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Publication Number: FHWA-RD-97-148

User Guidelines for Waste and Byproduct Materials in Pavement Construction

[**Asphalt Concrete**] [**Granular Base**]

WASTE GLASS

Material Description

ORIGIN

Glass is a product of the supercooling of a melted liquid mixture consisting primarily of sand (silicon dioxide) and soda ash (sodium carbonate) to a rigid condition, in which the supercooled material does not crystallize and retains the organization and internal structure of the melted liquid. When waste glass is crushed to sandlike particle sizes, similar to those of natural sand, it exhibits properties of an aggregate material.

In 1994 approximately 9.2 million metric tons (10.2 million tons) of postconsumer glass was discarded in the municipal solid waste stream in the United States. Approximately 8.1 million metric tons (8.9 million tons) or 80 percent of this waste glass was container glass.(1)

CURRENT MANAGEMENT OPTIONS

Recycling

Over the past decade, there have been widespread efforts to recover postconsumer glass. Bottle bill legislation, which provides for deposits during purchase of containers and deposit bottle returns at retail outlets, has been introduced in some states, but more often glass recovery and recycling have been attempted through the collection of waste glass at recycling centers or Material Recovery Facilities (MRFs).

MRFs are facilities that are designed to sort, store, and market municipal solid waste recyclables that are collected at the curb (source-separated materials). Curbside separation of glass involves homeowner or apartment dweller separation of container glass (or glass commingled with other recyclables such as ferrous and aluminum cans and plastic containers) in preparation for the transport of these materials to the MRF. Some communities that do not have curbside collection offer waste glass drop-off locations for collection. At most MRFs, waste glass is hand-sorted by color (white, amber, and green), and crushed for size reduction (generally to less than 50 mm (2 in) in size). Crushed (color-sorted) glass, which is commonly referred to as cullet, is marketed in most locales as a raw material for use in the manufacture of new glass containers.

Traditionally, glass recycling has involved the collection and sorting of glass by color for use in the manufacture of new glass containers. Recycling postconsumer glass from the municipal solid waste stream for use as a raw material in new glass products is limited, however, by the high cost of collection and processing (hand sorting) of waste glass(2,3), and specifications that limit impurities (e.g., ceramics, ferrous metal, paper, plastics and mixed-colored cullet) in the glass production process. In addition, during collection and handling of glass, high percentages of glass breakage (30 to 60 percent)(4) limit the quantity of glass that can actually be recovered using hand-sorting practices. Given these limitations, traditional glass recycling rates have been relatively low.

Disposal

The EPA has estimated that in 1994 approximately 9.1 million metric tons (10.1 million tons) or 77 percent of the waste glass generated in the United States was landfilled.(1)

MARKET SOURCES

Figure 20-1 provides a schematic representation of the flow of container glass in the United States along with potential recycling options.

In most cases, mixed-colored waste glass can be obtained by contacting the municipality that is responsible for the collection of recyclables or the MRF operator.

The quality of waste glass obtained from MRFs, which collect and process glass from municipal recycling collection districts, can vary widely and can contain dirt, paper, and plastics. Glass gradation can also vary widely. It can range in top size from 25 mm (1 in) to 100 mm (4 in). The exact physical characteristics of the glass from any given source will depend on the processing equipment (e.g., crushing and screening equipment) at the MRF and the degree of processing afforded the mixed colored glass.

HIGHWAY USES AND PROCESSING REQUIREMENTS

Asphalt Concrete Aggregate

Waste glass has been used in highway construction as an aggregate substitute in asphalt paving. Many communities have recently incorporated glass into their roadway specifications, which could help to encourage greater use of the material.

Granular Base or Fill

Crushed glass or cullet, if properly sized and processed, can exhibit characteristics similar to that of a gravel or sand. As a result, it should also be suitable for use as a road base or fill material.

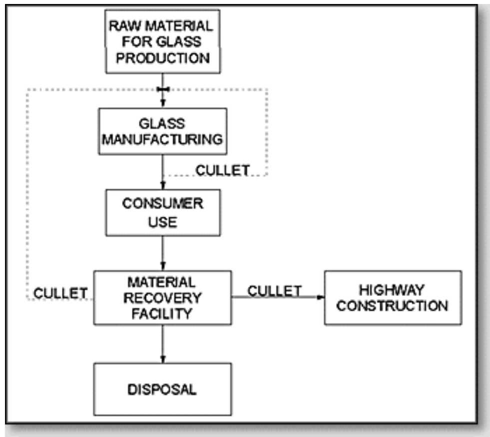

Figure 20-1. General overview of glass cycle in the United States

When used in construction applications, glass must be crushed and screened to produce an appropriate design gradation. Glass crushing equipment normally used to produce a cullet is similar to rock crushing equipment (e.g., hammermills, rotating breaker bars, rotating drum and breaker plate, impact crushers).[4] Because MRF glass crushing equipment has been primarily designed to reduce the size or densify the cullet for transportation purposes and for use as a glass production feedstock material, the crushing equipment used in MRFs is typically smaller and uses less energy than conventional aggregate or rock crushing equipment. Successful production of glass aggregate using recycled asphalt pavement (RAP) processing equipment (crushers and screens) has been reported.[3] Magnetic separation and air classification may also be required to remove any residual ferrous materials or paper still mixed in with the cullet.

