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

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

ACKNOWLEDGMENT

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Potential Use of Incinerator Residue as Aggregate for Portland Cement Concrete

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An evaluation, as a potential source of aggregate, of the residue that remains after the incineration of municipal refuse is described. The results of American Society of Testing and Materials acceptance tests indicate that incinerator residue can potentially be used as subbase and base-course material and aggregate for asphaltic concrete, portland cement concrete, and masonry units. Concrete strengths of approximately 27.6 MPa (4000 lbf/in^2) are possible. Medium-weight concrete blocks that meet ASTM C 90 specifications have been manufactured. Alkali-aggregate reactions cause expansion, but it appears that this problem can be controlled.

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

PROPERTIES OF NONMAGNETIC FRACTION

The nonmagnetic fraction can be described as a graded material made up of discrete particles >3.8 cm (>1.5 in) to <0.075 mm (<no. 200) in size. It is composed of glass, sand, slag, ash, and some metallic components. The coarse fraction can contain as much as 50 percent glass (1, 2). Some physical properties of the nonmagnetic fraction are given below (1 mm = 0.039 in):

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

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

The material was subjected to American Society of Testing and Materials (ASTM) acceptance tests to evaluate its potential as aggregate. The results were as follows (1 kg/m^3 = 0.062 lb/ft^3):

Test Property	Coarse Aggregate	Fine Aggregate
Clay lumps and friable materials (%)	0.5	
Los Angeles abrasion loss (%)	35.6	
Soundness loss ($MgSO_4$, five cycles) (%)	~5	~20
Organic impurities	OK	OK
Density (kg/m^3)	1280	960
Staining		Very light
Coating and stripping asphalt		OK
Loss on ignition (%)		

PORTLAND CEMENT CONCRETE

The potential use of residue as aggregate in portland cement concrete (PCC) is best evaluated by using the relation between water-cement ratio and strength. This relation, shown in Figure 1, includes combinations of residue with limestone and sand as replacements for coarse and fine components of aggregate. As a basis for comparison, the test results of a mix in which limestone and sand were used as aggregate are included.
It is apparent that, at higher water-cement ratios (lower strengths), the residue compares favorably with the limestone and sand. At lower water-cement ratios, the fine component of the residue appears to lower the strength of the mix. Its high porosity would tend to explain this. Replacement of the fine portion of the residue by sand appears to produce strengths that approach those of a normal concrete mix. Splitting strengths ranged from 10 to 15 percent of the compressive strength.

The use of residue as aggregate in PCC is complicated by a potential alkali-glass reaction. Johnston (3) found this to be true when he substituted waste glass for coarse aggregate in concrete. Johnston's data indicate that the detrimental expansion that occurs with significant replacements can be avoided by controlling the al-

Figure 1. Water-cement ratio versus strength.

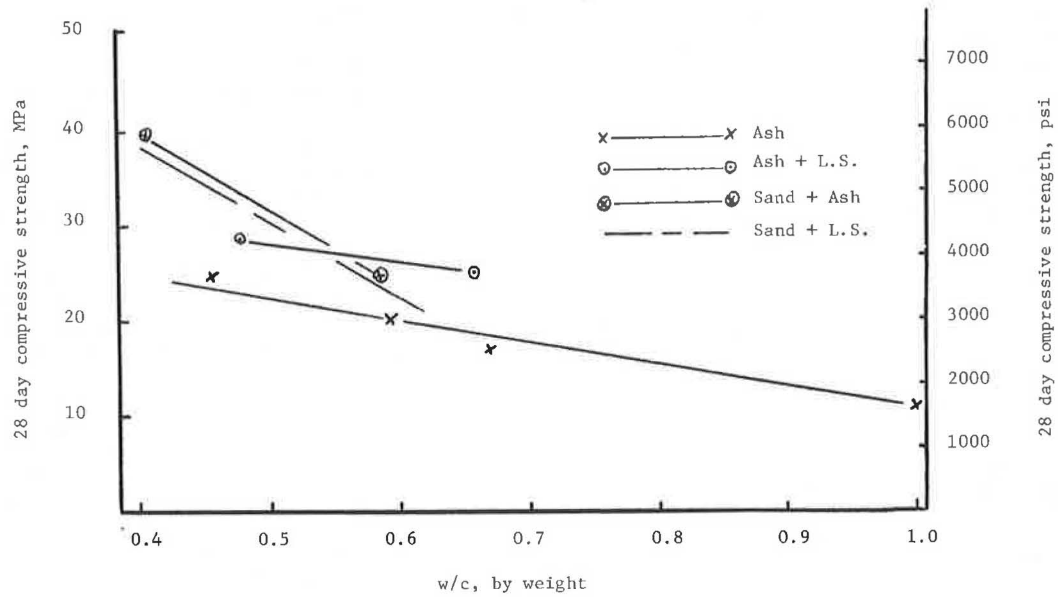


Figure 2. Expansion of concrete.

