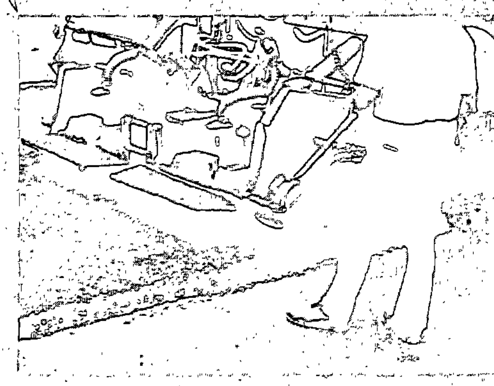
Report No. FHWA-RD-77-150

GUIDELINES FOR USE OF INCINERATOR RESIDUE AS HIGHWAY CONSTRUCTION MATERIAL



September 1977
Final Report

Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Washington, D. C. 20590

FOREWORD

This report contains information on the composition and characteristics of basic types of incinerator residue and a classification system for such residues. It discusses the use of unfused incinerator residues in structural fill, stabilized base, and bituminous paving applications, and includes recommendations for materials handling and preparation, laboratory testing procedures, engineering properties and design and construction procedures for these applications. Also contained in this manual are laboratory test procedures for determining the loss on ignition and the physical composition of incinerator residue samples. A summary of favorable and unfavorable situations for the utilization of unfused incinerator residue in highway or street construction is presented.

Sufficient copies of the report are being distributed to provide a minimum of one copy to each regional office, one copy to each division office and two copies to each State highway agency. Direct distribution is being made to the Division offices.

Charles F. Scheffey

NOTICE

Technical Report Documentation Page

1. Report No. FHWA-RD-77-150	2. Government Accession No.	3. Recipient's Catalog No. PB287512
4. Title and Subtitle GUIDELINES FOR USE OF INCINERATOR RESIDUE AS HIGHWAY CONSTRUCTION MATERIAL		5. Report Date September 1977
		6. Performing Organization Code
7. Author(s) R. J. Collins, R. H. Miller, S. K. Ciesielski		8. Performing Organization Report No.
9. Performing Organization Name and Address Valley Forge Laboratories, Inc. Six Berkeley Road Devon, Pennsylvania 19333		10. Work Unit No. (TRAIS) FCP No. 34C1-062
		11. Contract or Grant No. FH-11-8540
12. Sponsoring Agency Name and Address U. S. Department of Transportation Federal Highway Administration Offices of Research and Development Washington, D. C. 20590		13. Type of Report and Period Covered Final Report - Manual July 1974-Sept. 1977
		14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Contract Manager: W. C. Ormsby (HRS-23), J. A. Zenewitz (HRS-23)
FHWA Implementation Manager: W. C. Besselievre (HDV-22)

16. Abstract

Incineration of solid waste is a major means of refuse disposal in many major metropolitan areas. There are presently 141 operating municipal incinerator plants in 24 states and the District of Columbia. These plants are responsible for producing approximately 5 million tons of incinerator residue annually.

This manual contains background information on the composition and characteristics of basic types of incinerator residues. A recommended classification system is presented. The use of incinerator residues in structural fill, stabilized base, and bituminous paving applications are discussed. Included are specific recommendations for materials handling and preparation, laboratory testing procedures, engineering properties, and design and construction procedures for these applications.

This manual also includes recommended laboratory test procedures for determining the loss on ignition and physical composition of incinerator residue samples. A separate section is devoted to a summary of situations which are favorable, as well as unfavorable, to the utilization of municipal incinerator residue in highway or street construction. This manual discusses unfused residues from incinerator and pyrolysis operations. Fused residues from supplementary heat treatment are not considered in this manual.

17. Key Words Incinerator, Residue, Refuse, Aggregate, Construction, Highway	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		MF A01 PC A05

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Table of Contents

TABLE OF CONTENTS (continued)

List of Tables

List of Figures

List of Figures
(Continued)

PREFACE

The guidelines set forth in this manual have been prepared on the basis of the findings of the research work performed on FHWA Contract DOT-FH-11-8540, entitled "Technology for Use of Incinerator Residue as Highway Material." They have also been strongly influenced by work done by others. There are numerous footnotes contained herein referencing these works. Thus, these guidelines represent the authors best recommendations in keeping with the current state-of-the-art for the highway use of incinerator residue.

It is hoped that these guidelines will be followed in the further development of experimental roadway sections and in the construction of controlled fills. Users should be cautioned that the magnitude of documented use of incinerator residue is not nearly as great as that normally required for full acceptance of a highway construction material.

U. S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

SUBJECT: FHWA-RD-77-150, Guidelines for Use of Incinerator Residue as Highway Construction Material	FHWA BULLETIN September 13, 1978

Distributed with this bulletin is the subject report which should be of considerable interest to asphalt paving researchers and technologists. This report is based in large part on a companion volume, FHWA RD-77-151, "Technology for Use of Incinerator Residue as Highway Material," which is another product of the same intensive contract study of the subject matter.

In brief, this report contains information on the composition and characteristics of the basic residues. Also included, is a discussion of the usages of unfused incinerator residues in structural fill, stabilized base, and bituminous paving applications. In addition, there are specific recommendations for the handling and preparation of such residues, laboratory testing procedures, engineering properties, and design and construction procedures.

Sufficient copies of the report are being distributed to provide a minimum of one copy to each regional office, one copy to each division office and two copies to each State highway agency. Direct distribution is being made to the division offices. Additional copies for official use may be requested from Mr. Richard E. Hay, Chief, Materials Division, FHWA, HRS-20, Washington, D.C. 20590. These requests will be filled while our limited supply lasts. Additional copies for the public are available from the National Technical Information Service (NTIS), Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

G. D. Love
Associate Administrator for
Research and Development

Attachment

DISTRIBUTION: Headquarters
Special Regions
Division

OPI: HRS-23

Report FHWA-RD-77-150
Guidelines for Use of Incinerator Residue
as Highway Construction Material
Abstract and Report Request Form

This report contains information on the composition and characteristics of basic types of incinerator residue and a classification system for such residues. It discusses the use of unfused incinerator residues in structural fill, stabilized base, and bituminous paving applications, and includes recommendations for materials handling and preparation, laboratory testing procedures, engineering properties and design and construction procedures for these applications. Also contained in this manual are laboratory test procedures for determining the loss on ignition and the physical composition of incinerator residue samples. A summary of favorable and unfavorable situations for the utilization of unfused incinerator residue in highway or street construction is presented.

Sufficient copies of the report are being distributed to provide a minimum of one copy to each regional office, one copy to each division office and two copies to each State highway agency. Direct distribution is being made to the division offices.

To obtain additional copies of this report, please send in the request form below.

REPORT REQUEST FORM

Please send _______ copies of Report FHWA-RD-77-150, Guidelines for Use of Incinerator Residue as Highway Construction Material.

Name ______________________________

Agency ______________________________

Street ______________________________

City ______________________________

State ______________________ Zip ________

1. INTRODUCTION

The United States is faced with a problem of handling enormous volumes of solid wastes. Approximately 200 million tons of municipal solid waste are being generated in this country each year (1). The annual cost of collecting and disposing of municipal refuse is estimated to be in excess of $6 billion. With solid waste production increasing at an annual rate of 4 to 6 percent, the costs of solid waste management are expected to soar to more than $9 billion by 1980 (2).

Incineration is one of the principal methods used for the disposal of solid waste. Its main advantages are that it reduces the volume of incoming solid waste by 80 to 90 percent while practically eliminating the odor, vermin, and fire threat normally associated with municipal refuse. However, the incineration of refuse produces a residue which represents approximately 20 to 30 percent by weight of the refuse. These residues, which are a wet mixture of metals, glass, ash, and other components, must still be disposed of by landfilling in an environmentally acceptable manner.

The practice of incineration was introduced in this country before the turn of the century. The most significant upsurge in the construction of incinerator plants occurred following World War II. Most of the plants constructed during the late 1940's and early 1950's were small, batch operated units designed only to serve the local areas in which they were located. In time, population growth, urban sprawl, and the necessity for installing expensive air and water pollution control systems combined to render many of these plants functionally obsolete.

Since the early to mid 1960's, the trend has been to replace older plants with much larger, more centrally located

---

(1) *Kenahan, C. B., Sullivan, P. M., Ruppert, J. A., and Spano, E. F., "Composition and Characteristics of Municipal Incinerator Residues", U.S. Department of Interior, Bureau of Mines, Report of Investigations No. 7204, Washington, D.C., December, 1968, 20 p.*

(2) *MacDonald, Joseph A., "Will Solid Wastes Bury Us?", Engineering News-Record. Probing the Future. April 30, 1974, pp. 251-270.*

incinerators. In recent years concern over diminishing supplies of energy has resulted in the design of solid waste reduction facilities with energy recovery capabilities. The obvious need to conserve natural resources is responsible for a growing movement to extract valuable mineral and ceramic matter from municipal refuse and incinerator residue by means of resource recovery.

Nevertheless, despite these advances in incineration technology, the basic problem of what to do with the residue from incinerator plants still remains. Unfortunately, in many communities this problem is now assuming crisis proportions due to the lack of available landfill sites within a reasonable hauling distance from incinerator plants. Moreover, environmental agencies continue to impose stricter regulations pertaining to the disposal of incinerator residue and other solid wastes, contributing to the spiraling cost of solid waste management.

One of the most logical solutions to this problem is to utilize these residues in some manner. Previous study (3), as well as practical experience, has shown that municipal incinerator residues, when properly prepared and handled, can be successfully used as a construction material, particularly in highway and street construction.

The purpose of this manual is to provide engineers, municipal solid waste and street personnel, contractors, and other potential users of incinerator residue with a practical reference on the nature and properties of the material and recommended procedures for its use in various highway applications. Hopefully, the information provided herein will stimulate increased utilization of incinerator residue in situations where its use is economically justified.

2. Locations and Sources of Municipal Incinerator Residues

Figure 1 is a map showing the locations of municipal incinerator plants which were open as of December, 1975. At that time there were a total of 141 operating plants, located in 24 states and the District of Columbia. The encircled figures on the map represent the total number of incinerator plants located in each state. It has been estimated that 15 to 20 million tons (13.6 to 18.1 tonnes) of numicipal refuse are being incinerated annually, resulting in the generation of approximately 5 million

---

(3) *Walter, C. Edward, "Practical Refuse Recycling," Journal of Environmental Engineering Division, American Society of Civil Engineers, February, 1976, pp. 139-148.*

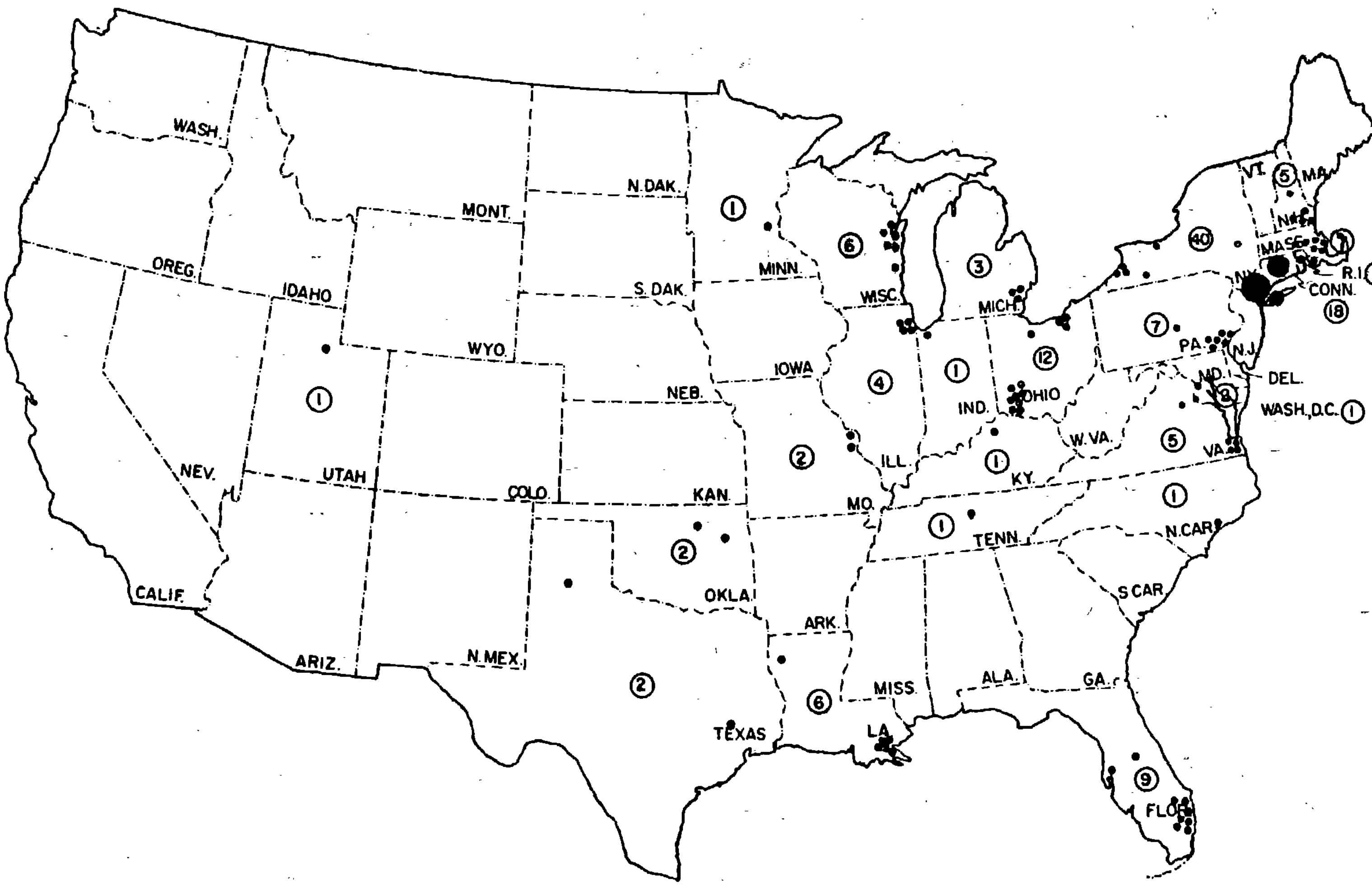


Figure 1. Locations of Operating Municipal Incinerator Plants

tons (4.5 tonnes) per year of incinerator residue (4).

The locations and capacities of operating municipal incinerator plants are summarized in Table 1. This table also lists the year in which the plant was constructed and the furnace operation and grate type employed in each plant. The information in Table 1 is helpful in predicting the type of residue that will result.

Furnace operation is categorized according to method of feeding the refuse into the combustion chamber, either by continuous or batch feeding. Generally, most incinerator plants constructed prior to 1960 are batch fed, while plants built after 1960 are mainly continuous fed (5).

There are several different types of grates used in incinerator furnaces. These grates are classified according to mechanical type. In the United States the most widely used grate types are the traveling, reciprocating, rocking, and circular. The first three types are used to feed refuse through a rectangular furnace, while the circular grate is used to feed refuse through a cylindrical furnace. A rotary kiln furnace could also be considered as a type of grate, since the rotation of the inclined kiln causes the refuse to move in a slow, cascading forward motion (6). The basic types of grates used in municipal incineration are shown in Figure 2.

Municipal solid waste is also subjected to volume reduction by means of pyrolysis. Pyrolysis is a process which chemically decomposes organic substances by applying heat at tempera-

---

(4) *Pindzola, D., and Collins, R. J., "Technology for Use of Incinerator Residue as Highway Material: Identification of Incinerator Practices and Residue Sources", U. S. Department of Transportation, Federal Highway Administration, Report No. FHWA-RD-75-81, Washington, D. C., July, 1975, 77 p.*

(5) *American Public Works Association, "Municipal Refuse Disposal". Third Edition, Copyright by Public Administration Service, Chicago, Illinois, 1970, 538 p.*

(6) *DeMarco, Jack; Keller, Daniel; Leckman, Jerold; and Newton, James L., "Municipal-Scale Incinerator Design and Operation". U.S. Department of Health, Education, and Welfare, Bureau of Solid Waste Management, 1969, 98 p.*

Table 1. List of Currently Operating Municipal Incinerator Plants

Number	Plant Location	Year Built	Refuse Capacity (Tons per 24 Hour Day)	Furnace Type & Grate
	CONNECTICUT (18)			
1.	Ansonia	1968	200	Cont./Trav.
2.	Bridgeport	1958	300	Batch/Mech.
3.	Bridgeport	1960	200	Batch/Rocking
4.	Darien	1941	130	Batch/Rocking
5.	East Hartford	1956	350	Batch/Rocking
6.	Greenwich	1938	150	Batch/Rocking
7.	Greenwich	1961	250	Cont./Rocking
8.	Hartford	1954	600	Batch/Mech.
9.	New Canaan	1956	125	Batch/Mech.
10.	New Haven	1963	720	Cont./Trav.
11.	Norwalk	1962	360	Cont./Trav.
12.	Norwalk (Bulky)	1968	144	No Grates
13.	Stamford (Old)	1942	150	Batch/Rocking
14.	New Stamford (New)	1973	360	Cont./Trav.
15.	Stamford (Multi)	1969	210	No Grates
16.	Stratford	1968	240	Cont./Trav.
17.	Waterbury	1952	300	Batch
18.	West Hartford	1956	300	Batch/Mech.
	FLORIDA (9)			
19.	Ft. Lauderdale #2	1954	250	Batch/Mech.

Table 1. List of Currently Operating Municipal Incinerator Plants (Continued)

Number	Plant Location	Year Built	Refuse Capacity (Tons per 24 Hour Day)	Furnace Type & Grate
	FLORIDA (Cont'd.)			
20.	Ft. Lauderdale (Wingate)	N.A.	660	Cont./Recip.
21.	Miami (NE)	1975	300	Cont.
22.	Miami (20th St.)	1951	600	Cont./Mech.
23.	Orlando	N.A.	100	N.A.
24.	Pahokee	N.A.	50	N.A.
25.	Pompano	1964	300	Cont./Recip.
26.	Pompano Beach	N.A.	300	Cont.
27.	Tampa	1967	750	Cont./Rot. Kiln
	HAWAII (3)			
28.	Honolulu (Kapaloma)	1961	200	Batch/Recip.
29.	Honolulu (Kewalo)	1962	200	Batch/Recip.
30.	Honolulu (Waipahu)	1969	600	Cont.
	ILLINOIS (4)			
31.	Chicago (Calumet)	1959	1200	Cont./Rocking
32.	Chicago (NW)	1970	1600	Cont./Recip.
33.	Chicago (SW)	1963	700	Cont./Rot. Kiln
34.	Cicero	1958	500	Cont./Rot. Kiln
	INDIANA (1)			
35.	East Chicago	1970	200	Cont.

Table 1. List of Currently Operating Municipal Incinerator Plants (Continued)

Number	Plant Location	Year Built	Refuse Capacity (Tons per 24 Hour Day)	Furnace Type & Grate
	KENTUCKY (1)			
36.	Louisville	1957	1000	Cont./Rot. Kiln
	LOUISIANA (6)			
37.	New Orleans (Algiers)	1963	200	Cont./Trav.
38.	New Orleans (East)	1967	400	Cont./Recip.
39.	New Orleans (Florida Avenue)	1958	400	Batch/Rocking
40.	New Orleans (7th Street)	1962	400	Cont./Trav.
41.	New Orleans (St. Louis St.)	1971	450	Cont./Rocking
42.	Shreveport	1960	200	Cont./Rocking
	MARYLAND (2)			
43.	Baltimore #4	1956	800	Batch/Rocking
44.	Montgomery County	1965	1200	Cont./Trav.
	MASSACHUSETTS (7)			
45.	Braintree	1971	240	Cont.
46.	East Bridgewater	1973	800	Cont./Recip.
47.	Fall River	1973	600	Cont./Recip.
48.	Framingham	1973	500	Cont./Recip.
49.	Marleboro	1973	150	Rot. Kiln
50.	Saugus (Resco)[1]	1975	1500	Cont./Recip.

Table 1. List of Currently Operating Municipal Incinerator Plants (Continued)

Number	Plant Location	Year Built	Refuse Capacity (Tons per 24 Hour Day)	Furnace Type & Grate
	MASSACHUSETTS (Cont'd.)			
51.	Weymouth	1965	300	Batch/Mech.
	MICHIGAN (3)			
52.	Central Wayne County	1964	800	Cont./Recip.
53.	Clinton-Grosse Pointe	1972	600	Cont./Rot. Kiln
54.	S.E. Oakland Co.	1953	600	Batch/Mech.
	MINNESOTA (1)			
55.	Kennsington Village	1971	96	N.A.
	MISSOURI (2)			
56.	St. Louis (North)	1956	400	Batch/Rocking
57.	St. Louis (South)	1951	400	Batch/Rocking
	NEW HAMPSHIRE (5)			
58.	Durham	1970	50	Batch
59.	Manchester	1937	100	Batch/Manual
60.	Nottingham	1975	10	Batch
61.	Plymouth	1975	30	Batch
62.	Windham	1975	30	Batch
	NEW YORK (40)			
63.	Babylon	1947	200	Batch/Manual
64.	Beacon	1964	100	Batch/Rocking

Table 1. List of Currently Operating Municipal Incinerator Plants (Continued)

Number	Plant Location	Year Built	Refuse Capacity (Tons per 24 Hour Day)	Furnace Type & Grate
	NEW YORK (Cont'd)			
65.	Buffalo	1954	650	Batch/Mech.
66.	Canajoharie	1964	50	Batch/Mech.
67.	East Chester	1962	200	Batch/Rocking
68.	Freeport	1964	150	Batch/Rocking
69.	Garden City	1963	175	Cont./Recip.
70.	Hempstead (Oceanside)	1965	750	Cont./Recip.
71.	Hempstead (Merrick)	1952	600	Batch/Mech.
72.	Hempstead (San. District #1)	1927	200	Batch/Man.
73.	Huntington	1966	300	Cont./Rocking
74.	Islip	1967	300	Cont./Trav.
75.	Lackawanna	1949	150	Batch/Manual
76.	Long Beach	1961	200	Batch/Manual
77.	Mt. Vernon	1949	150	Batch/Mech.
78.	Newburg	1965	240	Cont./Rocking
79.	New Rochelle	1939	150	Batch/Manual
80.	NYC (Betts Ave.)	1959	1000	Cont./Trav.
81.	NYC (Gansevoort)	1953	1000	Cont./Trav.
82.	NYC (Greenpoint)	1959	1000	Cont./Trav.
83.	NYC (Hamilton)	1961	1000	Cont./Trav.