Due to the relatively low glass-generation rates from small communities, stockpiles of sufficient size need to be accumulated to provide a consistent supply of material in order for glass use to be practical in pavement construction applications.

MATERIAL PROPERTIES

Physical Properties

Crushed glass (cullet) particles are generally angular in shape and can contain some flat and elongated particles. The degree of angularity and the quantity of flat and elongated particles depend on the degree of processing (i.e., crushing). Smaller particles, resulting from extra crushing, will exhibit somewhat less angularity and reduced quantities of flat and elongated particles. Proper crushing can virtually eliminate sharp edges and the corresponding safety hazards associated with manual handling of the product.

Uncontaminated or clean glass itself exhibits consistent properties; however, the properties of waste glass from MRFs are much more variable due to the presence of nonglass debris present in the waste stream. Table 20-1 lists some typical physical properties of waste glass collected from a number of MRF facilities.[2]

Table 20-1. Selected physical properties of waste glass.

Test	Glass Samples[a]		ASTM Test Method
	Coarse	Fine	
Particle Shape Angularity Flat (%) Flat/Elongated (%)	 Angular 20-30 1-2	 Angular 1 1	ASTM D2488
Specific Gravity[b]	1.96 - 2.41	2.49 - 2.52	ASTM D854[c] ASTM C127[c]
Permeability (cm/sec)	$\sim 2 \times 10^{-1}$	$\sim 6 \times 10^{-2}$	ASTM D2434

a. Coarse and Fine glass samples represent minus 19 mm (3/4-in) and minus 6.4 mm (1/4-in) samples, respectively, collected from several MRF facilities unless otherwise indicated.

b. Coarse specific gravity samples represent glass fraction greater than 4.75 mm (No. 4 sieve); fine samples represent glass fraction less than 4.75 mm (No. 4 sieve).

c. ASTM D854 and C127 procedures were used for the coarse and fine fractions, respectively.

Glass collected from MRF facilities can be expected to exhibit a specific gravity of approximately 2.5. The degree of variability in this value depends on the degree of sample contamination and is reflected in the range of specific gravity data shown in Table 20-1.

Crushed glass, which exhibits coefficients of permeability ranging from 10^{-1} to 10^{-2} cm/sec, is a highly permeable material, similar to a coarse sand. The actual coefficient of permeability depends on the gradation of the glass, which, in turn, depends on the degree of processing (crushing and screening) to which the glass is subjected.

The particle size distribution of glass received from MRF facilities can vary greatly. Table 20-2 presents typical glass gradation values for crushed glass received from a New York City MRF.[5]

Table 20-2. Waste glass gradation results.[a]

Standard Sieve Size	Average % Finer
25.4 mm (1 in)	100.0
12.7 mm (1/2 in)	98.7
6.35 mm (1/4 in)	86.0
3.18 mm (1/8 in)	32.6
0.84 mm (No. 20)	6.4
0.42 mm (No. 40)	3.2
0.21 mm (No. 80)	1.5
0.075 mm (No. 200)	0.6
a. Represents waste cullet collected from a City of New York MRF in 1993.	

Chemical Properties

Glass-formers are those elements that can be converted into glass when combined with oxygen. Silicon dioxide (SiO2), used in the form of sand, is by far the most common glass-former. Common glass contains about 70 percent SiO2. Soda ash (anhydrous sodium carbonate, Na2CO3) acts as a fluxing agent in the melt. It lowers the melting point and the viscosity of the formed glass, releases carbon dioxide, and helps stir the melt. Other additives are also introduced into glass to achieve specific properties. For example, either limestone or dolomite are sometimes used in lieu of soda ash. Alumina, lead, and cadmium are used to increase the strength of the glass and increase resistance to chemical attack. Various iron compounds, chromium compounds, carbon, and sulfur are used as coloring agents.

