# PennDOT RECYCLING MATERIAL BRIEF

## Crushed Glass Fact Sheet

**Introduction and Background**

Pennsylvania industry and consumers generated a considerable volume of waste each year. While some must be disposed in a sanitary landfill or as a hazardous material, other materials can be recovered and recycled. Recycling materials into high value-added products is most desirable if it is economically feasible. Using them in highway construction projects helps dispose of them constructively and avoids filling up landfill space. The possibility of using mixed color crushed glass in roadway construction has shown to be an attractive alternative to aggregate, especially where virgin aggregate sources are scarce and glass cullet is economically priced.

Successful recycling programs have produced large quantities of glass, primarily in the form of bottles and jars. Waste glass constitutes approximately 7 percent of the 200 million tons of municipal solid waste generated annually. A significant amount of glass is recycled directly back to the manufacturer. In the recycling process, some of the glass becomes broken, color-mixed, or otherwise contaminated, and cannot be used in container manufacturing. Crushed glass also known as glass cullet refers to waste glass produced as a result of breakage and rejection on quality control grounds during the manufacturing process. Some of this glass cullet is again used by manufacturer for the production of new glass containers, but it does have limitations such as color sorting and transportation.

PennDOT in conjunction with the Pennsylvania Department of Environmental Protection (PADEP) completed a research program at Drexel University (Drexel) to determine several of the basic physical, mechanical, and hydraulic properties of two sources of glass cullet in Southeastern Pennsylvania. D.M. Stoltzfus & Son, Inc. (Talmage,PA) and Todd Heller, Inc. (Northampton, PA) provided the glass cullet for this program. The physical property tests were performed in its fully processed (crushed or sieved), or its as-received (AR) condition. Tests were also conducted on the coarse fraction (CF) of each cullet sample which was selected to be representative of minimally processed glass cullet. A copy of the laboratory research report can be obtained upon request from the Bureau of Design, Environmental Quality Assurance Division, Pollution Prevention Section at 717-787-1024.

This fact sheet provides information on glass cullet physical properties, engineering parameters, and applications for the Pennsylvania Department of Transportation (PennDOT) use in civil engineering applications. This fact sheet is divided into the following sections:

**Material Properties** - describes the physical properties and engineering parameters of glass cullet.
**Applications** - describes glass cullet applications.
**Specifications** - presents existing PennDOT specifications.
**Conclusions** - presents conclusions and discusses implementation issues.

**Material Properties**

*General Observations*

Well processed and screened glass cullet typically does not contain debris (deleterious materials) in sufficient quantities to affect the engineering properties of the glass cullet (when within the less than 2% by weight). The debris consisted primarily of bottle labels, and metal and plastic caps. The supplied materials were angular; however, the particles were sufficiently small so as to not pose a handling hazard to the laboratory personnel, who were able to safely handle the glass using their bare hands.

*Engineering Parameters*

The test results are summarized below followed by a description of the physical properties, and engineering parameters evaluated and a comparison to traditional aggregate material properties:

**Summary of Engineering Parameters of Glass Cullet**

| Test | Parameter | Results[1] AR | Results[1] CF |
|---|---|---|---|
| Water Content ASTM D2216 | $w_n$ (%) | 2.4-4.2 | --- |
| Debris Content Gravimetric | $w_{debris}$ (%) | 0.3-1.8 | --- |
| Specific Gravity ASTM D854 | $G_S$ (-) | 2.48-2.49 | --- |
| LA Abrasion ASTM C131 | wear (%) | 24-25 | --- |
| Standard Compaction ASTM D698 | $\gamma_{d,\,max}$ (kN/m$^3$)<br>$\gamma_{d,\,max}$ (lb/ft$^3$)<br>$w_{opt}$ (%) | 107.5-111.9<br>16.9-17.6<br>11.9-13.2 | 93.5-99.2<br>14.7-15.6<br>6.5-12 |
| Modified Compaction ASTM D1557 | $\gamma_{d,\,max}$ (kN/m$^3$)<br>$\gamma_{d,\,max}$ (lb/ft$^3$)<br>$w_{opt}$ (%) | 111.9-117<br>17.6-18.4<br>10.8 | 108.1<br>17.0-17.1<br>7.8-9.9 |
| Hydraulic Conductivity* ASTM D3080 | k (cm/s) | 1.61-6.45 x $10^{-4}$ | 4.91 x $10^{-3}$ - 7.22 x $10^{-4}$ |
| Direct Shear Test* ASTM D3080 | $\phi_{ds}$ (°) | 56-61 | 48-54 |
| CD** Triaxial Test* US Army COE | $\phi_{tx}$ (°) | 46-47 | 44-45 |

*completed at 90% min. modified proctor density; ** Consolidated-drained
[1] Values based on two sources.

- Water Content (ASTM D-2216) - Six water content tests were performed on the glass cullet in its as-received condition. The results indicate that there was relatively little variation in water content for each supplier. This is to be expected from capillary effects (i.e., finer materials retain more water).

- Debris Content - Gravimetric debris content tests were performed on the glass cullet in its as-received condition. For each supplier, a bulk sample was collected from a drum container and weighed. Debris (material other than glass, e.g. bottle caps and labels, plastic tops, etc.) was manually removed and the sample was reweighed. The debris content was computed as the weight of debris divided by the weight of glass cullet. These materials had gravimetric debris contents of 0.3% and 1.8%.