Table 1. List of Currently Operating Municipal Incinerator Plants (Continued)

Number	Plant Location	Year Built	Refuse Capacity (Tons per 24 Hour Day)	Furnace Type & Grate
	NEW YORK (Cont'd)			
84.	NYC (South Shore)	1954	1000	Cont./Trav.
85.	NYC (SW Brooklyn)	1961	1000	Cont./Trav.
86.	N. Hempstead (Denton Avenue)	1956	250	Batch/Mech.
87.	N. Hempstead	1966	600	Cont./Rocking
88.	Ocean Bay Park	1930	18	Batch/Manual
89.	Ocean Beach	1935	18	Batch/Manual
90.	Old Bethpage	1967	400	Cont./Recip.
91.	Old Bethpage	1962	500	Cont./Recip.
92.	Patchogue	1935	35	Batch/Manual
93.	Port Chester	1951	120	Batch/Mech.
94.	Rye	1959	150	Batch/Mech.
95.	Saltaire	1935	18	Batch/Recip.
96.	Scarsdale	1959	150	Batch/Mech.
97.	Scio	1970	0.5	Batch
98.	Skaneateles	1973	30	Batch
99.	Tonawanda	1933	300	Cont./Recip.
100.	Valley Stream	1962	200	Cont./Trav.
101.	White Plains	1956	400	Batch/Rocking
102.	Yonkers	1951	400	Cont./Rocking

Table 1. List of Currently Operating Municipal Incinerator Plants (continued)

Number	Plant Location	Year Built	Refuse Capacity (Tons per 24 Hour Day)	Furnace Type & Grate
	NORTH CAROLINA (1)			
103.	Wrightsville Beach		NO DATA AVAILABLE	
	OHIO (12)			
104.	Cedarville	N.A.	15	Batch
105.	Cincinnati (Center Hill)	1964	500	Cont./Trav.
106.	Dayton (N. Montgomery County)	1940	600	N.A.
107.	Dayton (S. Montgomery City)	1970	600	Cont.
108.	Euclid	1956	200	Batch/Rocking
109.	Franklin[2]	1969	150	Fluidized Bed
110.	Lakewood	1951	300	Batch/Manual
111.	Lockland		NO DATA AVAILABLE	
112.	Miami County	1968	150	Cont./Pusher
113.	Parma	1956	70	Batch/Rocking
114.	St. Bernard		NO DATA AVAILABLE	
115.	Woodsville	1962	12	Batch/Mech.
	OKLAHOMA (2)			
116.	Cleveland	N.A.	18	Batch
117.	Tahlequah	N.A.	50	Batch
	PENNSYLVANIA (7)			
118.	Delaware County #1	1960	800	Cont./Trav. + Rot. Kiln

Table 1. List of Currently Operating Municipal Incinerator Plants (Continued)

Number	Plant Location	Built	Refuse Capacity (Tons per 24 Hour Day)	Furnace Type & Grate
	PENNSYLVANIA (Cont'd)			
119.	Delaware County #2	1961	500	Cont./Trav.
120.	Delaware County #3	1962	500	Cont./Trav.
121.	Harrisburg[3]	1973	720	Cont./Recip.
122.	Lower Merion Township	1969	250	Cont./Rocking
123.	Philadelphia (E. Central)	1966	750	Cont./Trav.
124.	Philadelphia (NW)	1960	750	Cont./Trav.
	RHODE ISLAND (1)			
125.	Pawtucket	1964	200	Cont./Trav.
	TENNESSEE (1)			
126.	Nashville[4]	1974	720	Cont.
	TEXAS (2)			
127.	Amarillo	1965	350	Batch/Recip.
128.	Houston (Holmes Road)	1967	800	Cont./Trav.
	UTAH (1)			
129.	Ogden	1966	450	Cont./Trav.
	VIRGINIA (5)			
130.	Alexandria #2	1966	300	Cont./Rocking
131.	Newport News	1968	400	Cont./Trav.

Table 1. List of Currently Operating Municipal Incinerator Plants (Continued)

Number	Plant Location	Year Built	Refuse Capacity (Tons per 24 Hour Day)	Furnace Type & Grate
	VIRGINIA (Cont'd)			
132.	Norfolk	1946	400	Batch/Mech.
133.	Norfolk	1968	360	Cont./Recip.
134.	Portsmouth	1963	350	Batch/Rocking
	WASHINGTON, D.C. (1)			
135.	Solid Waste Reduction Center #1	N.A.	1500	Cont./Rocking
	WISCONSIN (6)			
136.	Chilton	1972	85	Batch/Stationary
137.	DePere	1961	300	Batch/Stationary
138.	Green Bay	1966	360	Batch/Stationary
139.	Kohler-Sheboygan	1974	60	Cont./Trav.
140.	Port Washington	1965	75	Batch/Recip.
141.	Sheboygan	1965	240	Cont./Rocking

[1] Steam generation facility combined with resource recovery operation.

[2] Operated as a resource recovery facility.

[3] Designed and operating as a steam producing facility.

[4] Operated as an energy recovery plant.

NOTE: 1 short ton = .9072 tonne.

N.A. denotes information not available.

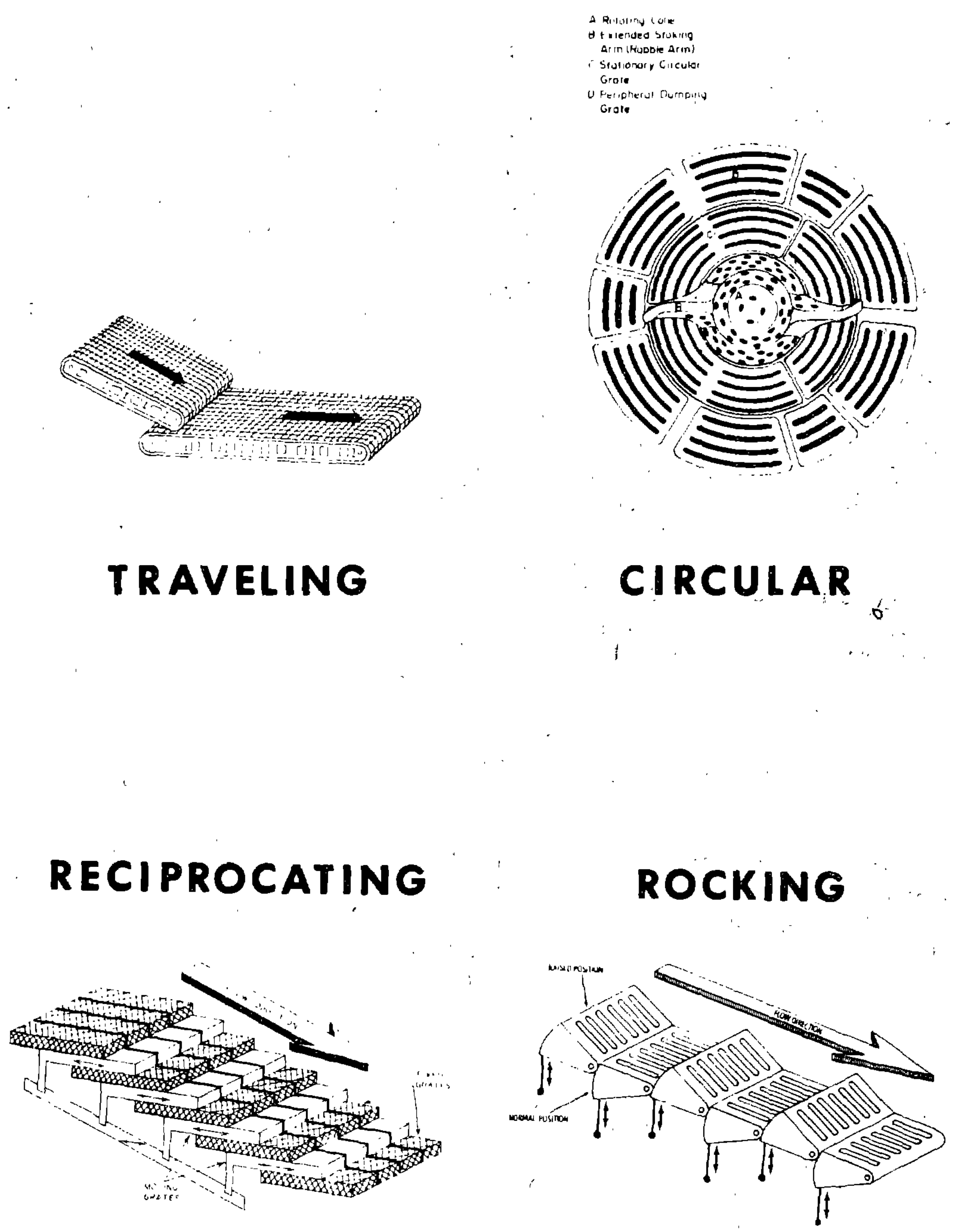


Figure 2. Types of Grates Used in Municipal Incineration

tures ranging between 1000° and 2000°F (583° and 1093°C), in the absence of oxygen. The process is essentially the same as the destructive distillation of coal to make coke for the steel industry.

Depending on refuse composition and operating conditions, pyrolysis of solid waste yields gas, organic liquids, and a char residue. Some advantages of pyrolysis compared to incineration are its ability to handle plastics and rubber wastes, the production of comparatively less residue (approximately 10 percent by weight), little or no air and water pollution, and the generation of useable fuel (7).

Although there were no municipal-scale pyrolysis plants in continuous operation at the end of 1975, there were several existing pyrolysis plants operating on a pilot scale at that time. Examples are Union Carbide's Purox plant in South Charleston, West Virginia and Carborundum Company's Torrax facility in Orchard Park, New York (near Buffalo). Monsanto has constructed a 1000 ton (900 tonne) per day Landgard pyrolysis plant in Baltimore, Maryland, which is expected to go into service sometime during 1977 (8). Occidental Research Corporation expects to complete construction of a new 200 ton (180 tonne) per day pyrolysis plant in El Cajon, San Diego County, California during late 1976 (9). The residue or char by-product from pyrolysis plants should also be considered for use as a highway construction material.

3. CLASSIFICATION OF INCINERATOR RESIDUES

Incinerator residue is a variable material. A classification system has been developed to facilitate the identification of different types of residues. The basis of this classification is the "degree of burnout" of the residue at the time

---

(7) *Liebeskind, Judith E., "Pyrolysis for Solid Waste Management", Chemtech, September, 1973, pp. 537-542.*

(8) *Phoenix Quarterly, "Resource Recovery: The Vision and the Vanities", Spring, 1976, pp. 8-9.*

(9) *Civil Engineering, February, 1976, pp. 71-72.*

of its discharge from the incinerator plant.

The degree of burnout of incinerator residue depends on the composition and moisture content of the incoming refuse and the efficiency of the incinerator operation. Municipal or household refuse consists of a combustible and non-combustible fraction. The combustible fraction may comprise from 60 to 80 percent of the refuse, depending somewhat upon seasonal variations, and is composed mainly of paper, food wastes, and yard wastes, along with smaller percentages of wood, textiles, plastics, leather, and rubber. The non-combustible fraction basically consists of metals and glass, along with varying amounts of miscellaneous material, such as bricks, rocks, and dirt.

The composition and moisture content of municipal refuse varies from one location to another, as well as during different times of the year. These variations have been identified and have generally been found to fall within predictable ranges. Therefore, the efficiency of the incinerator operation, expressed as the degree of burnout, is the most significant factor involved in determining the overall character of incinerator residue. The degree of burnout is a representation of the amount of combustible material in the refuse that is consumed during the incineration process.

The most reliable indicator of the degree of burnout of incinerator residue is the basic design of the furnace and grates. The proper combustion of solid waste in municipal incinerator plants is dependent on three basic factors: time, temperature, and turbulence. The refuse must be exposed to temperatures in the range of 1600° to 1800°F (871° to 982°C) for a sufficient period of time in order for satisfactory burning to occur. Generally, the more the refuse is agitated during burning, the higher the degree of burnout.

Municipal incinerator residues can be broadly classified into three categories, based on their degree of burnout. These categories are:

1. *Well burned-out*. These are residues from continuous fed incinerators with a high degree of grate agitation. Residues of this type are usually produced from plants having rotary kilns, reciprocating grates, or rocking grates. These residues comprise approximately 10 volume percent and 20 to 30 weight percent of the refuse input (10). Figure 3 is a

---

(10) *Achinger, W. C. and Daniels, L.E., "An Evaluation of Seven Incinerators". In Proceedings; 1970 National Incinerator Conference, American Society of Mechanical Engineers, New York, N. Y., 1970, pp. 32-64.*

Figure 3. Sample of Well Burned Incinerator Residue

picture of a typical well burned-out incinerator residue.

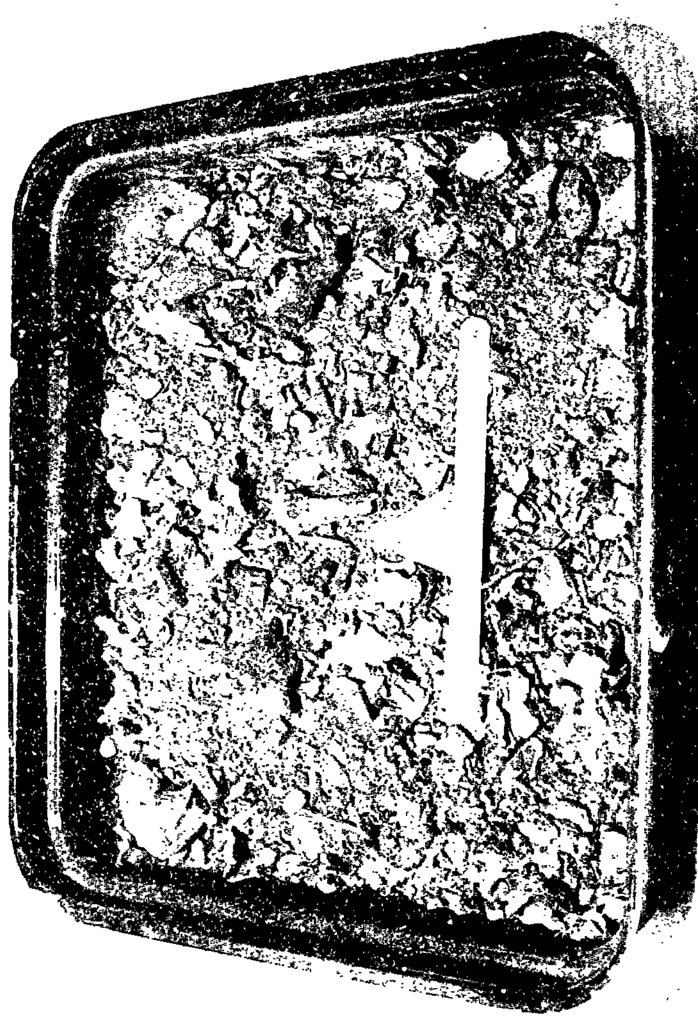
2. *Intermediately burned-out*. This category of residue is produced from continuous fed incinerators with traveling grates, which do not mechanically agitate or break down the burning refuse to any great extent. These residues can be expected to represent approximately 20 volume percent and 25 to 35 weight percent of the refuse input (10). An intermediately burned-out incinerator residue is pictured in Figure 4.

3. *Poorly burned-out*. These residues are the by-products from batch fed incinerators or very poorly operated continuous fed incinerators, particularly traveling grate plants. Variations in burning time in such plants significantly affect the degree of burnout, resulting a sizeable amount of unburned or partially burned combustible material. Typically, these residues comprise 30 to 40 volume percent and 30 to 40 weight percent of the refuse input (10). Figure 5 shows a poorly burned-out incinerator residue.

The efficiency of incineration at any plant can be influenced to some extent by differences in plant operations. The operational philosophies of supervisory personnel may vary widely from one plant to another. The frequency and amount of "downtime" required for maintenance at any plant could also affect the manner in which the plant is operated. The burning of wet refuse, collected during rainy periods, can also be handled in different ways. Depending on the methods employed for burning wet refuse, even the most modern plant may produce a poorly burned-out residue.

It must be kept in mind that incineration is used by municipalities solely for the purpose of reducing the overall volume of solid waste prior to disposal. The quality control of the resultant residue is ordinarily not an important factor which influences the operation of a municipal incinerator plant. Therefore, classification of a source of incinerator residue should not be based solely on the furnace operation and grate type; the manner in which the plant is operated should also be recognized and taken into consideration.

The classification of incinerator residues outlined in this report is based on normal operations at the plant. Sign-



ificant variations in plant operating procedures over an extended period of time could possibly result in a change in classification for a particular source of residue.

Residues from the pyrolysis of solid waste are a special class apart from incinerator residues. Pyrolysis residues are, in most cases, extremely well burned, uniformly graded, glassy materials which comprise approximately 5 to 10 volume percent and 15 to 20 weight percent of the refuse input (11). A typical residue from a pyrolysis operation is shown in Figure 6.

The suggested classification system (based on degree of burnout) is quite subjective. This means of classification is dependent to a great degree upon the visual inspection and judgment of the observer. It is, therefore, not as definitive as it should be for practical usage. Consequently, there is a need for a more definitive means of assigning a classification to a source of incinerator residue.

Table 2 lists additional criteria for quantitatively identifying the classifications of incinerator residue. Since the residues from pyrolysis operations are basically similar, the criteria noted in Table 2 will not be applied to these materials. The parameters used for these criteria are the loss on ignition (LOI) and the presence of organic impurities. Since these parameters are indicative of the content of carbon and organic matter in the residue, they can be readily related to the degree of residue burnout, upon which the classification system is based.

Although a minimal number of tests were used in the development of these criteria, the values for loss on ignition and the color ranges for presence of organic impurities are considered to be relatively accurate for classification of incinerator residues. However, it must be emphasized that proper sampling and a sufficient number of tests must be performed in order to make use of these suggested criteria. In the event the criteria for loss on ignition and presence of organic impurities indicate different residue classifications, the lesser degree of burnout shall be used as the classification of the residue.

---

(11) *Rofe, Rene; Ganotis, Chris G.; Schneider, Susan A.; and Yaffe, Harold J., "Energy Conservation Waste Utilization Research and Development Plan". The Mitre Corporation, Bedford, Massachusetts, July, 1975, 191 p.*

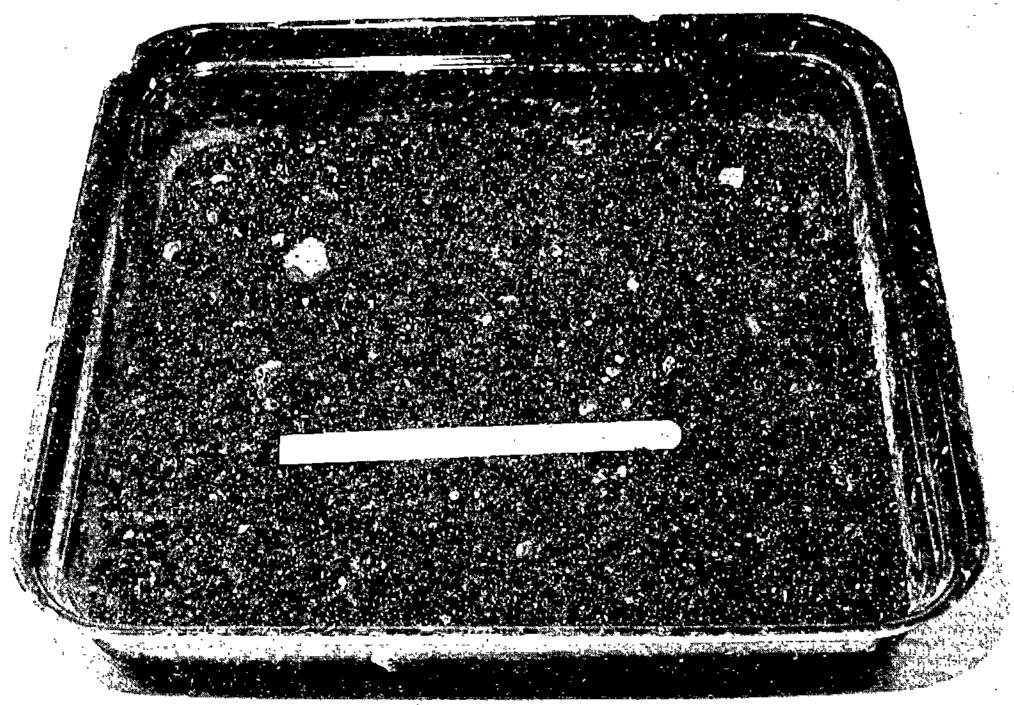


Figure 6. Sample of Pyrolysis Residue

Table 2. Suggested Criteria for Classification of Incinerator Residues

Type of Residue	Loss on Ignition (Percent)	Color of Organic Test Solution
Well burned	Less than 5	Lighter than standard
Intermediately burned	5 - 10	Same as standard
Poorly burned	More than 10	Darker than standard
Pyrolysis	Identification of the residue as coming from a pyrolysis process is sufficient.	

