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USE OF RESOURCE-RECOVERED GLASS IN STRUCTURAL CLAY PRODUCTS

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ABSTRACT

Five different recovered glass samples were evaluated as additions to a commercial brick mix in amounts of 10, 15, and 20 wt %. Based on the results, a large scale plant test run of full-size brick containing 0, 10, and 15 wt % minus 100-mesh (150 μm) ground glass was carried out.

It was determined that the cost of crushing (or grinding) the waste glass amounted to about $3.85/Mg and that a 10 wt % addition of the ground glass reduced the firing temperature of the building brick about 40°C. Scumming, due to sulphates present in the ground glass, could be a problem and may require the addition of barium carbonate to a brick mix.

INTRODUCTION

Research by the U.S. Bureau of Mines in 1970 showed that waste glass reclaimed from municipal refuse could be used as an effective flux for producing building brick and as a primary constituent in structural products. A satisfactory face brick could be produced from a clay mix containing up to 70% of minus 20-mesh (850 μm) waste glass [1]. When the waste glass was crushed to minus 200 mesh (75 μm), a 50% addition to a brick mix lowered the required firing termperature by 260°C [2].

In 1978, the U.S. Environmental Protection Agency (E.P.A.), under a contract with ASTM E 38, Reource Recovery, funded an evaluation of the use of resource-recovered glass in brick. The study was monitored by ASTM subcommittee E 38.06, Waste Glass in Construction Materials. The objective of the investigation was to provide data which would be useful in drafting required test methods and specifications for incorporating waste glass in structural clay products. This report decsribes the results of laboratory investigations leading to increased understanding of some of the properties of fired clay containing resource-recovered waste glass, as well as results of production tests on the cost of grinding waste glass and the properties of brick containing ground waste glass fired in a full-scale production run.

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LABORATORY TESTS

Test materials

Five representative 45-kg resource-recovered glass samples were obtained for use in the test. Sources of the glass were Teledyne National, Union Carbide Corp., Black Clawson Fibreclaim, Raytheon Service Co., and Occidental Research Corporation. The samples had been produced using several resource-recovery techniques as shown in Table 1. The samples were crushed in a rod mill to minus 100 mesh (150 μm) and representative samples were removed for physical and chemical characterization. Properties of the different glass samples are listed in Table 2.

A minus 8-mesh (2.36 mm) ground shale was obtained from the Glen-Gery Corporation, Reading, PA, for use as the clay fraction of the clay—ground-glass mixes.

Test procedures

Sample bars were extruded at an average of water content of 16% (which included 2 to 3 wt % additive A). The bars were 25 × 25 × 175 mm in size,

TABLE 1

Resource recovered glass samples

Source	Process techniques
Teledyne; Resource Recovery Facility, Texas, MD	Trommel, crush, Al removed, shaker (separate glass and mixed nonferrous metals).
Occidental; Resource Recovery Plant, El Cajon, CA	Shredder, magnetic metals removed, air classifier, light fraction dried, screened, and air tabled. This was a feed to the glass plant.
Union Carbide; Purox Facility, South Charleston, WV	Shredder, magnetic metals removed, Purox converter (vertical reactor; dryer, pyrolizer, combustor). Combustor produced char product (slag) of glass plus nonferrous metal at 1,650°C, which was drained off and quenched.
Raytheon; Burlington, MD	Processed at U.S. Bureau of Mines, College Park (run UR99): flail mill, air classifier, magnetics removed, horizontal air classifier (in place of rotary-drum air classifier), trommel, jig (glass was intermediate product).
Black-Clawson; Middletown, OH	Scalped with magnet; ferrous metals and organic materials removed. This plus 6.3 mm dried feed goes to optical sorters.

and were extruded with three different glass fractions (10, 15, and 20%) for each of the five glasses. In addition, a control group was extruded, i.e. 0% glass. Enough bars were extruded to provide a sufficient number of samples for four firing temperatures, i.e. 982°, 1,010°, 1,038°, and 1,066°C.

