

**TECHNICAL ASSISTANCE REPORT**  
**USE OF WASTE GLASS IN HIGHWAY CONSTRUCTION**  
**(Update — 1992)**

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(The opinions, findings, and conclusions expressed in this  
report are those of the author and not necessarily  
those of the sponsoring agencies.)

**Virginia Transportation Research Council**  
**(A Cooperative Organization Sponsored Jointly by the**  
**Virginia Department of Transportation and**  
**the University of Virginia)**

**Charlottesville, Virginia**

**January 1993**  
**VTRC 93-TAR2**



## ABSTRACT

Increasing pressures to recycle more wastes and minimize the amount of materials placed in landfills are forcing reconsideration of potential uses of waste glass in highway construction and maintenance operations. The federal government and many state legislatures are mandating studies to find such uses. Because the volume of aggregate needed for highway construction is so large, the use of waste glass in this manner offers a potential for utilizing most if not all glass unsuitable for other purposes.

This report provides the results of a literature search and telephone survey to determine current (1992) practices of selected state highway agencies regarding the use of crushed glass in highway construction. It is shown that similar viewpoints are held by most state highway agencies regarding such use:

1. Glass can be used as a component of unbound aggregates for embankments, trench backfills, backfills for walls, pipe bedding, gravel bases, ballast, etc., and in hot-mix asphalt base courses and surfaces.
2. Waste glass is not economically competitive with available sources of natural aggregates, nor is the available volume sufficient to reduce substantially the need for natural aggregates in a given geographical area.
3. No use has been made of glass in surfaces of main highways where high speeds and heavy truck traffic exist.
4. Cities and towns have successfully used glass in asphalt surface courses for construction and maintenance of their streets.
5. Use in highway construction can be cost-effective as an alternative means of disposing of waste glass collected in recycling programs where there is a need to avoid high landfill costs and conserve landfill space.
6. Cities and towns that have a public works department responsible for both waste management (including recycling) and street maintenance appear to be in the best position to use waste glass in a cost-effective manner. Cooperative efforts and mutually beneficial systems need to be worked out among waste management representatives, private recycling firms, highway construction agencies, and asphalt paving organizations.

Because local jurisdictions often have limited testing facilities, there is a recognized need among state highway agencies to provide specifications and guidelines for use by cities and counties in their state. The trend is to provide for optional use under established limitations.

Given a situation in which the use of waste glass is advantageous from an environmental viewpoint, highway engineers generally prefer that its use be in embankments or as a portion of the aggregate in base courses. Less restrictions are necessary for such applications. Larger glass particles and greater quantities can

be used. Upper permissible limits are not well established, but some states permit up to 25 percent in embankments, with stipulations that the top portions and sides of such embankments be all natural materials. Glass particles with a maximum size of 25 mm (1 in) have been used, and larger particles may be acceptable. Similarly, when used for backfill of trenches, etc., less restriction on the size and amounts of glass is required.

Because street and road maintenance or rehabilitation is likely to offer greater opportunity to use waste glass in urban locations than in new construction, the use of waste glass as a portion of the aggregate in hot asphalt mixtures for these purposes is of considerable interest in such locations. Concerns that have not been fully evaluated include the following:

- long-term stripping
- effects on skid resistance
- degree to which pullout of glass particles from the surface may create hazards to tires or persons (especially for residential streets)
- effects of glass in pavements to be recycled
- effects of glass handling and additions of glass during the mixing process on compliance with the regulations of the Environmental Protection Agency or health
- effects of the use of glass on established production procedures and material supplies. If the portion of the aggregate being displaced by the glass is part of the normal production stream and must be removed and wasted in order for the glass to be used, nothing will have been accomplished except to change the identity of the waste material.