The loss on ignition test is conducted in accordance with the method of test developed by the U. S. Environmental Protection Agency (12). A detailed description of the test procedure is given in Section 9, Appendix A, on page 82 of this manual. The test procedure involves the fine grinding of a representative sample of residue, obtaining a 50 gram sample for the test, subjecting the sample to a one hour exposure in a muffle furnace at 950° C (1742° F), and computing the loss in weight of the sample. The loss on ignition value is directly related to the carbon content or percentage of combustible material that is contained in the sample. Because of the

(12) *U. S. Environmental Protection Agency, Manual No. EPA-6700-73-01, "Physical, Chemical, and Micro-Biological Methods of Solid Waste Testing". Part 2, Office of Research and Monitoring, National Environmental Research Center, Cincinnati, Ohio, May, 1973.*

comparatively small sample size (approximately 50 grams), it is recommended that a series of tests be conducted for any material, so that a truly representative loss on ignition value can be obtained.

The test for Organic Impurities in Sands for Concrete (ASTM C 40) is simple to perform. It consists of adding a 3 percent NaOH solution to a sample of material in a standard glass container, shaking, and allowing it to stand for 24 hours, after which the supernatant liquid in the bottle is compared to that of a reference standard color solution. If the color of the supernatant liquid is darker than that of the reference standard color solution, the material may contain injurious organic compounds and should be further evaluated prior to use.

4. DESCRIPTION AND COMPOSITION OF INCINERATOR RESIDUE

4.1 PHYSICAL COMPOSITION AND PROPERTIES

Incinerator residue is a heterogeneous material derived from the combustion of municipal solid waste, which is subject to fluctuations in composition. The principal components of incinerator residue are glass, metals (ferrous and non-ferrous), mineral matter, and combustible and organic material.

The first comprehensive investigation of the physical composition of municipal incinerator residue was performed in 1968 by the U. S. Bureau of Mines (13). In this study residue samples were obtained from a rotary kiln furnace and a variety of grate-type furnaces which were in operation during that time in the Washington, D.C. area. The samples were processed and separated into their principal components by several methods. The average composition of the incinerator residues evaluated in the U. S. Bureau of Mines study is summarized in Table 3.

During the same period of time, similar analyses were

---

(13) *Kenahan, C. B.; Sullivan, P. M.; Ruppert, J. A.; and Spano, E. F., "Composition and Characteristics of Municipal Incinerator Residues", U. S. Department of Interior, Bureau of Mines, Report of Investigations No. 7204, Washington, D. C., December, 1968, 20 p.*

Table 3. Composition of Incinerator Residues from Early Studies (Percent by Weight)

Component	U. S. Bureau of Mines	Oceanside, New York	Stamford, Connecticut
Metals[1]	29.4	27.2	23.6
Glass	44.0	46.1	36.6
Mineral Matter[2]	17.6	24.1	36.0
Combustible and Organic Matter	9.0	2.6	3.8
	100.0	100.0	100.0

[1]Includes ferrous metals, non-ferrous metals, and mill scale.

[2]Includes sand, stones, clinkers, ash, ceramics, and filter cake.

performed by Arthur D. Little, Inc., (14), on residue samples from incinerator plants in Oceanside, New York, and Stamford, Connecticut. The findings from these analyses are closely related to the average composition figures developed by the Bureau of Mines, as shown in Table 3.

A more recent study of incinerator residues performed for the Federal Highway Administration (15) involved the analysis of residues from sources representing each type of incinerator in terms of grate design and anticipated residue type. Composition studies were performed on representative samples from each plant, according to type of residue. Table 4 presents the findings of these analyses and compares the average composition from all samples with the earlier data developed by the U. S. Bureau of Mines. These values are representative of the expected composition of different types of municipal incinerator residues in the United States. Figure 7 indicates the average composition of municipal incinerator residues, together with the range in the percentage for each component, as determined from the analytical studies.

The diversity of the components in the municipal incinerator residues accounts for certain unusual or unique characteristics of the material. For instance, the nature and occurrence of the various components of the residue are not always uniformly distributed throughout the material. In particular, much of the glass fraction of residue is found in those particle sizes larger than 1/4 inch (6.35 mm). By contrast, the mineral matter is more well distributed, with stones and ceramics com-

---

(14) *Kaiser, E. R.; Zeit, C. D.; and McCaffery, J. B., "Municipal Incinerator Refuse and Residue", In Proceedings; 1968 National Incinerator Conference, American Society of Mechanical Engineers, New York, N. Y., May 5-8, 1968, pp. 142-153.*

(15) *Collins, Robert J. and others, "Technology for Use of Incinerator Residue as Highway Material", U. S. Department of Transportation, Federal Highway Administration, Draft Final Report, Washington, D. C., October, 1976, 327 p.*

Table 4. Physical Composition of Incinerator Residue (Percent by Weight)

Component	Well Burned	Intermediately Burned	Poorly Burned	Average Composition	U.S. Bureau of Mines
Glass	39.9	51.5	45.7	48.0	44.0
Mineral Matter	39.5	17.5	13.1	21.0	17.6
Ferrous Metal	13.8	16.0	8.7	14.2	28.0
Non-Ferrous Metal	3.3	4.3	4.3	4.1	1.4
Combustible and Organic Matter	3.5	10.7	28.2	12.7	9.0
	100.0	100.0	100.0	100.0	100.0

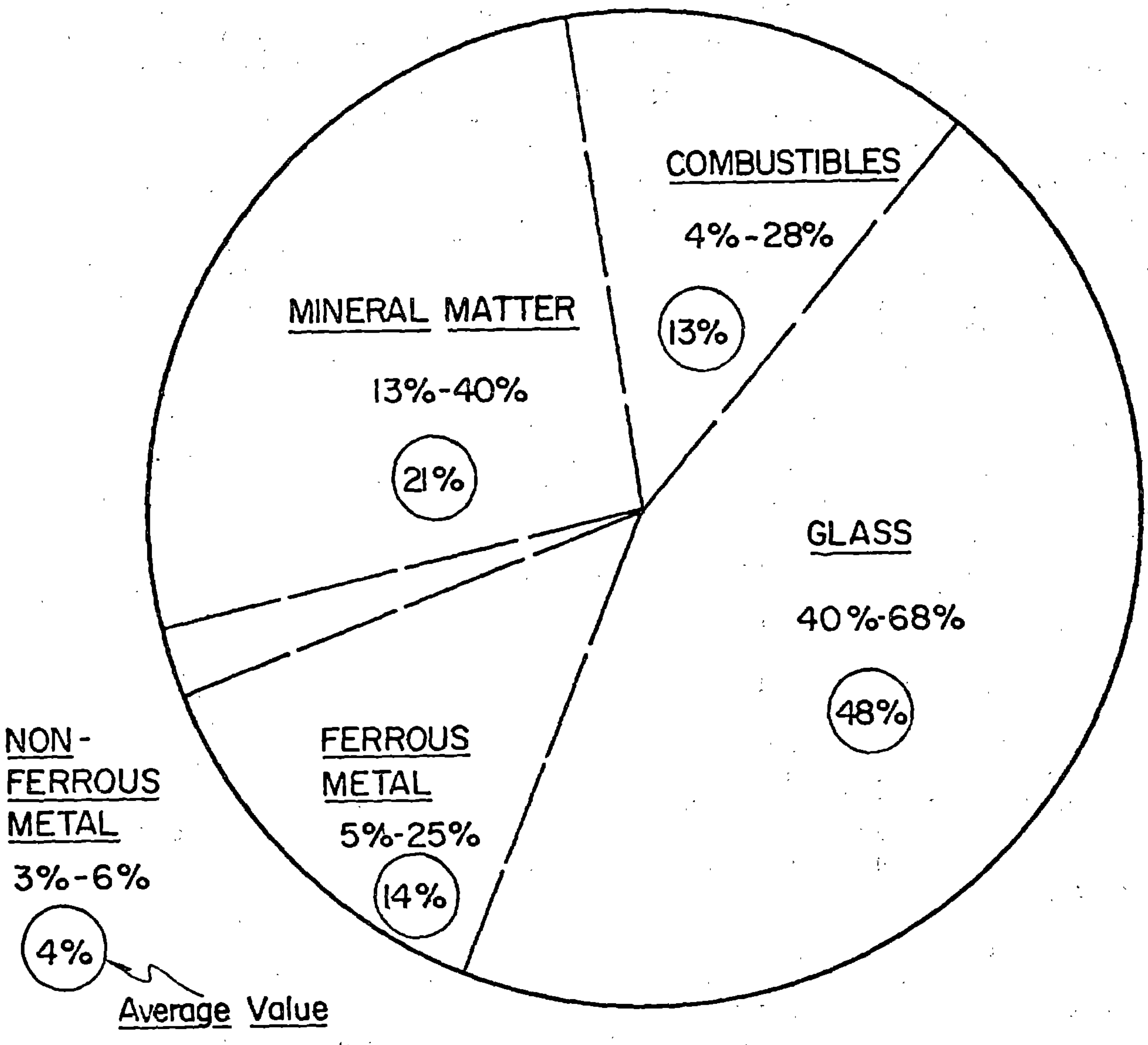


Figure 7. Average Composition of Incinerator Residue

prising the coarser fraction and ash, filter cake, and sand the finer fraction. Figure 8 is a picture which shows the principal components of incinerator residue.

The particle size distribution of incinerator residues is also of great interest to those intending to make use of the material. Incinerator residue is essentially a fairly well graded material. Aside from some occasional oversize materials (such as small appliances, auto parts, large chunks of metal, or rags), particle sizes range from 3 inches (76.2 mm) down to a nominal amount passing 200 mesh (0.074 mm). In general, the greater the turbulence on the incinerator grate, the finer the particle size distribution of the residue. Figure 9 shows the expected range of particle size distribution for residue as it was obtained from the incinerator, but with the particles removed whose largest dimension was greater than 3 inches (76.2 mm).

The moisture content of incinerator residue can vary widely, depending on the degree of burnout, the method of quenching, and the age of the residue. Moisture contents have been found to range from 15 percent for well-burned stockpiled residue to 60 percent for intermediately burned freshly quenched residue. Average moisture contents of incinerator residue samples from previous studies were found to average approximately 30 percent, although the moisture content of drained samples was found to be approximately 20 percent.

The unit weight of "as-received"* incinerator residue is also a variable which is dependent on the composition of the residue and its degree of burnout. As the degree of burnout improves, the unit weight of the residue increases. The dry rodded weight of incinerator residue can range from less than 50 pounds per cubic foot for poorly burned material to over 80 pounds per cubic foot for material with a high degree of burnout.

The physical composition of pyrolysis residue is considerably different from that of incinerator residue. In appearance, the residue is a black, glassy, sand-size material, not unlike a fine-grained boiler slag or a granulated lead smelter slag. Table 5 presents the physical composition of residue from the Monsanto pilot pyrolysis plant in St. Louis, which is a prototype of the Landgard plant in Baltimore.

---

*The term "as-received" means that the residue is in the same condition as when it came from the incinerator with two possible exceptions: 1) The pieces larger than 3 inches have been removed; and 2) The material may be drier than when it was sampled.

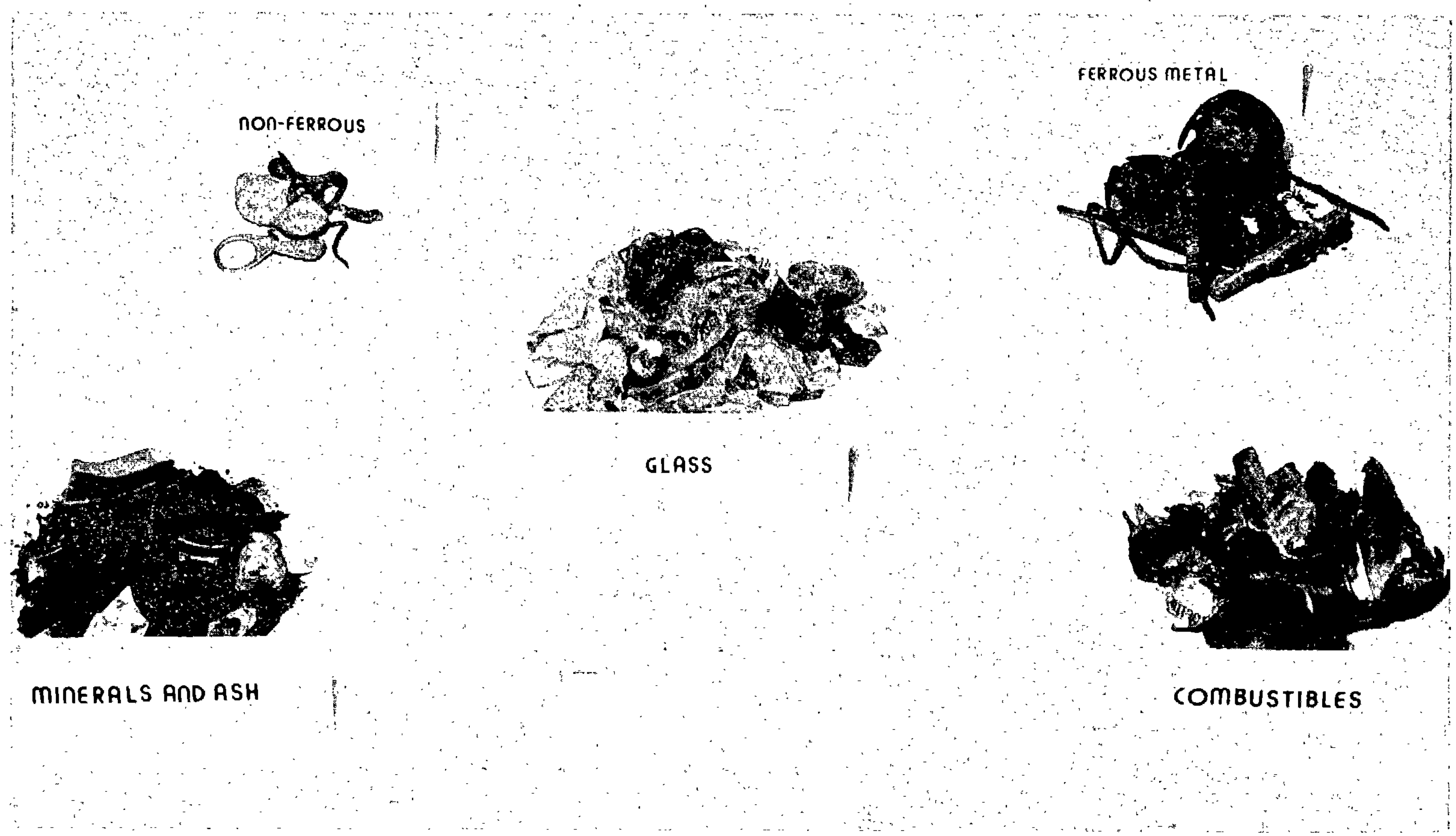


Figure 8. Principal Components of Municipal Incinerator Residue

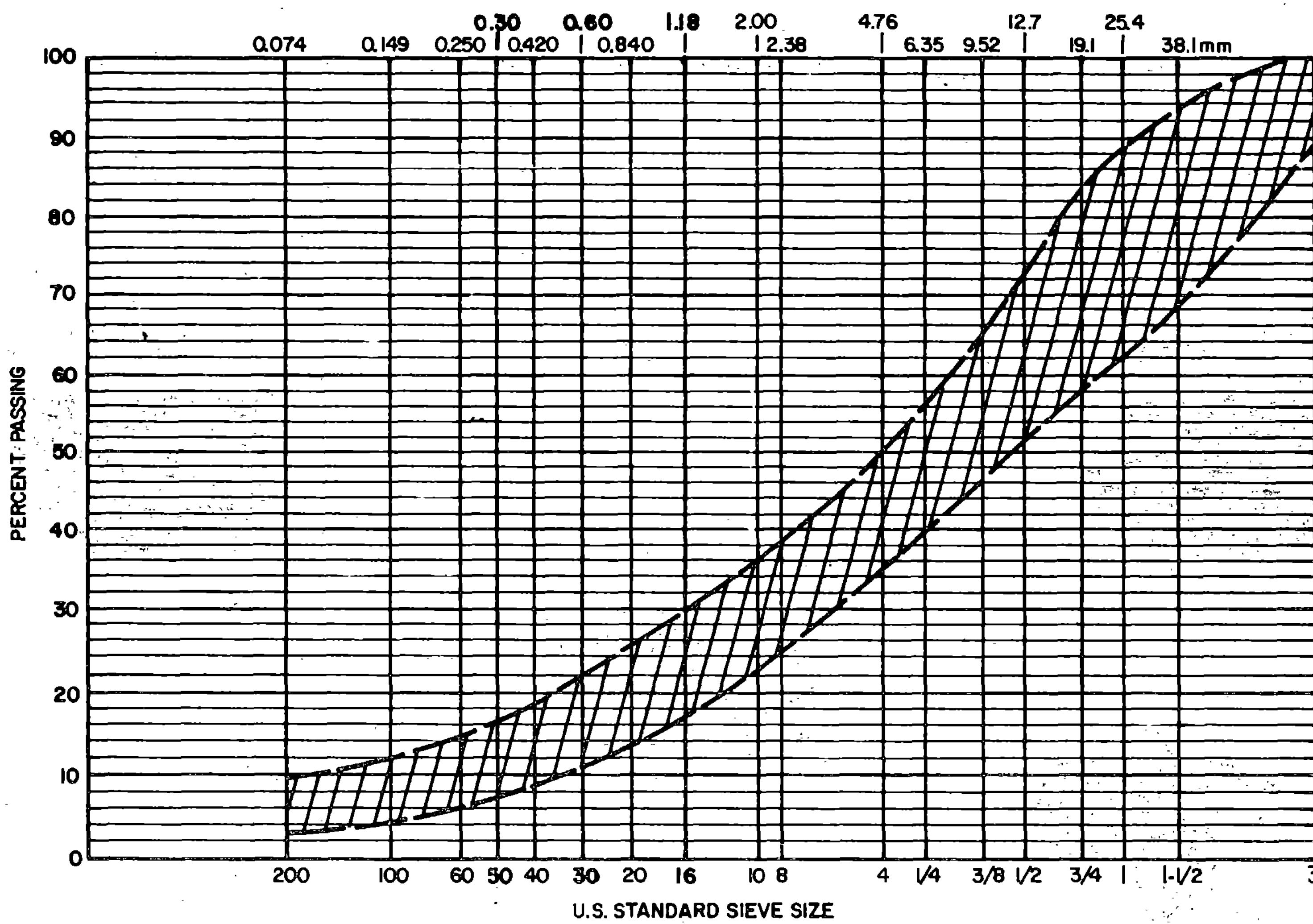


Figure 9. Particle Size Distribution of "As Received" Incinerator Residue

Table 5. Physical Composition of Pyrolysis Residue (Percent by Weight)

Component	Percent
Glass	65
Mineral Matter	28
Ferrous Metal	3
Non-Ferrous Metal	2
Carbon	2
	100

The residue described in Table 5 is referred to as a "glassy aggregate" because the majority of the ferrous metal and carbon char have been removed from the pyrolysis residue prior to final disposal. The ferrous metal is magnetically separated and the carbon char is removed by flotation (16).

(16) *U. S. Environmental Protection Agency, "Baltimore Demonstrates Gas Pyrolysis". Report No. EPA/530/SW-75d.i, Washington, D. C., 1974, 23 p.*

Figure 10 shows the gradation range of pyrolysis residue, as determined from two sources; one from Baltimore and one from Charleston, West Virginia. The gradation range of these two samples of pyrolysis residue is very well defined and is considered representative of the particle size distribution of the residue from most pyrolysis operations. However, each source of material must be investigated to determine its own particular characteristics.

Because of the low porosity and glassy nature of pyrolysis residues, the moisture content of these materials is very low, usually less than 1 percent. The unit weight of pyrolysis residues is considerably higher than that of incinerator residue. Dry unit weight values for pyrolysis residue are most likely to fall within the range of 110 to 120 pounds per cubic foot (1763 to 1922 kilograms per cubic metre).