After 'green weight' and length measurements were obtained, bars were air-dried for 25 h, then oven-dried at 105°C for 24h, and fired at a 38°C/h schedule, held at temperature for 1.5 h, then cooled to room temperature. Fired samples were then tested for compressive strength, efflorescence, absorption and shrinkage according to relevant ASTM procedures for structural

TABLE 2

Physical and chemical properties of ground, resource-recovered glass samples

	Source				
	Teledyne	Black Clawson	Raytheon	Occidental	Union Carbide
Chemical composition (%):					
SiO_2	69.30	70.99	68.56	69.93	57.7
Al_2O_3	1.99	2.21	2.46	5.54	10.9
TiO_2	0.07	0.05	0.09	0.23	0.77
Fe_2O_3	1.20	0.81	1.88	2.59	11.6
MgO	1.33	2.10	1.80	0.8	0.64
CaO	10.49	9.93	9.67	8.37	9.7
MnO	0.03	0.02	0.04	0.04	0.39
BaO	0.08	0.09	0.1	0.11	0.14
Na_2O	13.86	13.01	12.71	9.11	7.52
K_2O	0.39	0.42	0.49	1.22	1.2
B_2O_3	0.07	0.13	0.13	0.15	0.15
LOI[a] (700°C)	1	0.7	1.5	2.2	0
Particle size (%):					
Minus 100 mesh (150 μm)	89.2	79.5	98.2	94.5	99.5
Minus 200 mesh (75 μm)	63.9	45.7	82.9	68.4	95.5
Pyrometric cone equivalent	019→018	019—018	019→018	08—07	06—05

[a]LOI = Loss on Ignition.

clay products. Soluble sulphates were determined using the BarIdex method developed by Pittsburgh Plate Glass Company.

Test results

Total shrinkage results are shown in Table 3. Values listed are linear shrinkage resulting from drying and firing and results reported were averaged from three individual samples.

As would be expected, higher firing temperatures produce higher shrinkage. It is also apparent that higher glass contents tended to increase shrinkage. Additions of glass supplied by Occidental appear to have the least effect on shrinkage. The low Na_2O content and high loss on ignition (LOI) reported in Table 2 for this material would indicate a lower glass content.

Table 4 lists compressive strength values, and it is clear that inclusion of any glass increases strength, and that this increase can be as much as a factor of four at the higher glass additions.

Water absorption tests (5 h boil and 24 h soak) and saturation coefficient (ASTM C67) results are presented in Table 5. In general, there is a decrease

TABLE 3

Total fired shrinkage for glass—shale mixes (%)

Glass type	Glass addition (wt %)	Firing temperature (°C)			
		982	1,010	1,038	1,066
Control	0	2.2	2.8	3.8	5
Black Clawson	10	3.8	4.2	5.2	6.7
	15	3.8	4.3	5.5	5.6
	20	4	4.5	5.6	6.1
Union Carbide	10	3.5	4.1	5.2	6.4
	15	4	4.7	5.6	6.8
	20	4.3	4.7	5.8	6
Occidental	10	2.5	3.4	4.2	5.4
	15	3	4	5.1	6.1
	20	2.8	3.6	4.7	5.8
Teledyne	10	3.1	3.7	5	5.9
	15	3.2	4.2	5.5	6.6
	20	3.8	4.8	6.3	7.3
Raytheon	10	2.7	3.7	5.2	6.2
	15	3.5	4.3	5.6	6.8
	20	4.1	4.8	6	6.9

in absorption and saturation coefficient with an increase in temperature and glass content.

Results of efflorescence tests are shown in Table 6. The control group (without glass) does not effloresce. Every glass-containing specimen shows a white efflorescence, especially at lower firing temperatures. A trend does exist in that, at higher firing temperatures, efflorescence is lower or nil.

The test results indicate favorable benefits to be derived from the use of waste glass as an additive in fired-clay products. Perhaps the primary benefit is the ability to create a strong product (compressive strength) at a lower firing temperature, and thus lower energy requirements during processing. Normal clay ware of this type, if fired at 1,066°C with no glass addition, developes a compressive strength of about 62 MPa. In most cases, by using a 10% addition of waste glass materials, the same or higher strengths are attained at a firing temperature of 1,010°C, indicating a potential for energy conservation. One deleterious effect noted was the potential of efflorescence problems.

Based on the promising results of the laboratory scale tests it was decided to proceed with a large-scale production test to identify grinding costs of resource-recovered glass and the potential energy savings related to the lower firing temperature of, in this case, building brick.

TABLE 4

Compressive strength of glass—shale mixes (MPa)

Glass type	Glass addition (wt %)	Firing temperature (°C)			
		982	1,010	1,038	1,066
Control	0	17	25	42	62
Black Clawson	10	39	51	73	97
	15	51	66	95	101
	20	57	94	117	154
Union Carbide	10	54	63	78	107
	15	59	82	97	99
	20	69	93	132	164
Occidental	10	25	46	57	68
	15	39	57	78	97
	20	35	48	88	142
Teledyne	10	29	46	66	118
	15	35	62	77	167
	20	42	100	164	226
Raytheon	10	24	42	87	155
	15	50	67	123	170
	20	81	112	148	190