## TECHNICAL ASSISTANCE REPORT

### USE OF WASTE GLASS IN HIGHWAY CONSTRUCTION (Update — 1992)

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#### INTRODUCTION

The successful use of waste glass as a constituent in asphalt concrete pavements has been shown to be technically feasible, but most published reports have shown that it is not economical for an asphalt contractor to purchase clean glass of the proper grading in lieu of natural aggregates. When glass is used in this manner, the resulting product is generally referred to as glasphalt. The increasing pressures to recycle more wastes and minimize the amount of materials placed in landfills are forcing further consideration of the potential uses of waste glass either as glasphalt or in other applications. The federal government and many state legislatures are mandating studies to find such uses. Because the volume of aggregate needed for highway construction is so large, the use of waste glass for this purpose offers a potential for utilizing most, if not all, of the recycled glass unsuitable for other purposes. Thus, it is appropriate to consider the actions and recommendations of other states regarding the use of waste glass in highway construction as possible guidelines for procedures in Virginia.

#### PURPOSE AND SCOPE

The purpose of this study was to ascertain to the extent possible the amount of use of waste glass by various transportation agencies in the United States and how they use it. From this information, recommendations for a potential strategy to be utilized by the Virginia Department of Transportation were to be developed.

#### METHODS

A literature search and telephone survey were conducted to determine the present practices of selected state highway agencies and cities regarding the use of crushed glass in highway construction. The focus was to determine the use or proposed use of glass collected in recycling programs that is unsuitable for use as cullet by the glass industry. Emphasis in the literature search was on reports not avail-

able at the time the earlier Virginia Transportation Research Council (VTRC) report "Feasibility of Using Recycled Glass in Asphalt" was prepared.<sup>1</sup>

## FINDINGS

The information obtained and the activities of the organizations contacted, or from whom reports are available, are summarized in the following.

### Connecticut

In June 1989, the Connecticut Department of Transportation (ConnDOT) published the results of a feasibility study of utilizing waste glass in pavements.<sup>2</sup> This report reviewed information available in the technical literature in January and February 1989 and an assessment of the activities of state highway agencies at that time. The conclusions, recommendations, and final comment concerning the feasibility of using waste glass are quoted as follows:

1. Glass is not suitable for placement in portland cement concrete pavement or structures in ConnDOT facilities;
2. glasphalt was successfully mixed and placed on low-volume or low-speed sites in at least 45 locations in the U.S. and Canada between 1969 and 1988;
3. no high-speed highway applications of glasphalt currently exist. Most glasphalt has been placed on city streets, driveways, and parking lots;
4. potential problems with glasphalt that must be recognized and addressed include: loss of adhesion between asphalt and glass; maintenance of an adequate level of skid resistance; and breakage of glass and subsequent raveling under studded tires. Broken glass on the pavement surface may not be readily accepted in residential areas due to the potential for injury to pedestrians, animals and bicyclists;
5. long-term evaluation of skid resistance, such as that recently initiated on Long Island, has not been performed in the past;
6. glasphalt will ravel when used as a surface course in areas with studded tire usage;
7. the consensus of personnel from organizations contacted for the study is that glasphalt should not be used on high-volume, high-speed locations;
8. the reasons stated by other organizations for placing glasphalt generally fell into one or more of the following:
  - a. as research by glass manufacturers;
  - b. the glitter effect of glasphalt provides aesthetic value;

- c. as a symbolic gesture of recycling; and/or
  - d. to provide landfill space savings;
9. loss of adhesion between asphalt and glass will likely occur if hydrated lime is not used;
  10. the cost of using glasphalt will probably be higher than that of the conventional mixes, but there is a potential savings to regional recycling centers in landfill costs;
  11. due to the potential problems identified in this study, the use of glass in embankments may be preferred to its use in pavement.