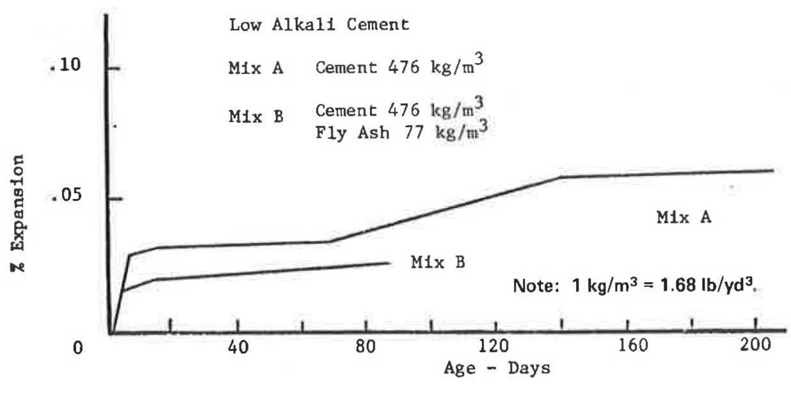
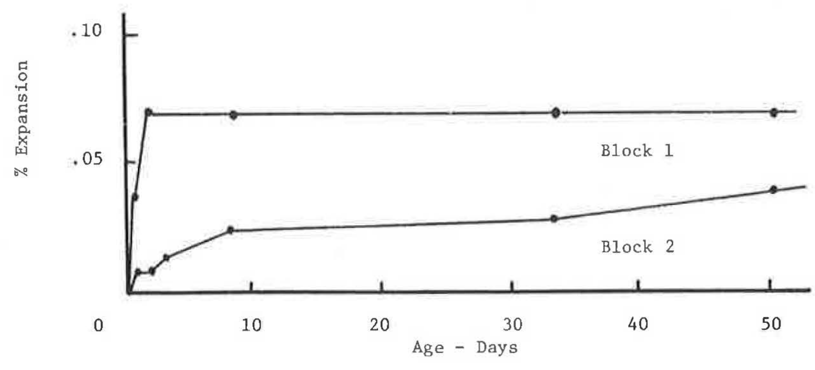


Figure 3. Expansion of concrete block.



kali content and using fly ash as a replacement for some of the cement.

Figure 2 shows available expansion data for concrete in which residue was used as aggregate. The expansion test results were obtained on concrete bars 8.9x8.9x29.2 cm (3.5x3.5x11.5 in) that were continuously moist cured at 21°C (70°F). As Johnston (3) points out, this approach is preferable to the standard mortar bar test (ASTM C 227) because it more readily identifies such variables as cement content and coarse-aggregate component.

It is interesting to note that significant expansions occur at an early age and then continue slowly over longer periods of time (Figure 2). This is similar to results obtained by Phillips and Cahn (4) in their investigation of the use of refuse glass in concrete block. The presence of additional fly ash in mix B reduces expansion by apparently dissipating the alkalies with the additional surface area available for reaction.

CONCRETE MASONRY BLOCK

The use of residue as aggregate in concrete block was investigated. The results are compared below with ASTM C 90 specifications (1 MPa = 145 lbf/in^2; 1 kg/m^3 = 0.062 lb/ft^3):

Property	ASTM C 90 Hollow Load-Bearing Units, Grade N	Blocks Made with Incinerator Residue
Compressive strength of individual units using gross area (MPa)	5.5	>5.5
Medium weight classification (kg/m^3)	1682-2002	1728
Maximum water absorption (kg/m^3)	240	232
Moisture content		
Percentage of total	35	35
Associated percentage of linear shrinkage	≤0.03	>0.3

The grading of the residue was altered to conform to that used locally in lightweight block. The blocks were fabricated in a manually operated single-block machine. Although they are not directly comparable with data for machine-manufactured units that are steam cured at low pressure, the data indicate a potential use for residue in this area. The possibility of alkali-glass reaction is also of concern in this case. Figure 3 shows the expansion characteristics of two blocks. Block 1 was water-cured at 21°C (70°F) after 24 h of exposure to a laboratory environment (~24°C and 50 percent relative humidity). After 24 h of exposure to laboratory air, block 2 was cured in water at a temperature of 82°C (182°F) for 24 h to simulate low-pressure steam curing. The block was then cured in water at 21°C. The increased initial expansion associated with block 2 is to be expected. The subsequent lack of expansion may be especially significant. The fact that these data are based on single blocks and do not include kiln curing must be kept in mind.

CONCLUSIONS

On the basis of tests carried out to date, the following conclusions appear to be warranted:

1. Incinerator residue can potentially be used as aggregate in PCC. Strengths of 27.6 MPa (4000 lbf/in^2) have been attained. The problem of alkali-aggregate expansion exists, but initial test data indicate that it can be controlled.
2. Incinerator residue can potentially be used as aggregate in masonry block. A medium-weight block that meets ASTM C 90 specifications has been manufactured in a manually operated block machine.

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Composition and Characteristics of Municipal Incinerator Residues

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The basic physical and chemical composition of municipal incinerator residues and their essential engineering properties are discussed. The analytic methods used in characterizing samples of incinerator residue from various sources are also discussed. Some unique characteristics of incinerator residue are identified, and the significance of these characteristics relative to the potential use of residue as construction material is outlined. A means for classifying the residues from municipal-scale incinerator operations is recommended.

Billions of dollars are spent each year on the collection and disposal of municipal solid waste in the United States. Although 90 percent of all solid waste is currently disposed of in landfills, incineration is the principal means of solid waste disposal in many U. S. metropolitan areas. The primary advantage of incineration is that it reduces the volume of incoming solid waste by as much as 80-90 percent, thereby extending