TABLE 5

Absorption results

Glass type	Firing temperature (°C)	10% glass addition			15% glass addition			20% glass addition		
		24 h soak (%)	5 h boil (%)	Sat. Coef.	24 h soak (%)	5 h boil (%)	Sat. Coef.	24 h soak (%)	5 h boil (%)	Sat. Coef.
Black Clawson	982	12.8	13.7	0.932	10.8	12	0.896	9.1	10.6	0.86
	1,010	12.7	15.1	0.842	10.2	13.4	0.763	7.8	11.5	0.677
	1,038	8.6	11.6	0.74	7	10.7	0.654	4.7	9.4	0.5
	1,066	6.4	9.7	0.661	6	9.5	0.63	2.9	6.3	0.461
Union Carbide	982	12.8	13.6	0.935	10.9	12	0.907	9.8	10.8	0.902
	1,010	11.5	13.7	0.839	9.8	12.6	0.778	8.6	11.5	0.748
	1,038	8.5	11.6	0.734	6.9	9.9	0.695	6.5	9.7	0.67
	1,066	5	7.8	0.641	3.9	6.9	0.569	4.9	7.7	0.633
Occidental	982	14.7	15.9	0.923	13.1	14.2	0.923	12.9	15.4	0.84
	1,010	12.9	15.8	0.816	11.4	14.4	0.79	10.4	13.3	0.782
	1,038	10.8	13.7	0.788	8.2	11.3	0.726	6.7	10.1	0.663
	1,066	7.1	10.3	0.682	5.5	8.9	0.621	3.8	7.2	0.532
Teledyne	982	13.5	15.4	0.879	11.7	14.2	0.826	9.6	12.6	0.762
	1,010	11.7	14.5	0.806	9.9	12.6	0.786	7.3	10.5	0.695
	1,038	8.7	11.8	0.74	5.9	9	0.653	3.8	6.9	0.547
	1,066	6.1	9.4	0.644	3.2	6.3	0.508	1.8	3.6	0.5
Raytheon	982	13.5	15.7	0.86	11	13.8	0.797	9.1	10.3	0.883
	1,010	11.9	13.9	0.858	9	11.8	0.761	7.9	10.8	0.735
	1,038	7.7	10.5	0.737	5.8	9	0.644	4.8	7.8	0.613
	1,066	4.8	7.6	0.631	3	6	0.499	2.5	5	0.501
		0% glass addition								
Control	982	17.1	18.2	0.94						
	1,010	15.5	18	0.862						
	1,038	13.1	15.6	0.84						
	1,066	9.9	12.6	0.782						

PRODUCTION TESTS

Test materials

About 3 Mg of jig-product cullet was obtained from Recovery I, the demonstration resource recovery plant then operated in the New Orleans, LA, area by the National Center for Resource Recovery. Characteristics of the as-received cullet are shown in Table 7. The brick mix used was a standard shale mix of the Glen-Gery Corporation production plant at Reading, PA.

Grinding of waste glass

A Model Palla 20 V Vibration Mill, manufactured by Humboldt Wedag, was employed for the production grinding test. The drive motor is rated at 1,200 rpm and 5.6 kW. Abrasion-resistant steel was used as the wear liner

TABLE 6

Efflorescence of glass-shale mixes (N — No efflorescence; SE — Slightly effloresced; E — Effloresced)

Glass type	Glass addition (wt %)	Firing temperature (°C)			
		982	1,010	1,038	1,066
Control	0	N	N	N	N
Black Clawson	10	SE	E	E	N
	15	SE	E	E	N
	20	E	E	E	N
Union Carbide	10	SE	N	N	N
	15	SE	SE	N	N
	20	SE	SE	SE	SE
Occidental	10	E	E	E	E
	15	E	E	E	SE
	20	N	SE	E	E
Teledyne	10	N	E	E	E
	15	E	N	E	SE
	20	E	SE	E	SE
Raytheon	10	E	SE	E	SE
	15	SE	SE	E	SE
	20	E	E	E	N

TABLE 7

Characteristics of as-received cullet

Particle size distribution (wt %):	
plus 25 mm	7
minus 25 plus 12.5 mm	43
minus 12.5 plus 6.3 mm	40
minus 6.3 plus 3.35 mm	9
minus 3.35 plus 2.36 mm	1
Composition (wt %):	
Moisture	3.1
Organic material	0.3
Non-glass[a]	5.7
Glass	94.1

[a]Mostly ceramics and stone (plus some metallics).

and the grinding medium consisted of 2.5 cm diameter steel rods lying the entire length of the grinding cylinder.

