slimes Problem: A Review and a Bibliography." U. S. Bureau of Mines Staff, Metallurgy Research Laboratory, Infor-

mation Circular No. 8668, Tuscaloosa, 1975. 41p.

This report describes the Florida phosphate mining industry, including mining and beneficiation methods, and discusses the generation and disposal of the slimes from phosphate flotation plants. Research into various methods for de-watering these slimes are described, together with current research and costs of disposal. A thorough bibliography of previous work pertaining to the generation and potential utilization of phosphate slimes is also presented.

74. Utley, R. W.; Lovell, H. L.; and, Spicer, T. C. "The Utilization of Coal Refuse for the Manufacture of Lightweight Aggregate." Pennsylvania State University, Special Research Report No. SR-46, September 1, 1964. 110p.

A brief history is given of the development of the lightweight aggregate industry in the United States. The mechanism of the bloating phenomena is discussed. The physical and chemical properties of the gravity fractions of three (3) representative coal refuse samples were investigated. These samples were separated into several specific gravity sink fractions and fired at 1250°, 1300°, and 1350° C. The fired products were evaluated for specific gravity, volume expansion, and compressive strength. Specific gravity fractions between 2.40 and 2.80 produced the highest compressive strengths. Firing temperatures should be in the range of 1300° to 1350° C. to assure optimum strength development.

75. Vasan, Srini. "Utilization of Florida Phosphate Slimes." In Proceedings: Third Mineral Waste Utilization Symposium, Chicago, March 14 - 16, 1972.

The potential utilization of huge quantities of phosphate slimes is hindered by the lack of a technique to economically de-water these slimes. Conventional rotary dryers are neither economical nor efficient. The use of a fluid-bed dryer is technically feasible, but costly. Once dried, the slimes are potentially useful for conversion into aggregate or ceramic products, such as brick or tile.

The most promising use developed was lightweight aggregate produced in a rotary kiln. This aggregate met the ASTM lightweight aggregate specification requirements. The aggregate was tested as coarse aggregate in a number of concrete formulations. Twenty-eight

day compressive strengths between 3000 and 4000 psi were observed. The bulk densities for these concrete mixtures were between 85 and 110 pounds per cubic foot.

76. Vogely, W. A. "The Economic Factors of Mineral Waste Utilization." In Proceedings; First Mineral Waste Utilization Symposium, Chicago, March 27 - 28, 1968.

Various types of mineral wastes are defined. The amounts of these wastes generated by different mineral industries are shown for 1965. These wastes are classified in three (3) categories based on their economic value and the cost to society for their generation or continued existence. Factors involved in conservation of mineral values and social costs attached to these wastes are discussed. In the opinion of the author, sixty percent of mineral wastes are potentially valuable.

77. Weaver, W. S. and Luka, R. "Laboratory Studies of Cement-Stabilized Mine Tailings." Canadian Mining and Metallurgical Bulletin, September, 1970. p. 988 - 1001.

An eight-year laboratory program was conducted by the Canada Cement Company, Limited, to determine the engineering properties of cement-stabilized tailings from two Canadian nickel mining operations. The effects of bulk density, tailings gradation, cement content, pozzolans and admixtures, and many other variables on the properties of cement-bonded tailings were investigated. Mix compositions were related to backfills, bulkheads, and mucking floor applications. Summaries of compressive and triaxial strength tests are presented in this report.

78. Wenger, M. E. and Schmidt, G. H. "Anthracite Refuse as an Aggregate in Bituminous Concrete." Pennsylvania Department of Transportation, Bureau of Materials, Testing, and Research, Project No. 70 - 8, June, 1970. 21 p.

This report presents the findings of a laboratory investigation conducted by the Bureau of Materials, Testing, and Research. The material evaluated was "processed" culm subjected to a sink-float operation to separate the coal, light shale, and sulfur-bearing compounds. This material meets specification requirements for Type A aggregate for the sodium sulfate and Los Angeles abrasion tests, but has an excessive amount of material passing the No. 4 and No. 8 sieves.

Marshall stabilities ranging from 2900 to 3400 pounds and flows from approximately 12.0 to 18.7 were obtained. It was noted that complete coating of particles larger than No. 4 sieve was difficult to obtain.

Specimens broken during the Marshall stability test showed a marked degree of fracture of the larger particles. Freeze-thaw tests were conducted on control specimens, specimens containing 100 percent culm, and specimens containing culm plus six percent limestone filler. Specimens with culm material showed signs of obvious distress after 230 cycles, whereas control specimens were relatively unharmed after 500 cycles. It was concluded that the processed culm aggregate may be more suitable for use in sub-base or shoulder construction.

79. Whitehurst, E. A. "Investigation of Three Electric Furnace Phosphate Slags as Fine Aggregates," Tennessee Highway Research Program, Reprint No. 5, September, 1957. 14p.

By-product slags from the production of phosphorus and phosphate fertilizer were evaluated for suitability as fine aggregate in Portland cement concrete and bituminous mixes. A calcium silicate slag produced by T.V.A. at Muscle Shoals, Alabama, was analyzed, along with two (2) slags produced by Monsanto Chemical Company at Columbia, Tennessee. These two slags were referred to as "hard slag" and "foam slag." These slags were compared with limestone and river sand, two naturally occurring fine aggregates. In the concrete investigation, the fine aggregates were used in combination with two coarse aggregates, limestone and river gravel. Only the limestone coarse aggregate was used in the study of bituminous mixes.

A cement factor of 6.0 sacks per cubic yard and a water-cement ratio of 0.58 by weight were used for all concrete mixes. Hard and foam slags used with limestone coarse aggregate produce satisfactory concretes from a strength point of view. The use of the calcium silicate slag as fine aggregate in concrete is questionable as far as its early strength is concerned.

Marshall and Hveem methods were used to evaluate bituminous mixtures. The hard slag and foam slag mixes, with the addition of appropriate filler material, demonstrate adequate stabilities for any present type of highway construction. The calcium silicate slag mix

will not meet stability criterion for light or heavy traffic and is not recommended.

80. Wilmoth, Roger C. and Scott, Robert B. "Use of Coal Mine Refuse and Fly Ash as a Road Base Material." Presented at First Symposium on Mine and Preparation Plant Refuse Disposal, Louisville, Kentucky, October 24, 1974. p263 - 275.

The suitability of using coal mine refuse by itself or in combination with fly ash as a material for road base construction was evaluated over a ten-month period at the U. S. Environmental Protection Agency's Crown Mine Drainage Control Field Site near Morgantown West Virginia.

Three (3) different base course mixtures were evaluated. The first mixture consisted of twelve inches of fly ash-treated coal refuse (seventy-five percent refuse and twenty-five percent fly ash). The second mixture consisted of six inches of fly ash-treated coal refuse and six inches of fly ash-treated coal refuse mixed with five percent lime. The third mixture consisted of fifteen inches of coal mine refuse. All base course mixtures were overlain by three inches of asphalt base and one inch of asphalt wearing surface.

A drainage monitoring system was installed to monitor the quality and chemical composition of the leachate from each mixture. Thus far, the effluents from the first two mixtures are not offensive. However, the acidity and metal concentrations of the third mixture are steadily increasing. It is concluded that the coal refuse base produced an undesirable leachate, while fly ash and lime tend to neutralize acidity from pyritic coal refuse discharge.

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