The recommendations made in the ConnDOT report were as follows:

1. Recycle and market as much glass as possible before attempting to use it in construction projects;
2. do not place waste glass in portland cement concrete pavement or structures;
3. obtain samples of contaminated glass most representative of what will be available in the future to facilitate an engineering evaluation of acceptance levels of contamination;
4. prepare laboratory mixes of glasphalt before any field placement to ensure that an acceptable mix meeting ConnDOT specifications can actually be produced;
5. use glasphalt only as a base course (if lab mixes prove acceptable) to alleviate potential safety problems associated with its use on surface courses, such as: inadequate skid resistance, raveling, and broken glass dislodged onto the surface;
6. use a maximum of 9.5 mm (3/8 in) size glass in glasphalt, add hydrated lime to prevent stripping and do not use spherical glass particles;
7. treat glasphalt pavement as a specialty item rather than a direct substitute for Class 4 base course material;
8. consider the use of glass in embankment material as an option to its use in pavement.

The ConnDOT report also included a final comment as follows:

For many reasons the concept of placing waste materials in pavements is not highly desirable from an engineering/materials stand point. Organizations such as the Asphalt Institute, ASTM, State DOT Research units, Universities and others have been attempting to improve upon the performance characteristics of pavements (both structural and safety) for many years. The Strategic Highway Research Program with its international following of study participants is currently involved with the same issue. The use of glass in place of trap rock, and/or other aggregates is not expected to enhance any performance aspect of the pavement. In fact, the potential exists for reduced friction levels and premature wear in surface courses. There is also an additional additive (hydrated lime) required at some additional cost.

The Federal Highway Administration and the Asphalt Institute urge caution in utilizing glasphalt. ConnDOT engineers are in agreement with their judgment. Any placement of glasphalt should be considered experimental initially, be preceded

by laboratory trial mixing and testing, and followed up with close monitoring of performance.

Finally, the pavement portion of a roadway should not be considered the ultimate long-term disposal solution for any waste material. All bituminous pavements have a useful life of 12-25 years. At the end of the period they must be either recycled, removed, or covered over with an overlay that has its own inherent 12-15 year life-cycle. Pavements are neither static nor permanent structures, and, as such, are not necessarily the best place to put otherwise unwanted materials.

As of September 1992, some towns in Connecticut were using some waste glass in asphalt mixtures placed on their own streets and parking lots but ConnDOT was not making use of the material in state-constructed projects. Where state approval is needed for construction in towns, approval is granted on a project-by-project basis. No ConnDOT-recommended specifications have been adopted. ConnDOT does permit the use of up to 25 percent of crushed waste glass in the aggregate being used for embankments and fills, with restrictions concerning its use near the surface and outer edges of such fills and embankments. The maximum size particle for this application, established by the Environmental Protection Agency (EPA), is 25 mm (1 in).

No specific performance evaluations were available.

## New York

### State DOT

The New York State Department of Transportation (NYSDOT) recently (1991) adopted a special provision to its standard specifications that permits the use of up to 5 percent crushed waste glass as aggregate for asphalt mixtures at the option of the contractor. Use is limited to base or intermediate layers and to surface layers on shoulders or parking lots. No use is permitted for high-speed surfaces. It is reported that there is interest among some asphalt paving contractors to use this option. In some cases, recycled glass is accepted at no fee or for a dumping charge and crushed at the asphalt plant. As of September 1992, only two pavement sections had been placed under this option and no reports of performance were available. Visual observations had given no indication of unsatisfactory characteristics. The NYSDOT special provision is included as Appendix A.

### New York City DOT

The New York City Department of Transportation (NYC-DOT) is making extensive use of recycled asphalt pavements (RAP) along with crushed glass.<sup>3, 4</sup> The amounts of glass are reported to vary from 0 to 20 percent of the aggregate in the asphalt mixture. A significant overall savings to the city is shown when the avoided landfill costs for disposing of the glass are taken into account. Other cities and towns in New York have also installed experimental sections. Generally, no problems have been reported in mixing and paving pavements containing the glass, and performance is reported as satisfactory.