Characteristics of the mill product are shown in Table 8. The particle-size distribution was comparable with glass used in the laboratory study, with differences probably resulting from variations in mill feed and characteristics of the grinding mill.

Compositions of the resource-recovered glass compares well with that used in the laboratory study. However, the pyrometric cone equivalent (PCE) of 022 was somewhat lower than those determined for comparable glasses in the laboratory study.

TABLE 8

Characteristics of mill product glass

Particle size (wt %):	
minus 100 mesh (150 μm)	93.8
minus 200 mesh (75 μm)	83.5
Chemical composition (%):	
SiO_2	70.1
Al_2O_3	2.1
Fe_2O_3	0.74
B_2O_3	1.5
CaO	9.1
MgO	1.11
Na_2O	11.1
K_2O	0.44
TiO_2	0.4
LOI	1.5
Water soluble sulphates[a] (wt %)	0.08
Pyrometric cone equivalent	022
Temperature equivalent	630°C

[a]Turbimetric, Pittsburgh Plate Glass Co., BarIndex method.

TABLE 9

Cost of ground glass for parallel-connected Palla vibration mills

Model	1981 equipment cost ($ in thousands)	Capacity (kg/h)	Power consumption (kWh/Mg)	Grinding cost per Mg ($)
20U	27	77	54	6.65
35U	54	432	52	4.70
50U	105	1,455	46	4.05
65U	210	3,205	44	3.85

The production rate on one cylinder of the Model 20 U mill was 38.6 kg/h, which can be extrapolated to give the throughput rates shown in Table 9. Shown are equipment costs, capacities, and power consumptions for parallel-connected Palla vibration mills. Capacities range from 77 to 3,025 kg/h with power consumptions of 54 to 44 kWh/Mg product. The grinding costs of $6.65 to $3.85/Mg of product at about 95% minus 100 mesh (150 μm) were based on a 4,000-h operating year and on power costs of $0.05 per kWh. Labor costs and plant overheads were not included. This compares to a cost of about $0.05 per Mg for shale ground at a brick plant.

Production of brick

Brick was manufactured by the stiff-mud extrusion process. The brick was set onto kiln cars, dried, and fired in a shuttle kiln. A full kiln car load of 1,100 to 1,200 brick included brick without glass (control), brick with 10% glass, and brick with 15% glass. Three firings were made to temperatures of 1,049°, 1,010°C and 993°C, and fuel consumption monitored. The firing data are listed in Table 10.

TABLE 10

Production firing of brick

	Test number		
	1	2	3
Temperature (°C)	1,049	993	1,010
Firing time (h)	51	40	41
Gas consumption (Mm^3)	15	12[a]	11

[a] Power failure for about 20 min. increased gas consumption.

Table 11 summarizes visual observations relating exterior appearance of the brick and size (length) of brick as a function of glass content and firing temperature. Generally, the brick became darker with increase in temperature and displayed a similar effect upon addition of glass. However, due to scumming (to a lesser or greater degree), color differences in the brick containing glass were difficult to detect. In general, scumming was intensified in the brick containing 15% glass. Water-soluble sulphates in the ground glass amounted to 0.08%, as reported in Table 8, and would require the addition of 2.1 kg of $BaCO_3$ per Mg of glass to prevent scumming. In 1984, the cost of $BaCO_3$ was $0.57/kg.

Textural differences were not readily apparent. Wire-cut faces displayed the normal texture associated with such an operation at a brick plant. Some bricks containing glass displayed more surface cracks than those normally caused by extrusion and firing as observed on the control (0% glass) bricks.

TABLE 11

Observations of fired brick

Added glass	Firing temperature (°C)		
	993	1010	1049
No glass addition			
Color[a]	1 (Pink—orange)	2 (Brown—orange)	4
Surface texture	Normal	Normal	Normal
Length (mm)	208	205	205
Scumming	None	None	None
10% glass addition			
Color[a]	5	7	8
Surface texture	Some cracks	Normal	Some cracks
Length (mm)	205	204	204
Scumming	Brick ends	Brick ends and face	Extensive
15% glass addition			
Color[a]	3	6	9
Surface texture	Normal	Some cracks	Slight cracks
Length (mm)	209	205	204
Scumming	Extensive	Extensive	Extensive

[a]Numbers indicate relative color 'darkness': 1 (lightest) —9 (darkest)

Some effects from stacking of the bricks were noted, such as loss of 'planeness' of the working face (characterized by more pronounced undulations), especially at 1,049°C. and enhancement of scumming where bricks were touching. The undulations can be related to increased fluxing in brick containing glass. None of the irregularities noted above would appear to be detrimental to the use of the brick.