4.2 CHEMICAL COMPOSITION

The chemical composition of incinerator residue, like its physical composition, depends upon the nature of municipal refuse and the degree of burnout at the incinerator plant. Previous studies (17, 18) have been performed to determine the composition of carbon-free incinerator residues from several different sources. The average of the chemical analyses from these studies has been reported as follows:

---

(17) *Bortz, S. A. and Pincus, A. G., "High Temperature Incineration". In Proceedings; National Industrial Solid Wastes Management Conference, Houston, Texas, March, 1970, pp. 244-254.*

(18) *Doty, W. J., et al, "The Analysis of Refuse and Ash for Union Electric Company", Ralston Purina Company, St. Louis, Missouri, May, 1972.*

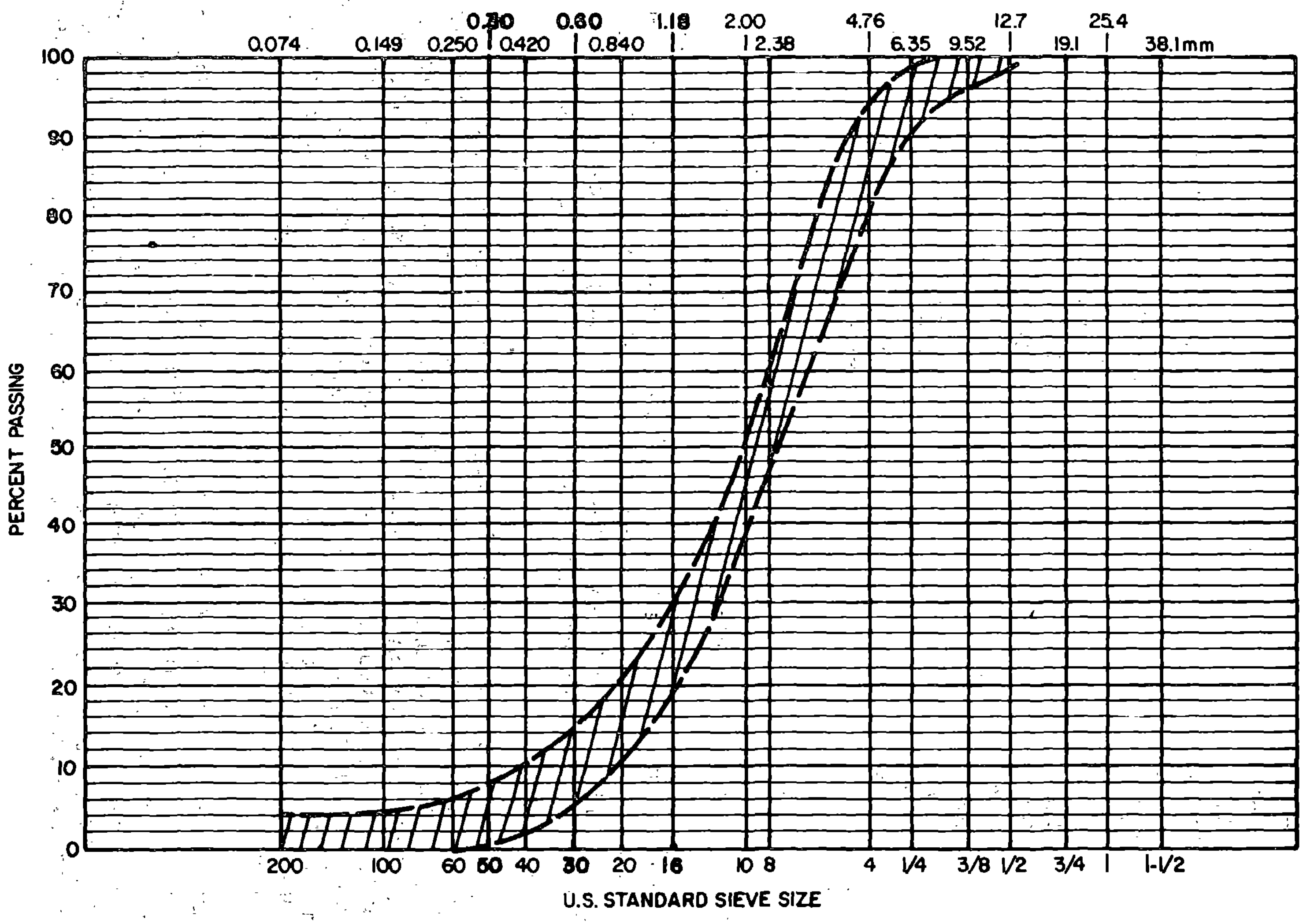


Figure 10. Particle Size Distribution of Pyrolysis Residue

Component	Percent by Weight
SiO_2	59.8
CaO	11.9
Al_2O_3	9.8
Fe_2O_3	4.0
TiO_2	1.0
MgO	3.0
ZnO	0.4
PbO	0.1
CuO	0.1
MnO	0.3
Na_2O	6.1
K_2O	0.5
SO_3	0.9
P_2O_5	0.5
Other	1.6
	100.0

Although individual samples of incinerator residue may vary somewhat from this average composition, the degree of variability should not be significant and the relationship between principal components should be essentially the same and should fall within known limits.

One difference in chemical composition between sources of residue will be the amount of carbonaceous material in the residue. This carbonaceous material is referred to in the previous section as combustible and organic matter. The most practical way of measuring the amount of combustible and organic matter in the residue is by means of the loss on ignition (LOI) test. However, this test does not provide an absolute value for carbon content of the sample due to oxidation reactions occurring with metals during the test.

Although the amount of carbonaceous material present in the residue is a function of the degree of burnout of the material, loss on ignition values from 2 to 15 percent or more can be expected. The chemical composition of a sample of incinerator residue should, therefore, also include the value of loss on ignition (LOI), which is indicative of the carbon content of the residue.

5. Incinerator Residue as a Structural Fill

In addition to landfilling, there has been a limited use of incinerator residue as structural fill material in different parts of the United States. During the past few years, the City of Tampa, Florida has been using residue from its rotary kiln incinerator as a fill or embankment material, and as subbase for parking lot construction (19). During World War II, incinerator residue was also used as embankment and subbase material in the construction of the Industrial Highway (Pennsylvania Route 291) near the Philadelphia International Airport (20). In addition, it has been reported that many of the streets in Brooklyn were built on compacted incinerator residue during and immediately after World War II (21).

Although there are no written reports documenting these applications, the successful performance of the facilities themselves offer evidence to the usefulness of incinerator residue in a highway fill. The following sections provide guidelines for controlling the quality of materials; for establishing laboratory procedures for design and control; and for developing construction procedures. The guidelines are applicable to those residues classified as either well burned or intermediately burned. Poorly burned residue should not be used as a structural fill. Special guidelines will be needed for pyrolysis residue, if and when it becomes available in sufficient quantity.

5.1 PREPARATION OF RESIDUE FOR USE

5.1.1 ACCEPTABLE TYPES OF RESIDUE

Residues classified as well burned or intermediately burned can be used as structural fill. Poorly burned residue should

---

(19) *Conatty, Norman, City of Tampa, Sanitation Department. Personal Communication.*

(20) *Cappelli, Dominick, Cappelli Brothers Trucking Company, Glen Mills, Pennsylvania. Personal Communication.*

(21) *Fenton, Richard, Assistant Commissioner, New York City Environmental Protection Administration. Personal Communication.*

not be used unless its physical characteristics have been considerably altered. Such improvement in physical characteristics may be accomplished by stockpiling and aging. The decomposition of the combustible and/or organic portion of the residue and the oxidation of the metals is a continuing process. As a result, the percentage of unburned combustible materials is reduced. The moisture content is also reduced and, in general, the residue becomes a more workable construction material.

It is estimated that stockpiling for at least six months to a year is required in order to produce noticeable improvement. Residue that is initially poorly burned and then stockpiled should be sampled and evaluated periodically. When it meets the criteria for intermediately burned residue, as shown in Table 2, it could then be used.

5.1.2 PROCESSING OF RESIDUE

It is necessary to remove from most residues the miscellaneous debris that would continue to decompose or that would be difficult to incorporate into an embankment. This debris consists of such things as: metal parts from appliances, toys and furniture; metal cans; and large pieces of wood.

The removal of all objects whose largest dimension is three inches (76.2 mm) or more would eliminate most, if not all, of this debris. In general, the residues will be better fill materials if the maximum particle size is reduced to two inches (50.8 mm) or less.

Removal of these larger objects can be accomplished by a combination of screening, magnetic separation, and by hand. Objects made from ferrous metals predominate; however, there is usually a significant fraction of combustible materials (unburned newspapers, magazines, and rags) and mineral matter (rocks, bricks). If magnetic separation is employed, it usually must be accompanied by screening or removal by hand.

5.2 LABORATORY DETERMINATION OF OPTIMUM MOISTURE CONTENT AND MAXIMUM DRY DENSITY

The classical laboratory method of determining the moisture-density relationships for soil and soil-like materials for controlled fill applications is the moisture-density or

Proctor test (ASTM Designation D 698). This test involves the compaction of the material in standard steel molds (4 inches or 101.6 mm in diameter by 4.56 inches or 115.8 mm high) using a standard compactive effort. The dry density of the compacted material must be determined for different moisture content values. The density and moisture content values are plotted on a graph, usually in the form of a smooth curve which identifies the moisture content value at which the maximum density occurs.

In order to perform this test with incinerator residue, ASTM Designation D 698, Method C, should be used. Method C specifies a maximum particle size of three-quarters of an inch (19.1 mm). Several factors must be recognized prior to using this test method with incinerator residue.

As has been shown in Sections 3 and 4, residue consists of diverse and dissimilar components (metals, glass, ash, etc.) with quite different particle properties. In addition, these components are not always distributed uniformly throughout the residue. The glass and metal fractions have little or no affinity for water, except on their surfaces, while the ash and combustible materials absorb high percentages of moisture. Some of the fractions are susceptible to degradation as they are compacted during the laboratory test. This degradation, as the test progresses, results in a test sample of continuously changing characteristics.

For these reasons separate residue samples should be used for each test point and special care should be taken to insure that they are representative of the residue being evaluated. There should be at least four, and preferably five, test points taken in order to establish a reliable moisture-density curve. It is also recommended that three separate moisture-density tests be performed so that the range of moisture contents and related densities can be thoroughly evaluated.

It has been found that a well defined optimum moisture content and maximum dry density is not always obtained. In such cases a subjective determination of the moisture range at which effective compaction can be obtained must be made. This determination should be based on the results of the moisture-density laboratory evaluation and the observations of the operator of the test. The moisture content beyond which the test sample begins to appear excessively wet or "mushy" should be considered to be the maximum moisture content for the attainment of proper compaction. The dry density at this moisture content should be used in the field in the same manner as the maximum dry density at the optimum moisture content, which normally results from the moisture-density test.

In cases where the moisture-density relationship shows an optimum moisture content, it will probably be between 16 and 20 percent. If the optimum moisture content is well defined, that value should be used for control purposes in the field. The maximum dry density of the compacted residue will probably vary from 75 to 105 pounds per cubic foot (1201 to 1682 kilograms per cubic metre).

5.3 CONSTRUCTION PROCEDURES

Most residues should be stockpiled prior to using as a structural fill. The reason for this is the high moisture content of the residue as it comes out of the incinerator. A program of moisture content monitoring of the stockpile should be carried out. This program should assist in the following:

1 - Determining when the moisture content of the residue is suitable for proper field compaction.

2 - Estimating the time required for the moisture content to decrease to a suitable value. For well-burned residues, the addition of slight amounts of water may be needed for adequate compaction if the moisture content after stockpiling is less than that required to achieve maximum dry density.

3 - Preparing a stockpile management plan that will tend to provide areas where moisture content uniformity can be established.

The successful fills constructed in the Tampa area were built by placing 12 inch (304.8 mm) loose lifts of aged incinerator residue and compacting each lift with steel wheel rollers (22). It is recommended that fills be constructed in layers with a loose thickness no less than eight inches (203.2 mm) and no more than twelve inches (304.8 mm). Each layer should be compacted before the application of a subsequent layer. Compaction should be continued until the compacted fill material is stable under repeated loading and does not deflect noticeably under the action of the roller. A recommended quantitative criterion for satisfactory compaction is a minimum of 95 percent of the maximum dry density as determined by ASTM Designation D 698.

Where incinerator residue is used in the top three feet (0.9 meter) of a highway embankment, the layer thickness should not exceed eight inches (203.2 mm) prior to compaction.

---

(22) *Conatty, Norman, City of Tampa, Sanitation Department. Personal Communication.*

The in-place density of the compacted residue for this use should be 100 percent of the maximum dry density as determined by ASTM Designation D 698. The top surface of the fill should be sealed with a coating of rapid curing asphalt cutback or emulsion, applied uniformly at a rate of from 0.1 to 0.3 gallons per square yard. The seal coat acts to prevent water evaporation and subsequent dusting of the top surface and inhibits the entry of surface water into the compacted fill.

Documented information relative to the most satisfactory type of compaction equipment is not available. However, the residue is cohesionless and equipment suitable for cohesionless materials would probably be the most effective. The use of vibratory compaction equipment should be considered.

The environmental effects of utilizing incinerator residue as fill must be evaluated in terms of proximity to ground water sources and the permeability and leachate characteristics of the compacted residue. There are currently no uniformly recognized test methods for the collection and evaluation of the leachate from a residue fill. The evaluation of potential environmental effects should be coordinated with the appropriate local regulatory agency. Potential hazard due to generation of gas may also need to be determined.

6. INCINERATOR RESIDUE AS STABILIZED BASE MATERIAL

Over the past twenty-five years, research studies and field installations have provided evidence that the addition of stabilizing agents (such as lime, cement, or pozzolans) improves the properties and performance of soils and graded aggregates. Of particular significance is the recognition and increased utilization of stabilized base course compositions in the construction of roadways and parking areas. These compositions involve the blending of a known proportion of a stabilizing agent with a soil and/or aggregate and the compaction of the blended mixture to its maximum density at optimum moisture content.

A patent has been granted for a base course mixture consisting of residue from a rotary kiln incinerator stabilized with hydrated lime (23). Data on these lime-treated residue

(23) *Gnaedinger, John P., "Materials and Method for Pavement Construction". U. S. Patent No. 3,293,999, United States Patent Office, Washington, D. C., December 27, 1966.*

compositions, termed "Chempac", has been developed by Soil Testing Services of Northbrook, Illinois. Several test installations of "Chempac" compositions have been placed in the Chicago area to demonstrate the applicability of the material as a base course for street and parking lot construction.

There are no other known field installations of stabilized bases that contain incinerator residues. Many of the recommendations contained in this section are based on the results of laboratory evaluations.

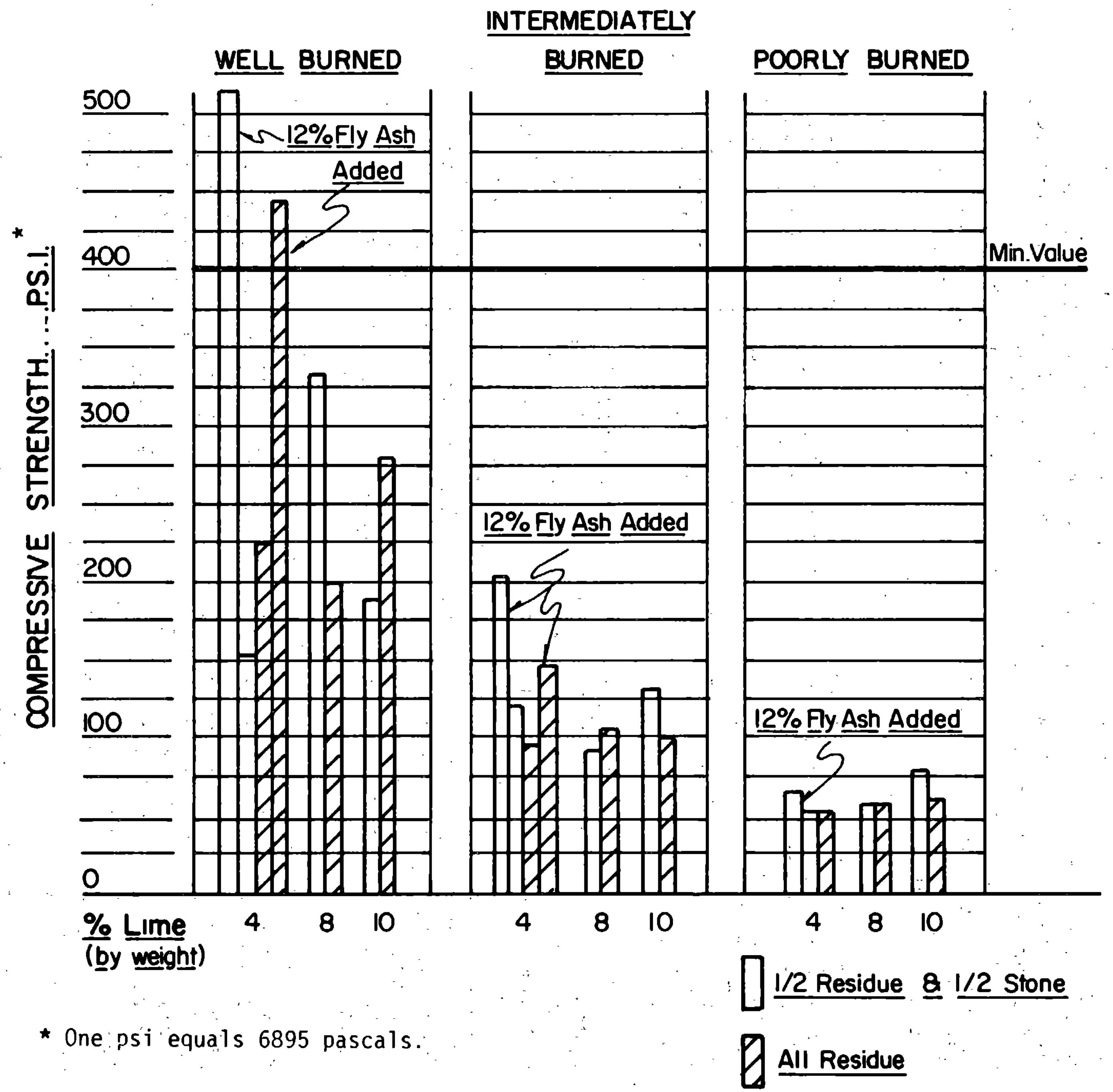
6.1 ENGINEERING PROPERTIES

Before attempting to utilize incinerator residue in stabilized base course mistures, it is necessary to be familiar with the engineering properties of these mixtures. The residue itself should not normally have a loss on ignition (LOI) value higher than 10 percent, except that in "Chempac" compositions the amount of carbon in the residue is preferred to be in the range of 10 to 15 percent by weight. This is because a carbonation reaction occurs in the "Chempac" mixtures between the calcium in the lime and the finely divided carbon in the residue. This reaction causes the formation of calcium carbonate and results in the gradual cementing of the coarser particles in the mixture (23).

Data are available on the laboratory determined compressive strength characteristics of stabilized base course mixtures using incinerator residue. Figure 11 shows the seven day compressive strength development of lime and lime-fly ash stabilized mixtures using incinerator residue after curing at 100° F (38° C). By blending the residue on an equal weight basis with crushed stone, a lime stabilized mixture using well burned residue with 8 percent dolomitic hydrated lime reached a seven day strength in excess of 300 psi.* Mixes containing well burned and intermediately burned residue stabilized with lime can be substantially improved in strength with the addition of fly ash to the mixture as shown in Figure 11. However, the addition of fly ash did not improve the low strength characteristics of poorly burned residue.

Most cured lime stabilized incinerator residue specimens exhibit freeze-thaw weight loss values of approximately 30 percent, which are more than twice the allowable durability requirements of the wire brush test. Even when blended with an

*One psi equals 6895 pascals.



* One psi equals 6895 pascals.

Figure 11. Compressive Strength of Lime Stabilized Base Course Mixtures

equal weight of crushed stone, most lime stabilized residue specimens still have freeze-thaw weight loss values in excess of the 14 percent maximum. The addition of fly ash to lime stabilized residue mixtures normally results in greatly improved durability, usually with freeze-thaw weight loss values considerably less than 10 percent. It is notable that the wire brush test for lime stabilized compositions has recently been replaced by a new vacuum saturation method described in ASTM C 593, although no test data is available at this time for lime stabilized residue specimens. Section 6.3.2 provides a brief description of this test.

The unconfined compressive strength of "Chempac" compositions has been found to be in the range of 200 to 300 psi* after 28 days of curing at 100° F (38° C). After 3 months of curing, these mixtures normally have compressive strengths of 300 psi or more and develop between 400 and 500 psi compressive strength after 6 months of curing. Values of "Chempac" from the CBR test can range from 60 to 120, compared to a value of 100 for crushed stone aggregate (24).

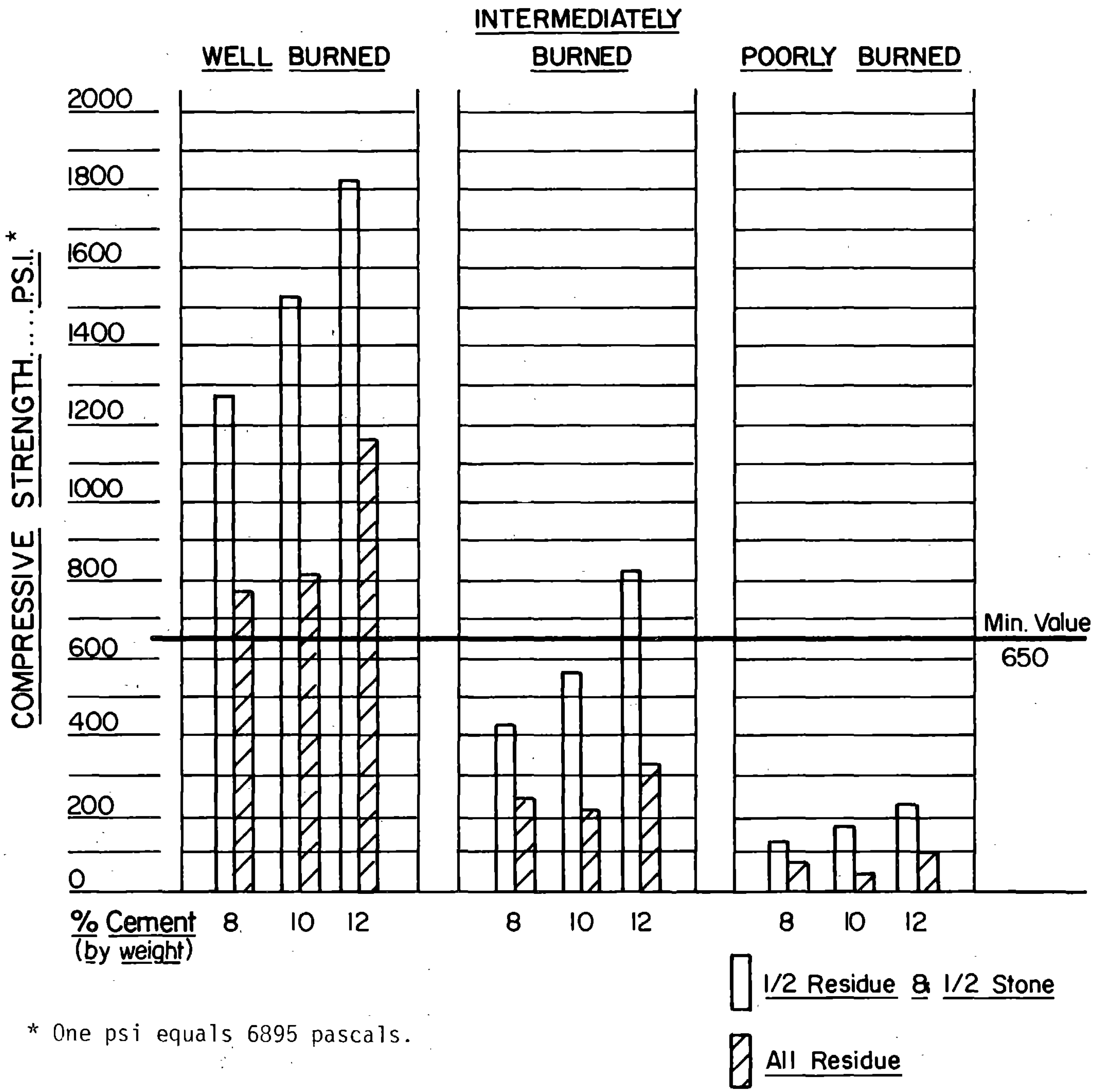
Figure 12 shows the seven day compressive strength development for cement stabilized base course mixtures using incinerator residue after curing at 70° F (21° C). Well burned residue can be stabilized with cement and meet minimum strength criteria. Blending with natural aggregate results in some extremely high seven day compressive strength values, well in excess of 1000 psi. According to Figure 12, it is possible to meet minimum compressive strength criteria by blending intermediately burned residue with natural aggregate. Minimum strengths cannot be achieved when poorly burned residues are used.