- Specific gravity (ASTM D-854) is a measure of a material's density, affects the dry, partially saturated, and saturated unit weights of porous media. Specific gravity values for crushed natural aggregate range from 2.60 to 2.83. Based on PennDOT's test results, the specific gravities for fine glass cullet range from 2.48 to 2.49. The values are about 5% to 10% lower than those of most natural aggregates.

- Gradation (ASTM D-653) is defined as (grain-size distribution) proportions by mass of a soil or fragmented rock distributed in specified particle-size ranges. It can affect engineering properties such as compaction, permeability, filtration, and shear strength. Gradation is

obtained by sieve analysis. PennDOT found that the gradation of glass cullet is generally similar to crushed rock and gravely sand and is controlled by the cullet processing method. Specifications will dictate the gradation required for each application.

- Los Angeles Abrasion Test (ASTM C-131) assesses the durability and abrasion resistance of aggregates. Durability is a material classification property that affects its suitability for roadway base course and fills under fluctuating loads. A Los Angeles (LA) Abrasion test was performed by PennDOT on samples of glass cullet in their as-received condition and had values of 24% and 25%. Natural aggregates typically have wear values in the range of 10% to 35%

- Direct Shear Tests (ASTM D-3080) is the maximum resistance on a soil or rock to shearing stresses. Shear strength is a design consideration that affects bearing capacity and is expressed by the angle of internal friction measured in degrees. Typical granular soils have a friction angle ranging from 27 (loose, silty sand) degrees to 55 degrees (dense, medium size gravel). Shear strength is a major design consideration for construction with glass cullet in embankments, roadway base courses, and engineering fill under foundations. PennDOT's test results indicate that the strength of cullet is about the same as natural aggregate. However, the shear strength tests results suggested that when compacted, crushed glass exhibited relatively little cohesion. This may reflect the natural variability of the crushed glass, its grain size distribution, compacted density, or moisture content.

- Compaction (ASTM D 653) is the densification of a soil by means of mechanical manipulation. Compaction is a design consideration that affects density control. Compaction characteristics include relationship of density and moisture content, effect of compaction method on density and potential gradation change, and sensitivity of material to weather conditions. Cullet and cullet-aggregate mixtures have favorable compaction characteristics. Similar to many natural aggregates, PennDOT's Standard and Modified Proctor compaction tests exhibit maximum dry densities that exceeded those of the Standard Proctor values by approximately 5% to 10%. The moisture-density curves results exhibited the characteristic convex shape of natural aggregates, suggesting that the glass cullet behaves in a manner similar to natural aggregates. However, heavy field compaction equipment can significantly affect density values for 100 percent cullet fills because of the gradation changes. *In addition PennDOTs test results also found that the compacted density of cullet is not sensitive to the moisture content, which means that cullet material can be placed and compacted during wet weather.*

- Permeability (ASTM D 653) is a design consideration in civil drainage applications such as foundations drainage, drainage blankets, and french drains, and in leachate collection and gas venting layers. Typical granular soils (sand or sand-gravel mixtures) have permeabilities ranging from 0.01 to 0.001 cm/sec. Data found from PennDOT research found that permeability tests of 100 percent glass cullet have permeabilities ranging from 0.04 to 0.06 cm/sec for fine cullet and 0.18 to 0.26 cm/sec for coarse cullet. This is comparable to natural sand and gravel. Therefore, drainage applications can use 100 percent glass cullet for fill material.

## Applications

Glass cullet is typically evaluated as classified well graded sand by the Unified Soil Classification System (USCS), or as a Number 10 aggregate by the American Association of Highway Transportation Officials (AASHTO). Potential aggregate applications for glass cullet and cullet-aggregate mixtures are categorized below:

General Construction Backfill
- Stationary loads (fill beneath foundations)
- Landscaping fill

Roadway Construction
- Base course
- Subbase or subgrade layer
- Embankment

Utility Construction
- Pipe Bedding
- Trench Backfill

Drainage
- Retaining Wall Backfill
- Foundation Drainage
- Septage Field Media
- Sand Filters (Wastewater)
- Drainage Blanket
- French Drains

Landfill Construction
- Leachate collection layer system

Other uses may exist, but the incorporation of glass in hot mix asphalt and structural concrete (other than flowable fill) may lead to performance problems.

## Specifications

Recycled glass aggregate has been used in PennDOT projects for pipe-bedding and trench backfill in place of virgin rock aggregate. These applications have resulted in cost-savings, but are still considered trial uses, since the availability and quality of recycled glass aggregate is highly variable. These glass cullet specifications provided below are available on PennDOT's Engineering and Construction Management Website (ECMS).

- Embankment fill – P – B02061
- Embankment fill – Section 206.2(a)1.1b,e, or 206.2(a)2
- Flowable fill – Section 220.2(j)

## Conclusions

The utilization of glass cullet in civil engineering applications is a potentially emerging market, subject to variability in costs of materials and contractors' perceptions of risk associated with glass cullet construction. However, the viable applications for glass cullet utilization offer many benefits including: creation of a product market for mixed glass; diversion of recyclable glass from disposal in a landfill; reduction in need for natural mineral resources; and improving the performance of poor quality gravel in cullet-aggregate mixtures.

Glass cullet and cullet-aggregate blends have been used in numerous civil engineering applications as an alternative to conventional granular materials. Glass cullet has physical properties similar to granular materials. The computational methods and tests to demonstrate glass cullet performance essentially are the same methods and tests used for granular materials. Several specifications can be applied to the usage of glass cullet in unbound construction aggregate applications. Cullet content is dependent upon the application, availability, and specification.