Physical and mechanical properties of the fired brick were determined according to ASTM C67-78, "Sampling and Testing Brick." The data were compared with standards for sewer, building and face brick [4] in order to determine compliance, and are summarized in Table 12.

Compressive strength increased with higher temperature and with increased glass content. However, there were some deviations from the laboratory study. First, strengths of control bricks were higher at comparable temperatures, and addition of more than 10% glass did not substantially improve strengths. These differences may be due to sample geometry and size, and to conditions of extrusion. All strengths conform to appropriate standards.

Absorption followed a similar trend as noted above, in that a decrease was not observed above a 10% glass addition. This was noted both in the 5-h boiling test and 24-h soak test. In general, the data display improved absorption compared to those determined in laboratory tests. Improvement in ab-

TABLE 12

Physical and mechanical properties of fired brick,[a] ASTM C67-78

Property (average of five bricks)	Firing temperature (°C) 993			1,010			1,049		
	Glass addition (%)								
	0	10	15	0	10	15	0	10	15
Compressive strength (MPa)	40	49	50	50	63	61	61	79	80
Absorption (%):									
5 h boil	13.8	11.1	11.4	12.0	9.1	9.7	10	7.6	8.2
24 h soak	12.2	9.1	9.6	10.4	6.9	7.6	8.2	5.1	5.9
saturation coefficient	0.89	0.82	0.83	0.86	0.75	0.79	0.82	0.68	0.72
Efflorescence	([b])	No[c]	([d])	No	No	Sl[e]	No	No	No
Compliance:									
ASTM C32-73	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ASTM C62-759	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ASTM C216-79	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes

[a]McCreath Laboratories Inc., Harrisburg, PA.
[b]One brick slightly effloresced, four bricks effloresced.
[c]No efflorescence observed.
[d]One brick effloresced, four bricks no efflorescence.
[e]All bricks slightly effloresced.

sorption also correlates with increased firing temperature. The improvement of saturation coefficient is especially notable, indicating that brick containing glass is potentially more resistant to the effects of freeze-thaw conditions. Absorption of all brick conform to applicable standards.

Efflorescence as observed on the fired brick deviated from that observed during laboratory tests. Most laboratory specimens displayed efflorescence whereas most production bricks did not display efflorescence. Scumming was observed on most fired-brick samples containing glass additions. Brick fired at 1,010° and 1,049°C conformed to specificiations, whereas those fired at 993°C varied in compliance.

At the lowest firing temperature, brick with 0% glass and 15% glass conformed to ASTM C32-73 (sewer brick) and ASTM C62-75a (building brick), whereas brick with 10% glass complied, in addition, to ASTM C216-75 (facing brick) [4]. At the higher temperatures all brick confromed to all standards.

It appears from both the laboratory and production test results that a 10% addition of minus 100-mesh (150 μm) resource-recovered glass could result in lowering the firing temperature of bricks by 40°C. In the shuttle-kiln firings used in the test runs a fuel saving of about 25% was observed (Table 10). This, however, would not be typical for commercial tunnel-kiln production. Based on experience at Glen-Gery, a 40°C lowering of the firing temperature would result in a reduction of about 5% in fuel costs. Using 1984 costs for natural gas \$167.32 per Mm^3 and an average firing cost of \$27 per 1,000 standard bricks, the use of 10% glass additions would reduce the firing cost of 1,000 bricks by \$1.35. Additional savings could result from increased production due to faster kiln throughout; however, this would only apply when a brick plant is running at full capacity.

CONCLUSIONS

Based on the results of the laboratory- and production-scale test runs made on the use of ground glass from municipal waste as an addition to a commercial brick mix, the following conclusions can be drawn:

(1) The lowest cost of grinding 95% minus 25 mm glass to 95% minus 100 mesh (150 μm) in a continuous Palla Vibration Mill would be about \$3.85 per Mg. This would relate to a \$1.20 per 1,000 standard solid bricks for a 10% addition of glass.

(2) With the particular brick mix tested, optimum results were obtained with a 10% addition of ground glass.

(3) A 10% addition of glass resulted in lowering the firing temperature of the bricks by 40°C. For bricks that are fired at 1,049°C in a production tunnel kiln this would amount to a saving of about 5% or about \$1.35 per 1,000 standard bricks for a natural gas-fired kiln. In the shuttle-kiln firings used in the test runs, a saving of about 25% in fuel was observed.

(4) Scumming due to sulphates in the ground glass could be a problem, requiring the addition of barium carbonate to the brick mix or water-washing of the ground glass prior to being used in the brick mix.

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