The durability of cured cement stabilized base course mixtures is determined by the wire brush test (ASTM D 560). The results of tests performed on these mixtures indicates that cement stabilized incinerator residue compositions are sufficiently durable to meet or exceed the criteria for weight loss after twelve cycles of freezing and thawing. In nearly all cases, freeze-thaw weight loss values for cement stabilized residue specimens were found to range from 1 to 5 percent, which is substantially below the maximum allowable weight loss of 14 percent.

* One psi equals 6895 pascals.

---

(24) *Gnaedinger, John P., President, Soil Testing Services, Northbrook, Illinois. Personal Communication.*



* One psi equals 6895 pascals.

Figure 12. Compressive Strength of Cement Stabilized Base Course Mixtures

6.2 PREPARATION OF RESIDUE FOR USE

In order to utilize incinerator residue as an aggregate in stabilized base course compositions, the material must be graded to conform to applicable specification requirements. The maximum particle diameter recommended for such use is 1-1/2 inches (38.1 mm), although sizes up to 2 inches (50.8 mm) in diameter may be permitted in some applications. The "Chempac" patent states that the maximum particle size of rotary kiln residue for use in such compositions be limited to 1 inch (25.4 mm).

Gradation control of incinerator residue can be achieved in several ways. Screening by means of a trommel is practiced at a number of incinerator plants. The trommel is a rotating metal drum with regularly spaced circular holes, normally 1-1/2 inches (38.1 mm) in diameter. One of the main advantages of using a trommel is its self-cleaning ability, due to the inclined rotational movement of the drum. A vibrating metal screen can also be used to separate the material at a desired size, although periodic cleaning of the screen is necessary. This reduces the efficiency of the screen and may require additional manpower for operation (25).

A hammermill shredder can also be used for size reduction of incinerator residue in much the same way that municipal refuse is shredded prior to further processing in resource recovery operations. The operational requirements of a shredding process, the amount of maintenance required for the shredder, and the economics of purchasing and operating shredding equipment are all factors which must be considered in this approach. On the surface, it would appear that the lower cost of screening or trommeling would outweigh the advantages of full use of the residue through shredding.

Another effective way of removing the larger size particles is through magnetic separation. A high percentage of the incinerator residue particles that are greater than 1-1/2 to 2 inches (38.1 to 50.8 mm) in size consist of ferrous metal, occurring as metal containers, small appliances, and auto parts. Removal of these and other ferrous materials from the residue

---

(25) *Walter, C. Edward, "Practical Refuse Recycling," Journal of Environmental Engineering Division, American Society of Civil Engineers, February, 1976, pp. 139-148.*

will in most cases effectively reduce the maximum particle size of the residue to that recommended for use in stabilized base course mixtures. In some cases magnetic separation may have to be accompanied by hand picking or screening of other oversize materials in order to meet gradation requirements.

The gradation range, shown in Figure 13, is representative of the gradation that can be expected from incinerator residue from which particles larger than 1-1/2 inches (38.1 mm) have been removed. The 1-1/2 inch (38.1 mm) size is usually the top size recommended for use in stone base and in the coarse aggregate component of stabilized bases. Figure 13 shows that incinerator residue is well graded from the coarse to fine and will probably meet gradation requirements for most stone and stabilized base courses.

The gradation range for a typical pyrolysis residue is shown in Figure 10. Pyrolysis residue is more uniform than other incinerator residues, with approximately 80 percent by weight between the No. 4 and No. 40 mesh screen sizes. Although no prior screening appears to be necessary before using pyrolysis residue, the material must be blended with conventional aggregate to achieve an acceptable gradation for use in base course mixtures.

Only well burned or intermediately burned residues should be used in stabilized bases. Poorly burned residue should not be used unless its properties have been improved by aging (see Section 5.1.1).

6.3 MIX DESIGN AND LABORATORY TEST PROCEDURES

Stabilized base course compositions consist of at least two components: an aggregate and a binder. In many cases, as in aggregate-cement stabilized base, water is added to provide the moisture necessary to compact the mixture and to hydrate the cement and thus form a cementitious composition. The following procedures pertain to stabilized bases where incinerator residue is used as the aggregate and the binder consists of lime, lime-pozzolan, or portland cement. The successful use of stabilized base course mixtures requires that such compositions be properly formulated and mixed so that good field performance can be obtained after the base has been properly placed using acceptable construction procedures.

Stabilized bases are usually designed to meet locally applicable requirements for such mixtures. These requirements

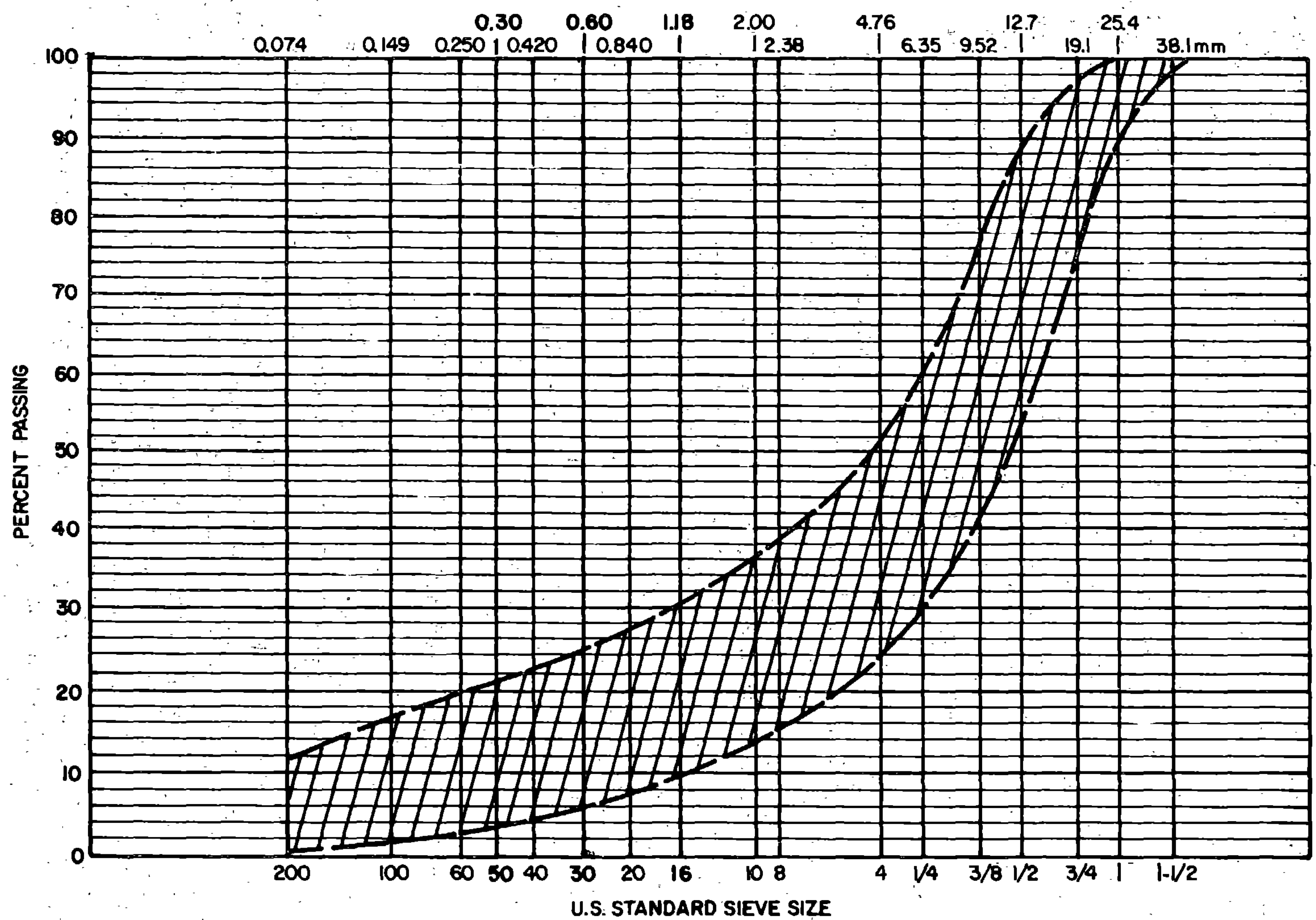


Figure 13. Gradation Range of Residue for Use in Base Course Mixtures

are generally in the form of state specifications. These specifications must obviously be used on highways that are part of the state system. Many times they are also written into the specifications for local and private construction. The procedural suggestions that are contained herein are designed to conform to existing state specifications for stabilized bases.

6.3.1 EVALUATION OF MATERIALS

INCINERATOR RESIDUE

The initial step involved in the laboratory evaluation is to select representative samples of all materials. This is particularly important in the case of incinerator residue because of its heterogeneous nature.

Residue sources should be surveyed, keeping in mind that only well burned or intermediately burned residues are to be used. A decision must be made as to whether stockpiled residue will be used or whether it will be used directly as discharged from the incinerator. It is strongly recommended that stockpiled material be used. It offers the following advantages over "fresh" residue :

1 - Reduced moisture content.

2 - Increased decomposition of organic substances.

3 - The potential for stockpile management in order to make available a more uniform material.

4 - The quantities of residue available for scheduled use are dependable and readily determined.

5 - Stockpiles are generally readily accessible to men and equipment.

After residue sources have been located, each source should be evaluated with respect to the following:

1 - Residue classification (Section 3; Table 2).

2 - Amount and characterization of large particles in the residue. The size that constitutes a large particle will vary depending on the particular application being contemplated and the applicable specifications; in general, however, two inches and more can be considered as "large" for prelimi-

nary evaluations. Plus two inches (51 mm) will also serve as a criteria for the large particles for most final evaluations.

3 - Gradation of the fine fraction.*

4 - A determination of the physical composition of the residue. Recommended procedures for such a determination are presented in Section 10, Appendix B, on page 85 of this manual.

5 - A determination of the presence of any hazardous or potentially hazardous substance. Further discussion of this matter is also included in Appendix B.

6 - Analysis of quantity available in relation to the quantity required.

If the residue from a potential source is typical in composition when compared with the compositions described in Section 4 (Table 4 and Section 4.2), the material should be considered suitable for further evaluation. This assumes that the residue contains no hazardous or potentially hazardous substances. If the composition of a particular residue is substantially different from that described in Section 4 (Table 4 and Section 4.2), special studies may be necessary to evaluate suitability of the material as an aggregate. This would also apply if hazardous or potentially hazardous substances are present.

In the event that a residue is determined to be typical, further evaluation would be based primarily on the results of performance type tests on the mixture. The recommended procedure for this evaluation will be presented in Section 6.3.2. This means that the standard aggregate tests, with the exception of gradations, would not be performed routinely for the purpose of material acceptance. It is recommended, however, that data continue to be collected on the aggregate properties of incinerator residue for possible future use.

CEMENT, LIME, POZZOLAN

These binders should be evaluated for acceptance in accordance with the appropriate state specifications. In the absence of a state specification on any of these materials, the applicable ASTM or AASHTO specification can be used.

**The fine fraction here being defined as the residue that remains after the "large particles" have been removed.*

6.3.2 MIX DESIGN

Mix design procedures involve the following steps:

1 - Design of trial mixes.

2 - Preparation of test specimens using the trial mix designs.

3 - Evaluation of trial mixes by compressive strength and durability tests.

4 - Selection of the proper mix.

DESIGN OF TRIAL MIXES

Trial selections of the percentage of binder, percentage of incinerator residue, and percentage of conventional aggregate (if any) must be made. The ranges of binder contents shown in Table 6 can be used in establishing trial mix designs. In general, the lower the dry density of the residue the greater should be the addition of binder. The need for greater amounts of binder can also be anticipated as the residue quality decreases.

At least two trial mixes will be required. The objective is to select the most economical mix that satisfies acceptable strength and durability requirements (performance criteria). Trial mixes should first be evaluated using the residue only as the aggregate. If these fail to satisfy the performance criteria, a second series of trials should be made replacing half of the residue component with a conventional aggregate. The conventional aggregate should be one that satisfies the requirements of the specifying organization for aggregates used in stabilized bases. If none of these mixes satisfy the performance criteria, the residue is probably unsuitable for use.

The determination of the optimum moisture content based on the moisture-density relationships for the mixture is an important part of the mix design. Stabilized base compositions should be designed so that with proper compaction a dense, stable product will result. Strength development is also usually enhanced when the mix components are in intimate contact with one another. Many studies have shown that strength development is directly proportional to compacted density. The procedures outlined in ASTM Designation D 558 are applicable for optimum moisture determinations.

Table 6. Recommended Binder Percentages for Trial Mix Designs of Stabilized Base Course Mixtures

Binder Type	Dry Density of Residue[1] (lbs/ft^3)*	Recommended Percent of Binder[2]
Lime	<70	8-15
	>70	6-12
Lime-Pozzolan[3]	<70	15-25
	>70	10-20
Cement	<70	6-12
	>70	4-10

[1]Dry rodded weight determined in accordance with ASTM Designation C 29.

[2]Expressed as percent by weight of total mix.

[3]Total percentage of lime-pozzolan should be composed of 1 part by weight of lime to 3 or 4 parts by weight of pozzolan.

* 1 lb/ft^3 equals 16 kg/m^3

Studies have shown that it is not always possible to obtain a well defined "optimum" moisture content for incinerator residue. In order to minimize this possibility individual samples of residue should be used for each point on the moisture-density test. Extreme care should be taken to insure that all samples are the same. The proper amounts of moisture should be incorporated into each sample and the material kept in a sealed container until it is used.

If incinerator residue is used to satisfy 100 percent of the aggregate requirement in a stabilized base course mixture, the optimum moisture content will probably occur somewhere between 15 and 20 percent. If it is blended on an equal weight basis with natural aggregate, the optimum moisture content of the mixture will probably occur somewhere between 10 and 15 percent.

In the event that the optimum moisture content is not clearly defined, other qualitative methods must be used to determine a moisture content to be used in the mixture. It has been observed that, beyond a certain moisture content, usually in excess of twenty percent, the compacted samples become quite "mushy", even though the dry density remains relatively high. A mix moisture content two percent below the moisture content at which the compacted specimen becomes "mushy" is a possible criterion. It may also be possible to correlate this with the moisture content at which water begins to be forced out of the bottom of the mold during the moisture-density test.

The optimum moisture content of stabilized base course compositions containing incinerator residue will vary according to the percentage of conventional aggregate that is blended with the residue in the mixture. As the percentage of conventional aggregate increases, the optimum moisture content will be reduced. However, variations in the percentage of the binder do not have a significant effect on the optimum moisture content.

PREPARATION OF TEST SPECIMENS

Test specimens should be prepared for each trial mixture for compressive strength and durability testing. These specimens should be molded in Proctor size molds (4 inches or 101.6 mm in diameter by 4.56 inches or 115.8 mm high). The test specimens must be cured for a period of at least seven days. Lime or lime-pozzolan stabilized mixes must be cured in sealed containers at a constant temperature of 100° ± 3° F (38° ± 2° C). Cement stabilized mixes must be cured in sealed containers at a constant temperature of 70° ± 3° F (21° ± 2° C).

COMPRESSIVE STRENGTH AND DURABILITY TESTING

The evaluation of trial mixes should be based on a three part program:

1 - Determination of seven day compressive strength for all trial mixes.

2 - Determination of twenty-eight day compressive strength for selected mixes.

3 - Determination of resistance to freezing and thawing for selected mixes.

At the end of the seven day curing period, the specimens are taken from the sealed containers, immersed in water for a four hour soaking period, removed from the water bath, capped with a sulfide based capping compound, and tested for unconfined compressive strength in accordance with the procedures described in ASTM Designation D 1663. The seven day compressive strength of a particular trial mix is the average value of the number of specimens tested for that mix. A minimum of three specimens should be tested for each trial mix.

Table 7 outlines suggested minimum seven day compressive strength values for stabilized base course compositions using different binder types.

Table 7. Minimum Seven Day Compressive Strength Criteria for Stabilized Base Course Mixtures

Binder	Medium and Heavy Traffic	Light Traffic or Parking Lots
Lime	300	200
Lime-Pozzolan	400	300
Cement	650	400

Stabilized base course mixtures whose average seven day compressive strength values are equal to or greater than the minimum strength criteria outlined in Table 7 should also be evaluated for compressive strength development after 28 days of similar curing. Normally, 28 day strength values are approximately twice as high as 7 day strength values. If the 28 day compressive strength is ninety percent greater than the 7 day compressive strength, the mixture possesses long-term strength gaining characteristics and should be further evaluated for durability.

The durability of lime and lime-pozzolan stabilized base course mixtures is evaluated in accordance with ASTM Designation C 593. The test method involves the vacuum saturation of cured test specimens for 30 minutes at a vacuum pressure of 24 inches (609.6 mm), followed by immersion in water and saturation of the specimen, and subsequent testing for unconfined compressive strength. The unconfined compressive strength of the specimen after vacuum saturation should not be less than 25 percent of the unconfined compressive strength before vacuum saturation.

The durability of cement stabilized base course mixtures is evaluated in accordance with the procedures outlined in ASTM Designation D 560. This durability test method for soil-cement mixtures involves the cyclic freezing and thawing of cured test specimens for 48 hour cycles. The specimens must be brushed with a special wire brush and the weight loss after brushing measured for each cycle. The procedure is repeated for a total of 12 freeze-thaw cycles or until the weight loss exceeds 10 percent of the original weight of the specimen.

In order to assist in the design of overlying pavement layers, the California Bearing Ratio (CBR) test, described in the preceding chapter, should be performed on stabilized base course compositions. A minimum CRB value of 80 has been recommended for lime treated incinerator residue compositions, since this is the minimum value usually required of gravel or crushed stone aggregates for base course (26). An equal or higher CBR value can be assigned to cement treated compositions.

SELECTION OF THE PROPER MIX

The selection of a final mix design for stabilized base

(26) *Gnaedinger, John P., President, Soil Testing Services, Northbrook, Illinois. Personal Communication.*

course mixtures containing incinerator residue should be based on the following criteria:

1. Minimum compressive strength after seven days of curing in accordance with the suggested values from Table 7.

2. An increase in compressive strength of at least 90 percent after 28 days of curing, compared to the compressive strength after 7 days of curing.

3. Stabilized base mixtures must exhibit sufficient durability characteristics. Lime or lime-pozzolan mixtures should not have more than a 25 percent loss in compressive strength after vacuum saturation. Cement treated mixtures should not have more than a 14 percent weight loss after 12 cycles of freeze-thaw and wire brushing.

6.4 Construction Procedures

6.4.1 PLANT MIXING

Stabilized base course mixtures using incinerator residue should be mixed in a conventional blending plant with a pugmill mixer. The use of mix-in-place methods are not recommended because there is less quality control when compared to plant mixing. The stabilizing agent (lime, cement, etc.) should be well dispersed with the incinerator residue during the mixing. Blending of the residue with natural aggregate should also be done in the pugmill mixer.

Plant mixing of the materials shall be done as close as possible to the optimum moisture content of the design mix, as determined in the laboratory in accordance with the procedures described in ASTM Designation D558. If the addition of water is necessary at the mixing plant, the water used must be suitable for use in portland cement mixtures. The mixture should be transported to the job site in covered trucks to prevent evaporation of water and to protect the mixture during periods of rainfall.

6.4.2 SPREADING AND COMPACTION

Before spreading and compacting can occur, the subgrade must be properly prepared. The subgrade should be prepared in accordance with generally acceptable practice.

It is extremely important that stabilized base compositions containing incinerator residue be adequately compacted. The moisture content of the material at the time of placement must not exceed the optimum value by more than two percent. The subgrade material should be in a moist condition so there will not be any absorption of moisture from the base course.

The air temperature at the time of spreading and compaction should be at least 40° F (4° C) and preferably over 50° F (10° C). The material should not be worked during rainy weather. No material should be placed once the average daily temperature falls below 50° F (10° C). Respective state specifications should also be consulted to determine construction cutoff date requirements for stabilized base course mixtures.