Most glass bottles and window glass are made from soda-lime glass, which accounts for approximately 90 percent of the glass produced in the United States. Lead-alkali-silicate glasses are used in the manufacture of lightbulbs, neon signs, and crystal and optical glassware. Borosilicate glasses, which have extraordinary chemical resistance and high temperature softening points are used in the manufacture of cooking and laboratory ware.(6) Table 20-3 lists the typical chemical compositions of these glasses.

Table 20-3. Typical chemical composition of glass types.

Constituent	Soda-Lime(7)	Lead(7)	Borosilicate(8)
SiO_2	70 - 73	60 - 70	60 - 80
Al_2O_3[a]	1.7 - 2.0	--	1 - 4
Fe_2O_3	0.06 - 0.24	--	--
Cr_2O_3[b]	0.1	--	--
CaO	9.1 - 9.8	1	--
MgO	1.1 - 1.7	--	--
BaO	0.14 - 0.18	--	--
Na_2O	13.8 - 14.4	7 - 10	45
K_2O	0.55 - 0.68	7	--
PbO	--	15 - 25	--
B_2O_3	--	--	10 - 25
a. Higher levels for amber-colored glass. b. Only present in green glass.			

Glass is generally considered an inert material; however, it is not chemically resistant to hydrofluoric acid and alkali. Expansive reactions between amorphous silica (glass) and alkalis (such as sodium and potassium found in high concentrations in high alkali Portland cement) could have deleterious effects if glass is used in Portland cement concrete structures.(8,9)

Mechanical Properties

Typical mechanical properties for glass are listed in Table 20-4.(2) is a brittle material that fractures from tensile stress. Gravel-sized particles greater than 4.75 mm (No. 4 sieve) size exhibit relatively poor durability when compared with conventional aggregate materials. The internal friction angle or shear strength and bearing capacity of crushed blended aggregates high, its compactibility insensitive to moisture content. Due vitreous, inert nature, can be expected good soundness properties, but frictional properties.

Typical mechanical properties if waste glass are shown in Table 20-4.

Table 20-4. Typical mechanical properties of waste glass.

Test	Results	Test Method
Los Angeles Abrasion (%)	30 - 42	ASTM C131
Maximum Dry Density, kg/m^3 (lb/ft^3 Optimum Moisture (%)	1800 - 1900 (111 - 118) 5.7 - 7.5	ASTM D1557
Angle of Internal Friction (deg)	51 - 53	ASTM D3080
California Bearing Ratio (%) 15% glass 50% glass	132 42 - 125	ASTM D1883
Hardness (measured by Moh's Scale of Mineral Hardness)	5.5(10)	

Other Properties (Thermal, Reflection, and Glare)

Glass is known for its insulating or heat-retention properties (low thermal conductivity). Aggregates and aggregate mixtures with low thermal conductivity can help to decrease the depth of frost penetration.

Studies conducted at the Colorado School of Mines in the early 1970's reported that glass aggregate pavements take a longer time to cool down due in part to the lower thermal conductivity of glass, when compared to natural aggregates.[11] Recent thermal conductivity test results (ASTM C518) for mixed-colored crushed glass are presented in Table 20-5.[2] Comparison of the results for crushed glass with those for a natural gravelly sand aggregate mix show that glass can be expected to exhibit higher heat retention than natural aggregate materials.

Table 20-5. Thermal conductivity test results.

Material	Apparent Thermal Conductivity[1] Watts/Meter - °K	
	Sample 1	Sample 2
Crushed Glass	0.315	0.260
Gravelly Sand	0.463	0.638
1. Results are presented for two separate samples.		

The high reflective properties of glass can be a desirable property in highway construction if they assist in delineating the roadway surface from the surrounding environs. Excessive reflection could, however, result in glare that could adversely affect roadway visibility. There are no documented studies on the quantities of size fractions of glass in pavements that are likely to produce excessive glare. There is, however, a noticeable glass reflection in pavements with glass fractions exceeding 15 percent by weight.

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[**Asphalt Concrete**] [**Granular Base**]

Page Owner: Office of Research, Development, and Technology, Office of Infrastructure, RDT

Topics: research, infrastructure, pavements and materials
Keywords: research, infrastructure, pavements and materials
TRT Terms: research, facilities, transportation, highway facilities, roads, parts of roads, pavements, Waste products as road materials--Handbooks, manuals, etc, Pavements, Asphalt concrete--Design and construction--Handbooks, manuals, etc, Pavements, Concrete--Design and construction--Handbooks, manuals, etc, Pavements--Additives--Handbooks, manuals, etc, Fills (Earthwork)--Design and construction--Handbooks, manuals, etc, Roads--Base courses--Design and construction--Handbooks, manuals, etc, Wastes, Environmental impacts, Recycling
Scheduled Update: Archive - No Update needed

This page last modified on 03/08/2016