Spreading of these mixtures can be accomplished by means of mechanical spreading equipment normally used in the placement of stabilized base materials. An asphalt paving machine or a spreader box will spread the material to a uniform thickness. When using a stabilized base mixture in parking lot construction, the material can simply be dumped from the truck and spread by a bulldozer or motor grader to the desired thickness. Regardless of the spreading method used, the compacted thickness of the base course material should not exceed 8 inches (203.2 mm). The uncompacted thickness necessary to produce a desired compacted thickness should be determined before placement of the base course.

Where the design thickness exceeds 8 inches (203.2 mm), the base course must be constructed in several layers. The minimum compacted thickness of any layer should not be less than 4 inches (101.6 mm). The in-place density of each layer must be satisfactorily verified before the next layer can be placed. The in-place density of each layer of compacted base course material can be determined using any of the normally accepted field density measurement techniques.

A minimum density of 98 percent of the maximum dry density value determined in the laboratory from ASTM D 558 must be obtained for each layer of compacted material. If a lower value is found in the field, that layer must receive additional compactive effort and moisture, if necessary, until the recommended density value is recorded.

When several layers of compacted fill material are being placed, each previous layer should be maintained in a moist condition until the next succeeding layer is placed. The top 1 to 2 inches (25.4 to 50.8 mm) of the previous layer should be scarified or raked so the layers will be able to knit together. Compaction of each layer should begin as soon as possible after placement.

Initial compaction is usually best achieved with a pneumatic-tired roller or vibratory roller. Further compaction of each layer should be with a three wheeled or tandem steel wheeled roller. The number of passes required to achieve the desired compaction should be determined in advance by means of a test layer of the material. Depending on the particular equipment used and the layer thickness, from four to ten passes of the roller may be necessary to obtain the required density. The roller used should have a minimum rating of 10 tons.

The top layer should be compacted to a density of at least 100 percent of the maximum dry density of the material. The top layer should be kept high enough so that the surface after compaction will be at or slightly higher than the required finish grade, rather than below grade. Finished grading should be accomplished by removing excess material with a motor grader, scarifying the top of the layer, and recompacting by rolling to assure a smooth finished surface.

Immediately following completion of the placement of the stabilized base course, the finished surface should be sealed by the application of a bituminous curing material, either a medium curing or rapid curing liquid asphalt or an emulsified asphalt, applied at a rate of from 0.1 to 0.3 gallons per square yard. This seal coat acts as a curing agent and also prevents the infiltration of water, which could cause surface leaching of the base course.

A three day time period is recommended between the application of the seal coat and the placement of a bituminous wearing surface, particularly for stabilized base materials using lime as the binding agent. It has been reported that, due to a carbonation reaction, an evolution of hydrogen gas has been observed during this period from "Chempac" compositions. If a final surface were to be applied immediately, pressure from the evolving gas could possibly cause bursts in the asphalt surface. After three days, the gas pressure will dissipate and the wearing surface material can safely be applied (27).

The bituminous wearing surface should be mixed and placed in accordance with applicable local or state specifications. Appropriate thickness design methods shall be used, based on anticipated traffic loadings. A minimum thickness of 1-1/2 inches (38.1 mm) is recommended. No traffic of any kind should be permitted on the stabilized base material until after the completion of the bituminous wearing surface.

---

(27) *Gnaedinger, John P. "Material and Method for Pavement Construction". U. S. Patent No. 3,293,999. United States Patent Office, Washington, D. C., December 27, 1966.*

7. INCINERATOR RESIDUE AS AGGREGATE IN BITUMINOUS MIXTURES

To date, the most promising use of incinerator residue for highway construction appears to be as an aggregate substitute in bituminous paving mixtures. A considerable amount of laboratory data has been developed to substantiate the fact that acceptable paving mixtures can be produced when incinerator residue is used (28, 29, 30, 31, 32).

The performance of a number of such mixtures has also been monitored in the field and results to date indicate that these applications have performed in an acceptable manner. Incinerator residue has been successfully used in experimental base course installations in Houston, Texas, and Baltimore, Maryland. It has also been incorporated into two experimental wearing surface mixtures in the Philadelphia area and one in Harrisburg, Pennsylvania. On the basis of the field performances, incinerator residue cannot at this time be recommended for use as an aggregate substitute in surface courses. A patent has been granted for the use of in-

---

(28) *Collins, Robert J., et al, "Technology for the Use of Incinerator Residue as Highway Construction Material", U.S. Department of Transportation, Federal Highway Administration, Final Report Draft, October, 1976, 409 p.*

(29) *Haynes, J. and Ledbetter, W. B., "Incinerator Residue in Bituminous Base Construction", U.S. Department of Transportation, Federal Highway Administration, Report No. FHWA-RD-76-12, Washington, D. C., December, 1975, 91 p.*

(30) *Lauer, K. R. and Leliaert, R. M., "Profitable Utilization of Incinerator Residue from Municipal Refuse". In Proceedings; Fifth Mineral Waste Utilization Symposium, Chicago, Illinois, April 13-14, 1976, pp. 215-218.*

(31) *Lilge, E. O., "The Conversion of City Refuse to Useful Products", Compost Science, July-August, 1970, pp. 20-24.*

(32) *Walter, C. Edward, "Asphalt Road Composition and Process of Making Same", U.S. Patent No. 3,907,582, United States Patent Office, Washington, D. C., September 23, 1975.*

cinerator residue in asphaltic road compositions for both base course and wearing surface applications (33).

7.1 ENGINEERING PROPERTIES

A knowledge of the engineering properties of incinerator residue paving mixtures is of great value to potential users. Before using incinerator residue in bituminous mixtures, however, some information must be known about the physical properties of the residue itself. Adequate sampling of incinerator residue is essential to assure that testing will provide representative results. The gradation of the residue is most important. The material should be well graded from the coarse to the fine sizes, as indicated in Figure 13.

The loss on ignition of the residue should not exceed 10 percent and is recommended to be equal to or less than 5 percent, if possible. The specific gravity of the residue must be determined, as well as the absorption characteristics of the material. In general, specific gravity values will probably range from 2.20 to 2.60, although somewhat lower values may be obtained from the more poorly burned residues.

The abrasion resistance of the residue should meet the requirements of aggregate for use in bituminous mixtures. Abrasion loss values can be determined using ASTM Designation C 131, Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine. For use in base courses and binder courses, the abrasion loss must not exceed 50 percent. For use in wearing surface mixtures, the abrasion loss must not exceed 40 percent. The abrasion loss for most incinerator residues has been found to range from 33 to 45 percent.

Most residues do possess acceptable resistance to abrasion, according to criteria used in the above test method. However, because the charge (the number and weight of steel balls used in the testing machine) is varied according to the gradation of the material being tested, coarser graded materials usually have higher abrasion losses than finer graded materials. Because of the presence of ash and combustible material in the residue, abrasion loss values may be less than expected, since these components may not be as readily reduced by the charge. If the abrasion loss is close to the allowable value, it is advisable

(33) *Ibid.*

to consider further laboratory evaluation.

The engineering properties of bituminous paving mixtures are evaluated by using the design criteria from applicable asphalt mix design methods. Since each state is responsible for specifying the mix design method to be used, engineers are advised to refer to local practice and to review pertinent literature from The Asphalt Institute with reference to mix design (34).

The most widely used method of testing asphalt mixes is the Marshall mix design method (ASTM Designation D 1559). The test involves placing compacted specimens in a Marshall testing apparatus which measures the load carrying capability (stability) and movement or strain (flow) of the specimen under loading conditions.

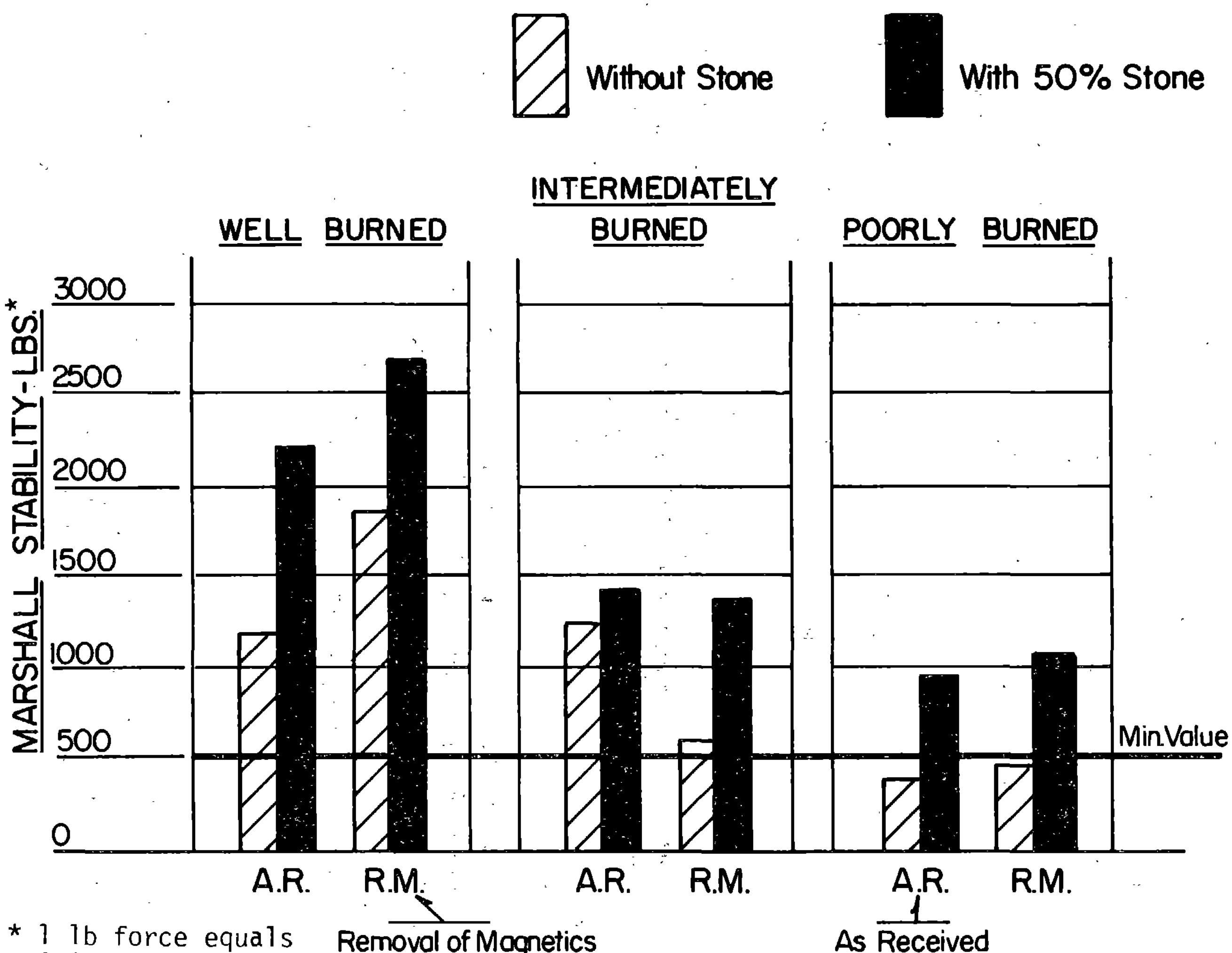
Marshall stability values for open graded base course mixtures using different classes of "as received" (AR) incinerator residues are shown in Figure 14. A comparison is made of stability values at optimum asphalt content* for these mixtures, using the residue by itself and blended with 50 percent by weight of crushed stone aggregate. In each case, the blending with aggregate improved the stability of the mix. In practically all cases, the blended mixes possessed stability values higher than those of mixtures in which only incinerator residue was used. The removal of ferrous metals (RM) had the effect of slightly improving stability values of blended base course mixtures in most cases.

A further advantage of blending the residue with aggregate is a reduction in the amount of asphalt required for complete particle coating, compared with mixes using all residue. Adequate coating of blended base course mixes should be achieved with from 5 to 8 percent of apshalt by weight of total aggregate. Depending on the degree of burnout of the residue, the amount of asphalt required for complete particle coating of the

---

(34) *Asphalt Institute. "Mix Design Methods for Hot-Mix Asphalt Paving", Manual Series No. 2 (MS-2), College Park, Maryland, February, 1962, 177 p.*

*In addition to the use of design criteria, the optimum asphalt content of bituminous paving mixtures containing incinerator residue is determined on the basis of completely coating the surface of all aggregate particles in the mixture.



* 1 lb force equals 4.448 newtons

Figure 14. Marshall Stability of Bituminous Base Course Mixtures

all 100 percent residue mixes can be 10 percent or more by weight of total aggregate in the mix.

Marshall stability values for dense graded binder course mixtures using different classes of "as received" (AR) incinerator residues are shown in Figure 15. The stability values compared in Figure 15 are at optimum asphalt content for the all residue and blended residue mixes. Extremely high stability values have been recorded for mixtures in which the total aggregate consisted of well burned residue. Slightly higher stability values have been observed at asphalt contents below the optimum required for complete particle coating.

The percentage of optimum asphalt content is considerably lower in the blended mixes than in the all residue mixes. As observed previously, stability values are markedly improved by blending intermediately and poorly burned residue with crushed stone. The removal of magnetics (RM) does not appear to have a significant effect on the stability of the mix, although the presence of oxidized ferrous metal may have an adverse effect on the asphalt stripping characteristics of the mix.

The Marshall stability values shown in Figure 15 confirm earlier observations made by Texas Transportation Institute and the City of Baltimore. Haynes and Ledbetter (35) observed Marshall stabilities between 1500 and 2000 pounds* for "Littercrete" mixtures containing 89 percent incinerator residue with a loss on ignition of 5 percent and a maximum particle size of 1 inch (25.4 mm). Walter found that Marshall stability values at optimum asphalt content ranged from 1300 to 2000 pounds* as the percentage of treated residue in the paving mix was varied (36).

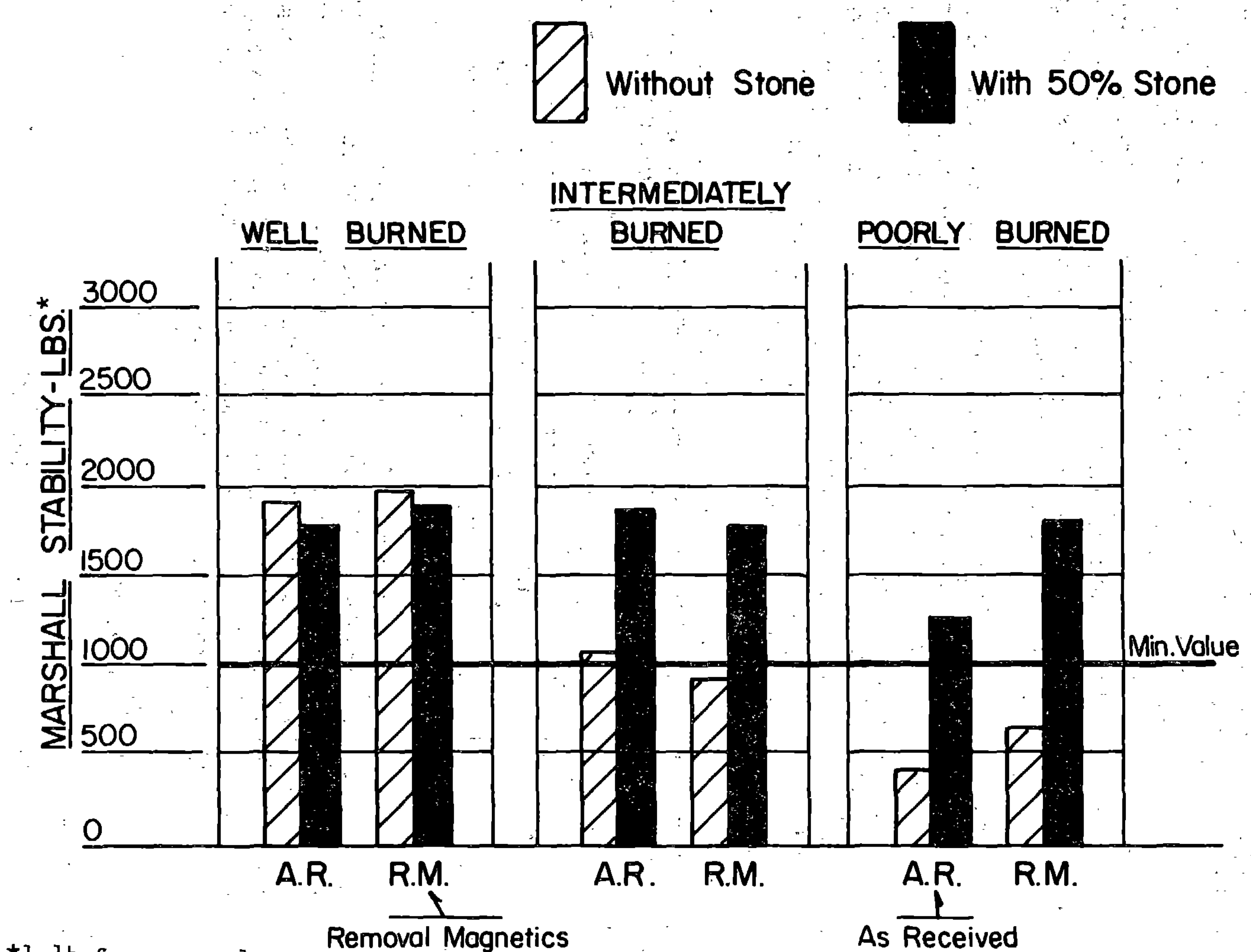
The optimum asphalt content of dense graded binder course mixtures containing 50 percent by weight of incinerator residue can be expected to range from 6 to 9 percent by weight of total aggregate in order to achieve complete particle coating. When complete particle coating and proper compaction are achieved, the amount of air voids in the paving mix are generally reduced to values within specification requirements.

* 1 lb force equals 4.448 newtons

---

(35) *Haynes, J. and Ledbetter, W. B., Op. Cit., p. 61.*

(36) *Walter, C. Edward, "Practical Refuse Recycling", Journal of the Environmental Engineering Division, American Society of Civil Engineers, February, 1976, pp. 139-148.*



*1 lb force equals 4.448 newtons

Figure 15. Marshall Stability of Bituminous Binder Course Mixtures

Figure 16 compares Marshall stability values for wearing surface mixtures using "as received" (AR) and magnetically removed (RM) incinerator residues screened to passing 1/2 inch (12.7 mm) size. As with binder mixes, highest stability values at optimum asphalt content were recorded with mixes containing well burned residue. Although the stability values at optimum asphalt content were lower for well burned residue blended with stone, compared to the all residue mixes, the optimum stability values were not the highest stabilities recorded for the blended mixes. Higher stabilities were recorded at somewhat lower asphalt contents, but without complete particle coating, which is particularly important for wearing surface mixes.

Blending with conventional aggregate generally improves the stability, flow, and air voids characteristics of incinerator residue mixes. The optimum asphalt content is correspondingly lower than for 100 percent residue mixes. The optimum asphalt content for blended mixtures is generally in the range of 6 to 9 percent by weight of total aggregate for binder course and wearing surface mixtures.

The addition of lime improves the Marshall stability of incinerator residue wearing surface mixes and enhances the anti-stripping characteristics of these mixes. Compacted specimens at optimum asphalt content with approximately 2 percent by weight of hydrated lime should be able to meet or exceed the retained strength criteria of the immersion-compression test. "Littercrete" specimens using a 2 percent lime slurry addition exhibited an average retained strength of 82.8 percent (37).

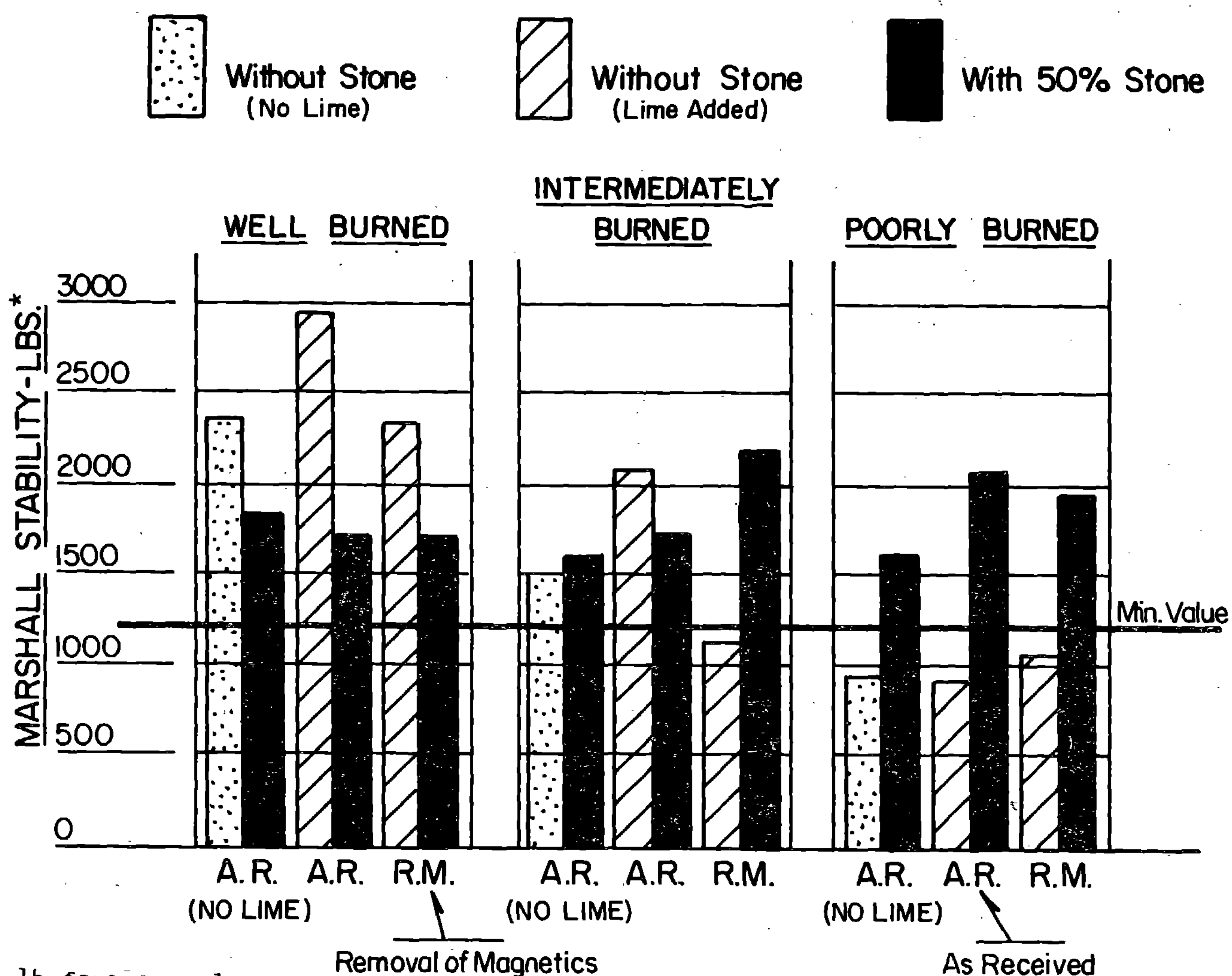
Marshall flow values for mixtures using incinerator residue are somewhat erratic. Often these values vary in an inconsistent manner as the asphalt content of the mix is varied. At optimum asphalt content, as determined by complete particle coating and Marshall stability, the flow values of these mixes are sometimes greater than the recommended maximum values of 16 or 18, as prescribed by the Asphalt Institute (38). Similar observations were noted by Lilge in a study of possible construction uses for incinerator residue, performed in 1970 at the University of Alberta in Canada (39).

---

(37) *Haynes, J. and Ledbetter, W. B., Op. Cit., p. 59.*

(38) *Asphalt Institute. "The Asphalt Handbook", Manual Series No. 4 (MS-4), College Park, Maryland, July, 1962, 441 p.*

(39) *Lilge, E. O., Op. Cit., p. 24.*



* 1 lb force equals
4.448 newtons

Figure 16. Marshall Stability of Bituminous Wearing Surface Mixtures

The calculation of air voids values in bituminous mixtures containing incinerator residue involves different procedures from those normally used in conventional paving mixtures. In conventional paving mixtures, calculation of air voids is based on the specific gravity values of the aggregate materials and the paving mixture. In order to calculate air voids in residue paving mixtures, the maximum theoretical specific gravity of the mix must be determined using ASTM Designation D 2041 (Rice Method). Due to the absorptive properties of the residue, it is recommended that complete coating of the particles in the mix be assured prior to testing of the mix using the Rice Method. A more detailed discussion of the determination of specific gravity will be presented in Section 7.3.

Some laboratory testing has also been performed on bituminous base course mixtures using pyrolysis residue. Marshall tests were performed during 1971 at the University of Missouri-Rolla on a mixture of 16 percent by weight sand and stone and 84 percent by weight of washed pyrolysis residue from Monsanto's pilot plant in St. Louis, Missouri. Maximum stability values exceeded 2000 pounds and flow values were within specification ranges. Although the specimens tested did not fully satisfy Marshall design criteria with respect to air voids or voids in mineral aggregate, the report noted that adjustments in asphalt content and aggregate particle size gradation should bring the values of the voids within specification limits (40).

The Baltimore County Department of Public Works also evaluated bituminous mixtures using pyrolysis residue. The material used was the "glassy aggregate" portion of the residue from the Landgard pyrolysis plant in Baltimore. A base course mixture using 40 percent by weight pyrolysis residue blended with 60 percent by weight crushed stone was designed to meet gradation specifications of the Maryland State Roads Commission. This mix satisfied all Marshall design criteria with asphalt contents of 6 and 6.5 percent by weight of total mix. A maximum stability value of 1700 pounds was observed for this mix. On the basis of favorable test results, the City of Baltimore intends to use the "glassy aggregate" for resurfacing of city streets (40).

7.2 PREPARATION OF RESIDUE FOR USE

Incinerator residue must be sized to meet definite grada-

---

(40) *Zulver, Elliott. City of Baltimore, Department of Public Works. Personal Communication.*

tion requirements in order to be considered acceptable for use in bituminous paving mixtures. Although specifications for mix gradations vary somewhat from one state to another, certain maximum particle size ranges are recommended as guidelines for the preparation of the material. For use in base course or binder course mixtures, the maximum particle size should not exceed 1-1/2 to 2 inches (38.1 to 50.8 mm). For use in wearing surface mixtures, the maximum particle size should not exceed 1/2 to 3/4 inch (12.7 to 19.05 mm).

The techniques of material preparation described in Section 6.2 are equally applicable to the size control of incinerator residue for use in bitumimous paving mixtures. Probably the most economical and efficient means of achieving gradation control of incinerator residue is through the use of a trommel. If the size opening is set at approximately 1-1/2 inches (38.1 mm), much of the ferrous fraction is recovered in the form of cans and oversize metal. As noted in Section 6.2, the trommel is more efficient than a vibratory screen and probably involves less expense and maintenance than a shredder.

The removal of ferrous metal from incinerator residue is advantageous for two reasons. First, the ferrous metal is a source of revenue in most areas, depending on the market conditions for scrap metal. Secondly, oxidation of ferrous metal in the residue adversely affects the adhesion of asphalt to the ferrous metal particles, increases the amount of asphalt required for coverage, and could ultimately be detrimental to the performance of the paving mixture (41).

The use of graded incinerator residue as an aggregate in wearing surface mixtures should consume approximately 50 to 75 percent by weight of the "as received" residue*, as shown in the gradation curve of Figure 9. If the residue is used as an aggregate in base course mixtures, between 70 and 95 percent by weight of the "as received" residue can probably be utilized.

After screening, the resulting residue is usually a well graded material. The gradation range of incinerator residue separated at the 1-1/2 inch (38.1 mm) screen has been shown in Figure 13. The gradation range of incinerator residue separated

---

(41) *Walter, C. Edward. President, Urban Aggregates, Inc., Baltimore, Maryland. Personal Communication.*

*Refer to page 29 for an explanation of the meaning of "as received" residue.

at the 1/2 inch (12.7 mm) screen is shown in Figure 17. These figures represent the range of particle size distribution which can normally be expected after screening of incinerator residue, regardless of the degree of burnout. In general, graded incinerator residue should be able to satisfy the gradation requirements of most specifications for bituminous paving aggregate in base course or wearing surface applications.

Because of inherent lack of particle strength and subsequent decomposition of combustible and organic matter, it is recommended that poorly burned residues not be used in bituminous paving mixtures. These residues should be aged sufficiently to satisfy criteria for intermediately burned residue prior to use as paving aggregate. Aging of incinerator residue is considered the equivalent of an extended burnout of the material. Preferably, residue used in bituminous mixtures should approach the characteristics of well burned material.

Because of the fine-grained, glassy nature of pyrolysis residue, no size separation is needed prior to the use of this material. However, because of its uniformity of particle size distribution, as shown in Figure 10, pyrolysis residue must be properly blended with conventional aggregate materials in order to meet gradation requirements for bituminous base course or wearing surface mixtures.

7.3 MIX DESIGN AND LABORATORY TEST PROCEDURES

The design of acceptable paving mixtures using incinerator residue must be determined on the basis of established design parameters, where possible, as well as economic considerations. Each is important in the determination of a final mix design.

Because of the absorptive nature of incinerator residue in comparison with conventional aggregate materials, a greater percentage by weight of asphalt must be used in mixes containing incinerator residue. This is because some asphalt is absorbed into the residue particles, particularly the finer sizes, thereby increasing the amount of asphalt needed to attain complete coating of the aggregate particles in the mix. The high filler-asphalt ratio in these mixes also stiffens the binder and impedes good coating.

Although the percentage of asphalt required in a mix containing incinerator residue is higher than that of a conventional paving mix, the specific gravity of the residue paving mix is lower. As a result, the total amount of asphalt required in each mix is comparable. The reason a higher percentage of asphalt is needed in a residue paving mix is mainly due to asphalt absorption by certain components of the residue.

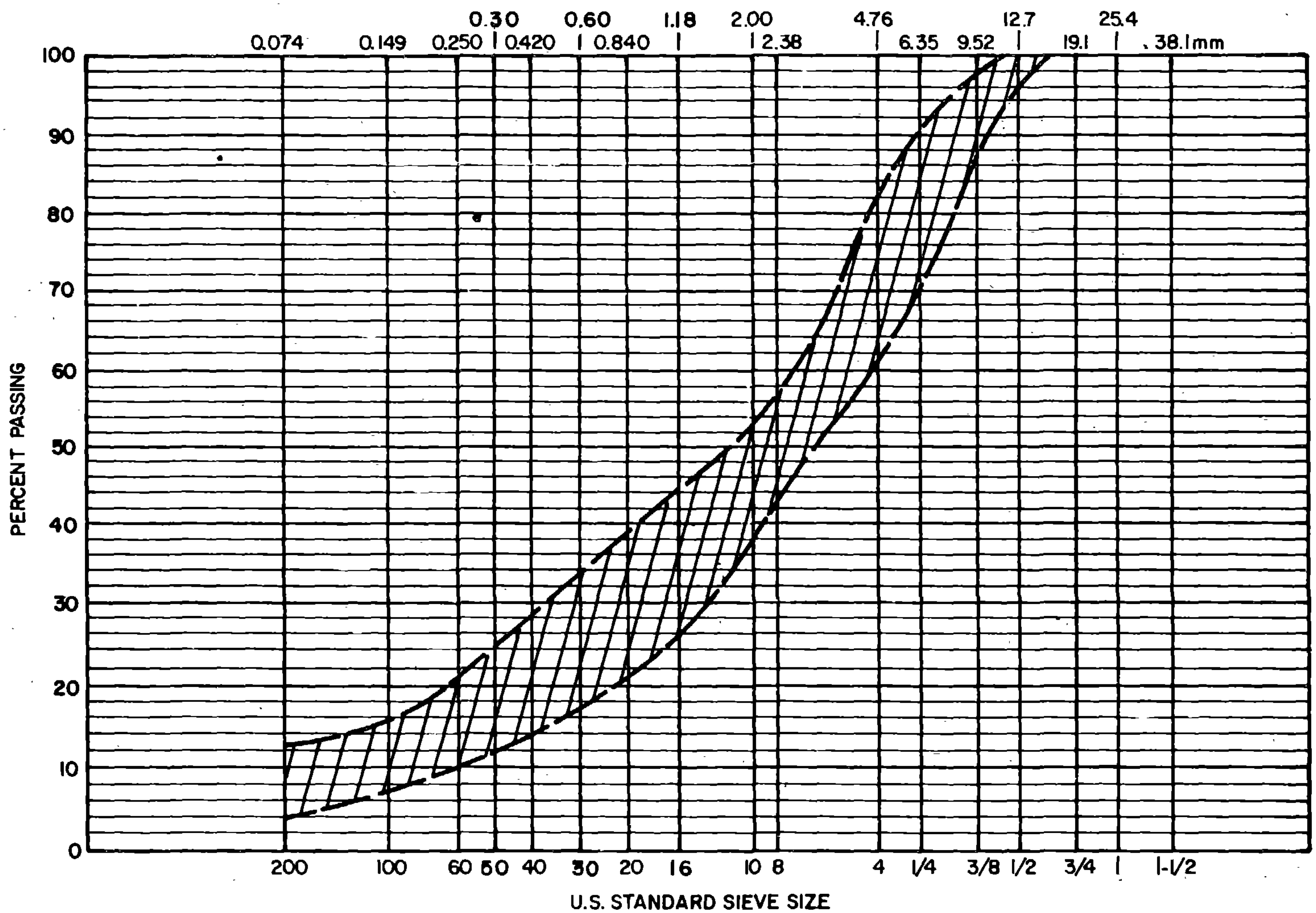


Figure 17. Gradation Range of Residue for Use in Wearing Surface Mixtures

It is important that potential users of incinerator residue in bituminous paving mixtures be aware that the weight-volume relationships of these mixtures are somewhat different from those of conventional paving mixtures. Since residue paving mixtures have a lower specific gravity than conventional paving mixtures, a given weight of residue mix will provide greater area coverage than the same weight of conventional mix.

As noted in Section 7.1, the best way to reduce the need for increased asphalt in mixtures containing incinerator residue is to blend the residue with conventional aggregate. In most cases, blending of residue with aggregate also improves the engineering characteristics of the mix. Walter studied the relationship between optimum asphalt content and percentage by weight of incinerator residue to the total aggregate in the mix and determined that the optimum asphalt content decreased as the percentage of residue was reduced. He concluded that the most economical mix should have been between 40 and 55 percent by weight of residue (42). For practical purposes, it is recommended that, in all base course and wearing surface mixtures using incinerator residue, the residue comprise no more than 50 percent by weight of the total aggregate in the mix.

The gradation of bituminous mixtures containing incinerator residue is equally as important as the gradation of conventional mixtures. The gradation of oven-dried incinerator residue must be carefully determined using a sufficient number of samples to be representative of the material. When designing the gradation of the final mix, the gradation limits of a desired conventional mix can be used, in accordance with local specifications.

The choice of the aggregate or aggregates to be used in blending with the residue is a function of the desired mix gradation and the observed gradation of the residue. Whenever possible, a mix should be designed in which the gradation represents approximately the middle of the desired gradation range. Initial mix design determinations should be based on 50 percent by weight of the total aggregate in the mix being incinerator residue. Initial mix gradation can be checked using control sieves after blending the components. Control sieves are recommended to be 1/2 inch (12.7 mm), 8 mesh, and 200 mesh sizes. However, when preparing specimens for final mix design evaluation, the materials should be separated and reconstituted on each sieve fraction.

Once the desired gradation of the incinerator residue mix

---

(42) *Walter, C. Edward, "Practical Refuse Recycling", Journal of the Environmental Engineering Division, American Society of Civil Engineers, February, 1976, pp. 139-148.*

has been determined, it is then necessary to design the mix to determine its optimum asphalt content. In selecting the optimum asphalt content, due consideration must be given to the stability, flow, air voids, density, and workability characteristics of the mix.

At the present time, there are three asphalt mix design methods used in the United States. These are the Marshall (ASTM Designation D 1559, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus); the Hveem (ASTM Designation D 1560, Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus); and the Hubbard-Field (ASTM Designation D 1138). As previously noted, the majority of states have adopted the Marshall mix design method. Furthermore, the greatest amount of data pertaining to bituminous mixtures containing incinerator residue has been developed using the Marshall mix design method. Therefore, discussion of mix design procedures will focus mainly on this method.

Marshall test specimens are prepared by compaction into molds 4 inches (101.6 mm) in diameter by 2.5 inches (63.5 mm) in height, in accordance with Marshall mix design compaction procedures. A separate mix design must be developed for each aggregate type used or each variation in the amount of residue used. All test specimens should receive 50 compaction blows on each side of the specimen, unless otherwise specified.* Each specimen must be accurately measured before testing and an appropriate correction factor used if the height of the specimen deviates from the 2.5 inch (63.5 mm) requirement. The compacted specimens are immersed in a heated water bath for 30 minutes and then removed and tested in the Marshall apparatus to measure stability and flow values. Voids values must be determined by calculations based on specific gravity measurements of the constituents and on the compacted plugs.

The optimum asphalt content is determined from the Marshall mix design method in accordance with the following criteria:

	Base Course	Binder Course	Wearing Surface
Minimum Stability (lbs)*	500	1000	1200
Flow (.01 in)*	8-18	6-16	6-16
Air Voids (percent)	3-8	3-5	3-5

*A pound force equals 4.448 newtons and 1 inch equals 25.4 millimetres.

*The number of compaction blows is a function of the design traffic and end use of the material. For heavy traffic, 75 blows are required.

Additional Marshall design criteria specified for determination of optimum asphalt content include voids in mineral aggregate (VMA) and voids filled with asphalt (VFA). Because of the difficulties normally encountered in accurately computing the value of air voids in residue paving mixes, limits for values of VMA and VFA have not been included in the mix design criteria for such mixtures. However, optimum asphalt content for residue paving mixes should also be determined on the basis of complete coating of all aggregate particles by the asphalt binder.

The range of asphalt content for mixtures using incinerator residue will vary based on the composition and degree of burnout of the residue, the nature of the aggregate(s) used, and the desired gradation of the mix. The objective of determining the optimum asphalt content is to select the percentage of asphalt which produces a mix capable of satisfying the above criteria, while sufficiently coating the aggregate particles with asphalt. The most economical mix is determined by the lowest asphalt content which satisfies these requirements. As a general rule, the optimum asphalt content for residue mixes will probably be somewhere between 5 and 8 percent by weight of aggregate for base courses and binder courses, and between 6 and 9 percent for wearing course mixtures, as noted in Section 7.1.

The most difficult design parameter to accurately determine when evaluating paving mixtures containing incinerator residue is the percentage of air voids in the mixture. Due to the absorptive nature of the incinerator residue in these paving mixtures, it is necessary to determine the maximum theoretical specific gravity of the paving mix by means of the Rice Method (ASTM Designation D 2041) in order to compute the percentage of air voids. Because of the difficulty in determining when the material has reached a saturated surface-dry condition, a modified "dry-back" method using wet bulb and dry bulb thermometers is recommended. The test procedure is performed as follows:

The saturated material is spread evenly with a fan providing a current of moving air over the surface. A thermometer is hung above the material at a predetermined position. After the air temperature is noted, the thermometer is placed into the saturated material, removed, and placed at its original position. As the moisture on the bulb is removed through evaporation, the temperature is depressed, and the difference between the air temperature reading (dry bulb) and the moistened thermometer (wet bulb) is noted. The procedure is then repeated until the last noted difference in temperatures is one-half the originally noted difference. When this occurs, the material being tested is considered to be in a saturated surface-dry condition.

This procedure, based on a concept suggested by Rice (43), has proven to be the most reliable for determining the water absorption and apparent specific gravity of a sample of incinerator residue. Although the absorption of asphalt binder is less than that of water, the use of this procedure for bituminous mixtures containing incinerator residue will yield corrected maximum theoretical specific gravity values which will normally permit the calculation of reasonable air voids values. It is recommended that the apparent specific gravity value determined from this "dry-back" procedure be used in the computation of air voids in the paving mix.

The workability and coatability of bituminous mixtures containing incinerator residue is more critical than for conventional mixes because of the degree of asphalt absorption by the residue. Depending on the gradation of the mix, complete coating of aggregate particles may not be visually evident until the asphalt content reaches a value of 7 or 8 percent by weight of total aggregate in the mix. The optimum asphalt content must be determined in accordance with Marshall design criteria, but must also be based on complete coating of the aggregate particles for wearing surface and binder course mixes and at least 95 percent coating for base course mixes. The degree of particle coating can be determined by the Ross count method (ASTM D 2489).

For wearing surface and binder course mixtures, the anti-stripping characteristics of the mix are quite important. This is particularly true since nearly 50 percent of the residue is composed of glassy particles with smooth surfaces, offering very little adhesion for the asphalt binder. To improve this condition, the addition of up to 2 percent by weight of hydrated lime to the aggregate has been found to be quite effective in improving asphalt adhesion (44). Hydrated lime may be added to the mix in one of two ways. It can be applied to the residue stockpile in a slurry form or added directly to the mix in the pugmill as dry powder. In either case, the final mix gradation should be modified to account for the introduction of the additional fines from the hydrated lime.

In order to evaluate the anti-stripping characteristics of wearing surface and binder course mixtures, the immersion-

---

(43) *Rice, James M., U. S. Department of Transportation, Federal Highway Administration, Fairbanks Highway Research Laboratory, McLean, Virginia. Personal Communication.*

(44) *Malisch, Ward R., University of Missouri-Rolla, Civil Engineering Department, Rolla, Missouri. Personal Communication.*

compression test (ASTM Designation D 1075) is recommended. This test provides an index of the retained strength of a bituminous mixture, i.e., a measure of the relative gain or loss in strength of the compacted mix after immersion in water compared to the strength of the original mix. Compacted specimens are immersed in a water bath either at 140° F (60° C) for a period of 24 hours, or at 120° F (49° C) for a period of 3 days. Strength measurements are performed on triplicate specimens in accordance with the procedures described in ASTM Designation D 1074, Compressive Strength of Bituminous Mixtures.

The index of retained strength is calculated as follows:

$$\text{Index of retained strength} = \frac{S_2}{S_1} \times 100$$

where S_1 = average compressive strength of dry specimens

S_2 = average compressive strength of immersed specimens

The immersion-compression test can be performed on laboratory specimens of incinerator residue mixes prepared at optimum asphalt content, and on laboratory compacted material taken from the field during mixing or placement. The index of retained strength is recommended to be a minimum of 70 percent in order to consider a design mixture suitable for placement in a wearing surface or binder course.

In summary, the design of bituminous mixtures using incinerator residue involves determination of the mix gradation by blending with conventional aggregate(s) and selection of the optimum asphalt content by means of an approved mix design method. The proper coating of the aggregate particles and the evaluation of the retained strength of the mixture must also be considered when deciding on the optimum asphalt content. The addition of hydrated lime is recommended in order to improve asphalt adhesion and the anti-stripping properties of the paving mixtures.

7.4 CONSTRUCTION PROCEDURES

7.4.1 PLANT MIXING

The mixing and placing of bituminous paving mixtures containing incinerator residue can be accomplished using the same methods and equipment presently employed in the asphalt paving industry. There are, however, some material preparation and handling considerations with which users of incinerator residue should be aware.

Only well burned or intermediately burned residue should be used in a paving mixture. The loss on ignition of the residue should not exceed a value of 10 percent. Sufficient sampling and testing should be conducted to verify the average loss on ignition value. The residue should also be stockpiled and drained prior to use so that it has a moisture content of 20 percent or less.

The use of poorly burned residue results in high absorption and greater asphalt requirements, relatively low stability values, low mix density, and possible particle degradation under loading. Poorly burned residue should be stockpiled, aged, and re-evaluated prior to its approval for use in bituminous paving mixtures.

The loss on ignition of the residue is significantly reduced when passing the material through the aggregate drier at the asphalt plant. However, the drying of incinerator residue may result in considerable dust generation at the plant. This is a major consideration and proper steps must be taken to minimize the dusting associated with the drying of residue.

It is important to handle the residue so that proper gradation and moisture control can be maintained while minimizing dust generation at the plant. The use of screens, trommels, and/or magnetic separation equipment to achieve maximum particle size has already been discussed. Once properly graded residue has been delivered to the site at the asphalt plant, it should be stockpiled in its "as received" condition until it is ready for use.

If the residue is stockpiled in its "as received" condition, moisture will drain from the stockpile and the moisture content will eventually be reduced to the 15 to 25 percent range. At this moisture content, it should be dry enough to handle easily without dusting. However, more heat energy will be required to dry out the residue than is normally required for the drying of conventional aggregates. Therefore, additional drying time will be required and the capacity of the plant will be somewhat reduced.

Although proper material preparation will reduce the dust produced at the plant, some dust generation will still occur during the drying of the residue. The dust that is collected during drying should be returned to the pugmill during the mixing operation in order to prevent loss of fine material in the mix. Most asphalt plants are now equipped with dust collection facilities which permit the return of particulates to the pugmill. However, if fines are returned to the pugmill without metering, these fines may not be introduced in controlled amounts, but fed in clumps. Nevertheless, it has been determined that dust collected during drying of the residue is not injurious to bag filters of dust collection facilities.

When residue is stored in the cold bins, its moisture content and absorbent properties sometimes cause the material to gain a certain amount of cohesion, resulting in a "clumping" effect. To combat this, the residue should be fed from cold bins equipped with vibrating devices, whenever possible, to reduce or prevent this "clumping" of the material and assure proper feeding. It is important that the residue be properly sized before being placed in the cold bin in order to prevent clogging of the feed gates by oversize material in the residue.

As noted previously, the addition of hydrated lime in amounts of approximately 2 percent by weight of total mix is suggested to reduce or prevent asphalt stripping from the glass particles in the residue. Hydrated lime can be added at the asphalt plant either by using the mineral dust feed system or by dumping from bags directly into the pugmill. Since the latter method does not permit precise metering of the lime content, it is recommended that the lime be added at the pugmill in even bag multiples. For example, if the pugmill has a 2000 pound(9007 kg) mixing capacity, 2 percent of the total mix would be 40 pounds(18 kg) Since lime is normally packed in 50 pound (23 kg) bags, one bag of lime should be dumped into the pugmill for each mixing cycle. This would represent a lime content of 2.5 percent. There should be a mixing time of at least 1 minute in the pugmill to allow for the complete mixing of the incinerator residue, conventional aggregate, asphalt, and hydrated lime.

The initial batch of incinerator residue mixed at the plant should be closely examined visually to determine whether any adjustment is needed in the asphalt content of the mix. In particular, the mix should be inspected to determine whether there are any uncoated or partially coated particles. It is especially important to make sure that the glass particles are all well coated with asphalt. If the mix is properly coated, it should have a slightly shiny appearance and there should be some cohesion between coated aggregate particles. However, the mix should not appear too wet. This indicates excessive asphalt, which will eventually result in bleeding of the pavement during warm weather.

Since each pugmill has its own characteristics, which are a function of screen efficiency and overall plant operation, a word of caution is added about the use of a design mix containing incinerator residue as absolutely indicative of the final job mix at the plant. It is recommended instead that the design mix data be used to mix a pilot batch at the plant.

This pilot batch can then be evaluated in the laboratory to compare its gradation, asphalt content, and mix design values with the original laboratory design data. Variations between laboratory and plant mix data would indicate what, if any, adjustments need to be made to the final mix design at the plant.

It has been observed that the percentage of asphalt required to attain complete particle coating at the plant is often 1.0 to 2.0 percent lower, by weight of total aggregate, than the optimum asphalt content determined in the laboratory. This is because a substantial proportion of the fines consist of organic and combustible particles which are burned off during the drying process. Therefore, the job-mix formula must be reduced accordingly to compensate for less surface area to be coated.

Another cautionary note is considered necessary with respect to determination of the asphalt content of the job mix. In the laboratory the asphalt content is often expressed in terms of percent by weight of total aggregate in the mix. However, the asphalt content in the plant is normally expressed as a percentage of the total mix. Therefore, the particular means of expressing the asphalt content must be determined and appropriate adjustments made as necessary.

The temperature of the paving mix as it leaves the pugmill is to some degree a function of the type and grade of asphaltic binder material used in the mix. In general, for most mixes using asphalt cement, the temperature of the mix as it leaves the plant should range from 280° F (138° C) to 310° F (155° C). Covered and/or insulated trucks should be used to retain the temperature of the mix for haul distances over several miles.

7.4.2 SPREADING AND COMPACTION

Procedures to be followed in the placement of paving mixtures containing incinerator residue are basically the same as those used for conventional paving mixtures. The air temperature during spreading and compaction of bituminous mixtures should be at least 40° F (4° C) and rising. The temperature of the residue paving mix during placement should be between 275° F (135° C) and 300° F (149° C) in order to obtain the proper workability of the mix. Under no circumstances should the paving material be placed during rainy weather.

Prior to placement of the mix, the subgrade or base surface should be primed to permit some adhesion between the surfaces. In the case of an overlay, the existing pavement should receive a tack coat to help seal cracks and bond the overlay to the existing surface.

Plant mixes containing incinerator residue can be placed using a paving machine, a spreader box, or even by hand on small jobs. The handling of these mixes should not be noticeably different from that of conventional paving mixes. It is important that a uniform thickness of the paving material be attained during the spreading operation.

Although incinerator residue mixes have a slightly lower unit weight than conventional mixes, it is still essential that the proper mix density be obtained in the field. The material should be rolled immediately after spreading, but no more than five minutes after the mix has been placed. At least two ten-ton rollers should be required on the site at all times. A three wheeled roller or tandem roller should be used as the breakdown roller. The second rolling can be made by a pneumatic roller or a tandem roller. The final pavement density should be an average of 95 percent of Marshall compacted density for base courses and 98 percent for wearing surfaces (45). The surface of the mix should be closely examined during rolling to make sure that there are no surface irregularities.

---

(45) *Asphalt Institute. "Specifications and Construction Methods for Asphalt Concrete", Specification Series No. 1 (SS-1), College Park, Maryland, June, 1964, 108 p.*

8. Summary of Situations Favorable and Unfavorable to the Utilization of Incinerator Residue in Highway Construction

A review of the preceding chapters of this publication provides evidence that it is definitely feasible to utilize municipal incinerator residue in highway construction. Although the material has not as yet been widely used for this purpose, there are many examples of its successful application in structural fills, stabilized base courses, and bituminous paving mixtures. In view of favorable data which has been developed from extensive laboratory investigations, as well as a number of successful field installations, the incorporation of incinerator residue into bituminous paving mixtures now appears to be the most promising means of utilizing the material in highway construction.

However, potential users of incinerator residue must be cautioned that the material should definitely not be considered for use in portland cement concrete mixtures. In addition to the inherent strength limitations of the residue itself, it does contain a certain percentage of free aluminum, which, although it is a minor component of the residue (approximately 2 to 4 percent by weight), is responsible for detrimental chemical reactions in these mixtures. Specifically, the free aluminum in the residue reacts with the cement during hydration, resulting in the formation of hydrogen gas. The gaseous hydrogen rises through the mixture in the form of bubbles, resulting in significant volume expansion and accompanying reductions in compressive strength.

In general, the circumstances which are most favorable for the utilization of municipal incinerator residues are:

1 - Comparatively high cost of residue disposal. This may also be accompanied by pressure from environmental regulatory agencies for more environmentally acceptable means of residue disposal.

2 - An efficient, well operated incinerator plant which produces a well burned or intermediately burned residue in relatively large quantities. This type of material is most readily useable for construction purposes.

3 - The ability of the incinerator plant to meet or exceed applicable air and water pollution standards. Normally, this requires the installation of expensive pollution control systems. If such equipment has been installed, it can generally be interpreted as a long-term committment on the

part of the municipality to the continued use of incineration in solid waste disposal.

4 - Available equipment used for the processing of residue. The existence of equipment such as screens, trommels, or magnetic separators is a necessary first step for the preparation of incinerator residue prior to its use in highway construction.

5 - The existence of favorable market conditions for materials recovered from incinerator residue. This applies primarily to ferrous metal, although other components of municipal solid waste, such as glass and aluminum, may be separated from the refuse prior to incineration.

6 - High cost or scarcity of aggregate materials for paving. This may be of particular significance if the municipality has the capability of producing its own paving material and employs its own personnel for paving installation.

There are also a number of circumstances or situations which are not favorable for the use of incinerator residue. Among these situations are the following:

1 - The use of batch-type incinerators, many of which are of low capacity, produce a poorly burned residue, are outmoded, and are unable to meet current air and water pollution standards.

2 - The necessity for the installation of costly pollution abatement equipment. Most municipalities are unable to economically justify the high cost of such equipment unless the incinerator plant in question is a modern, well operated, high volume operation.

3 - Readily available disposal sites located adjacent to or within close proximity of the incinerator plant. If there is adequate landfill space for the foreseeable future and the disposal of residue is acceptable at such sites, it may then be more economically attractive to dispose of the residue rather than attempt to utilize it.

4 - Lack of equipment for processing of residue. Unless such equipment can be obtained in used condition, its purchase and installation could represent a significant capital expenditure to a municipality.

Present concerns for the development of alternative energy sources and the conservation of non-renewable resources have already begun to influence solid waste management systems. The technology is already available and in use for the recovery of materials and energy from solid waste, as well as the application of refuse-derived fuel for conversion into electricity. In urban centers of the country, future treatment of solid waste will probably involve a variety of such solutions, each geared to the specific needs and conditions of the particular community it is designed to serve.

Although such new systems (or combinations of systems) may be alternatives to conventional incineration or landfilling, it is felt that, in most populated areas, incineration must be part of the overall solution to solid waste disposal. In this way, desired volume reduction can be achieved. However, the refuse should be prepared prior to incineration so that valuable materials can be extracted from the solid waste and the heating value of the refuse can be increased. This will provide opportunity for optimum control of incineration and the recovery of energy in some form from the burning of the solid waste (46).

Such new developments in the incineration of municipal refuse should certainly offer increased opportunities for the utilization of the resultant residues. It is expected that residues from newly designed recovery-type incineration processes will be of a higher quality than most of the residues from conventional incinerator plants. Therefore, utilization of presently available residues will not only advance the state-of-the-art of incinerator residue usage, but will also create the proper environment for timely utilization of improved residue materials as they become available. It will be necessary, however, to develop essential technical information for such materials in conjunction with their experimental use, in the same manner that information for residues from conventional incineration processes was developed for this publication.

---

(46) *Fernandes, J. H. and Shenk, R. C., "The Place of Incineration in Resource Recovery of Solid Waste". In Proceedings; 1974 National Incinerator Conference; American Society of Mechanical Engineers; New York, N. Y., 1974, pp. 1-9.*

9. APPENDIX A - RECOMMENDED TEST PROCEDURE FOR DETERMINING LOSS ON IGNITION (LOI) OF INCINERATOR RESIDUE SAMPLES

The following procedure for determination of loss on ignition (LOI) of incinerator residue samples is based on laboratory procedures developed by the U. S. Environmental Protection Agency (EPA) for determining percent ash and percent weight loss of solid wastes on heating. The EPA procedures have been slightly modified so they may be applied only to incinerator residue.

EQUIPMENT REQUIRED

The following equipment is needed to run this test:

1 - Analytical balance, with 0.1 mg readability.

2 - Crucibles, Coors porcelain, minimum 100 ml size, with lids.

3 - Dessicator, large size, either Pyrex or stainless steel.

4 - Furnace, muffle, with indicating pyrometer and temperature controller.

5 - Gloves, asbestos.

6 - Mats, asbestos board, 12" by 12" by 1/8" (305 mm by 305 mm by 3.2 mm) thick.

7 - Oven, drying, capable of maintaining temperatures up to 110° C.

8 - Potentiometer, direct reading, capable of reading temperatures ranging from 0° up to 1000° C.

9 - Spatula, Fischer No. 14-357.

10 - Tongs, crucible, Fischer No. 15-208.

SAMPLE PREPARATION

A representative sample of approximately 1000 grams of incinerator residue shall be obtained and dried in an oven to a constant weight at a temperature of 100° to 105° C (212° to 221° F). Prior to sampling, all oversize material (greater than 2 inches or approximately 50 mm) shall be removed. The dried sample shall be divided by quartering or by means of a sample splitter so that approximately 200 to 250 grams of dried sample are separated and available for testing.

The particle size of the separated sample shall be reduced by initially screening this sample through a 40 mesh (0.420 mm) sieve and retaining the material passing through the 40 mesh sieve. The material retained on the 40 mesh sieve shall be further reduced in size using a hammermill, crusher, pulverizer, or laboratory mill. The screened and ground materials shall be thoroughly mixed and then redried for 2 hours at the previously specified temperature range. Following final drying, three samples, each approximately 50 grams, shall be taken from the screened and ground material for testing.

TEST PROCEDURE

Place each of the 50 gram samples into a 100 ml Coors porcelain crucible (with lid). Weigh each of these containers on the analytical balance and record the weight to the nearest .0001 of a gram. Transfer the covered crucibles (with lids) to a cool muffle furnace. Carefully tilt each crucible lid at an angle sufficiently large to insure air circulation over the sample.

Gradually raise the temperature of the muffle furnace to 600° C (1112° F) over an approximate 30 minute period. Muffle the crucibles and samples for a period of 1 hour at 600° C (1112° F). At the end of 1 hour, turn off the furnace and immediately transfer first a lid, then its corresponding crucible, to a stack of at least three asbestos mats. Recover each crucible immediately and repeat until all crucibles and samples are removed from the furnace. Allow the covered crucibles to cool for 3 to 5 minutes, then transfer to a dessicator. After each crucible, lid, and sample have cooled to room temperature, weigh them on the analytical balance and record to the nearest .0001 gram. Calculate initial and final sample weights and percent weight loss.

After weighing, once again transfer the covered crucibles (with lids) into the muffle furnace, making sure to tilt each crucible lid as before. Gradually raise the temperature of the muffle furnace to 950° C (1742° F) over an approximate 45 minute period. Muffle the crucibles and samples for a period of 1 hour at 950° C (1742° F). At the end of 1 hour, turn off the furnace and repeat the previously described procedures for removal and cooling of crucibles and lids. After each crucible, lid, and sample have cooled to room temperature, weigh them on the analytical balance and record to the nearest .0001 gram. Calculate final sample weights and percent weight loss.

CALCULATIONS

Initial and final sample weights and percent weight loss are calculated as follows:

Initial sample weight (grams) = B-A

Final sample weight at 600° C (grams) = C-A

Final sample weight at 950° C (grams) = D-A

Weight loss on ignition at 600° C (grams) = B-C

Weight loss on ignition at 950° C (grams) = B-D

Percent loss on ignition at 600° C $= \frac{100(B-C)}{(B-A)}$

Percent loss on ignition at 950° C $= \frac{100(B-D)}{(B-A)}$

where:

A = initial weight of crucible and lid (grams)

B = initial weight of crucible, lid, and sample (grams)

C = final weight of crucible, lid, and sample (grams) after heating to 600° C and cooling in dessicator

D = final weight of crucible, lid, and sample (grams) after heating to 950° C and cooling in dessicator

REPORT

Although the percent loss on ignition of each sample is calculated after heating to 600° C and 950° C, the actual loss on ignition (LOI) value of the original sample of incinerator residue shall be reported as the average percent loss of the three test samples after heating to 950° C, unless otherwise specified.

10. APPENDIX B - RECOMMENDED TEST PROCEDURES FOR DETERMINING PHYSICAL COMPOSITION OF INCINERATOR RESIDUE SAMPLES

The analytical methods outlined in this appendix are similar to those reported by the U. S. Bureau of Mines in a 1968 study entitled "Composition and Characteristics of Municipal Incinerator Residues" (U. S. Bureau of Mines Report of Investigations No. 7204, December, 1968). These techniques were also employed in a study for the Federal Highway Administration entitled "Technology for Use of Incinerator Residue as Highway Material," and are summarized as part of report number FHWA-RD-

SAMPLING OF INCINERATOR RESIDUE

The proper sampling of incinerator residue is an important initial step in the proper evaluation of this material. Sampling of freshly burned incinerator residue should be performed on a regular basis (preferably at least monthly) in order to account for seasonal and operational variations. When sampling, a typical day's output should be obtained. It is recommended that one or more 55 gallon drum samples be obtained at least once during every eight hour shift, or more frequently if there is a noticeable change in operating conditions. If sampling cannot be done at the discharge chute, then freshly dumped residue should be sampled.

Each time a sample of residue is obtained, the temperature at the grate corresponding to time of sampling should be recorded. Other significant observations (bed height on grate, physical appearance of residue, fluctuations in grate temperature, etc.) should also be noted as necessary. It is recommended that the maximum particle size of the residue obtained during sampling be limited to material smaller than 3 inches (76.2 mm) on a side by means of a portable screen.

PHYSICAL COMPOSITION

A representative sample of incinerator residue should be prepared from 55 gallon drum samplings by evenly spreading out the material from the drums and quartering to obtain a sample which is approximately 50 pounds (110 kilograms) dry weight. Prior to determining the physical composition of a representative sample of incinerator residue, random small samples should be taken for moisture content and wet density determination.

The 50 pound sample shall be weighed, oven dried, reweighed, and then screened on a 10 mesh sieve. The material retained on the 10 mesh sieve shall be weighed and separated by hand into the following components:

1 - Glass

2 - Ferrous metal

3 - Non-ferrous metal

4 - Combustibles (paper, wood, organics)

5 - Mineral matter (stones, sand, ceramics, ash)

Because of the uniform visual appearance of incinerator residue in the finer sizes (-10 mesh), the physical composition of the material passing the 10 mesh sieve must be determined chemically. The amount of material passing the 10 mesh sieve must first be weighed, and then ground to -100 mesh. The five principal components noted above can then be determined chemically by the following means:

1 - Glass - Since glass is approximately 70 percent silica, the silica in the finer fraction of the residue can be identified by means of gravimetric determination, including sodium carbonate fusion. The silica can then be converted to percent glass by multiplying by a factor of 1.43.

2 - Ferrous metal - The percentage of iron found in the finer fraction of the residue can be determined by volumetric chemical analysis.

3 - Non-ferrous metal - The overwhelming majority of non-ferrous metal found in incinerator residue is aluminum, with a much smaller percentage of copper. Trace amounts of other metals may also exist and these will be discussed in greater detail. To determine the total alumina (Al_2O_3) content, gravimetric analysis is used. It is possible that some of the total alumina (Al_2O_3) may be present in glass and ceramics. There is at this time no reliable method for determining free aluminum (Al) in the finer fraction. Copper can be identified by atomic absorption.

4 - Combustibles - The amount of combustible and organic matter present in the fine fraction of a sample of incinerator residue can be determined by means of the loss on ignition (LOI) test, described in the preceding appendix.

5 - Mineral matter - The amount of mineral matter can be determined by adding the percentages of the preceding four components and deducting the total from 100 percent. The remainder represents the percentage of the finer fraction of the sample that is composed of mineral matter.

In order to determine the physical composition of the total sample of incinerator residue, the results of hand separation of the coarse (+10 mesh) fraction must be combined with the results of chemical analyses of the fine (-10 mesh) fraction. These results must be combined proportionally according to the relative weight of each fraction to the total sample.

PRESENCE OF HAZARDOUS SUBSTANCES

The presence of hazardous or potentially hazardous substances must also be determined during a laboratory evaluation of a sample of incinerator residue. Those substances of main concern are the toxic heavy metals, such as cadmium, chromium, lead, mercury, and zinc. Other trace elements which must also be identified are arsenic and selenium.

The potential for leaching of these substances is greater in the finer sizes (-10 mesh). Therefore, it is recommended that the portion of the sample passing the 10 mesh screen be used for evaluating the presence of hazardous substances.

Atomic absorption analysis shall be used in identifying the presence of cadmium, chromium, lead, mercury, selenium, and zinc. The presence of arsenic is determined by colorimetric analysis of the arsine reaction with diethyldithiocarbonate.

Since these substances are trace elements, they will most probably be found in extremely low percentages in incinerator residue. The percentage of lead or zinc should not exceed 1 percent. The percentage of each of the other trace elements noted above should not exceed 0.1 percent.

If these percentages are exceeded, a leachate analysis should be performed, employing an applicable method of leachate testing. The leachate should then be evaluated by means of atomic absorption analysis and the results should be compared with U. S. Public Health Service drinking water standards. Values of trace elements in the leachate which occur in percentages which exceed the drinking water standards are indicative of a potential health and safety hazard and should be more closely investigated.

☆U.S. GOVERNMENT PRINTING OFFICE: 1978 724-760/1264 1-3

FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

6. Prototype Development and Implementation of Research

This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. Improved Technology for Highway Maintenance

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

---

* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

FHWA

R&D