Table 1  
GRADING OF WASTE CRUSHED GLASS

Sieve Size	Percent Passing
9.5 mm (3/8")	100.0
6.3 mm (1/4")	85.0
3.2 mm (1/8")	53.2
850 $\mu$ m (No. 20)	17.1
425 $\mu$ m (No. 40)	8.8
180 $\mu$ m (No. 80)	3.6
75 $\mu$ m (No. 200)	1.2

As of September 1992, it was reported that New York City is continuing the use of crushed waste glass in its streets with satisfactory results. The city is continuing the practice as reported by Castedo and Watson.<sup>3</sup> The grading of the crushed glass being used is shown in Table 1. The report further stated:

The use of glass as substitute of aggregate in paving materials is well documented and it is a technique widely used in many U.S. states, Canada, and Europe since the late 1960s. The use of RAP in paving mixtures is more widespread and common than glasphalt and it is a technique totally accepted by federal, state, county, and local highway agencies.

Initial glasphalt production by the NYC-DOT was limited to experimental field sections where tests were performed for skid resistance . . . and overall pavement performance. Test results showed that the glasphalt produced by the NYC-DOT hot mix asphalt plant . . . has no different skid resistance properties than regular 6F paving mixtures. Continuous laboratory and field evaluations have shown thus far that waste glass can be used satisfactorily as an asphalt mix aggregate for paving and resurfacing New York City streets. Current evaluation efforts are being concentrated on low speed roads.

For the past year and a half the NYC-DOT asphalt paving mix production consisted of (depending on the availability of RAP and/or waste glass), a combination of RAP that varies from 0 to 30 percent; waste glass from 0 to 20 percent; and virgin aggregate with 5.8 to 6.2 percent AC-20 asphalt binder.

Records of skid resistance measured in accordance with ASTM E 274 (skid numbers) were not found. However, Castedo and Watson reported the results of using the British pendulum tester (BPN) on some sections of New York City pavements as follows:

1. *New York City glasphalt test sections:*

- E. 19th St. & Ave. V: Avg. BPN = 60, 61, 60
- E. 19th St. & Ave. V: Avg. BPN = 67, 64
- E. 19th St. & Ave. V: Avg. BPN = 56, 58
- E. 19th St. & Ave. V: Avg. BPN = 62, 61

2. *Control test section (regular 6F mix): E. 19th St. & Ave. W: Avg. BPN = 64, 66, 61.*

Although not standard U.S. practice, recommended BPN values for wet pavement surfaces were given as follows:

- BPN > 65: "good" for high speed traffic
- BPN > 55: "generally satisfactory"
- BPN > 45: "fair"
- BPN < 45: "potentially slippery."

Thus, by these criteria, the New York pavements would be considered "generally satisfactory."

### New Jersey

The New Jersey Department of Transportation (NJDOT) permits the optional use of up to 10 percent (of the aggregate) of waste glass in asphalt base courses. Two gradings are permitted. One has a top size of 19 mm (3/4 in), and the other a top size of 9.5 mm (3/8 in). An antistripping agent is required when the coarse material (passing 19 mm) is used but is not mandatory for the finer material (passing 9.5 mm). The source of the glass must be approved by the department. Maximum limits for foreign materials are paper—2.5 percent; metal—3.0 percent; plastic—0.3 percent; other—0.5 percent. Very limited use has been made of this option to date. One disincentive is the cost of the antistripping agent.

NJDOT also adopted an incentive program in July 1992 under which asphalt mixture contractors are paid a \$1-per-ton bonus for each ton of base mixture containing 5 to 10 percent of the crushed glass. Negotiations are under way (as of September 1992) for several projects, but none has as yet been installed under this option.

### Pennsylvania

The Pennsylvania Department of Transportation permits the use of some crushed waste glass in embankments. Such glass is used as it is crushed at the recycling center. Glass is also being used experimentally as a part of the backfill for pipe trenches. Other experimental use has been in the aggregate for asphalt mixtures with percentages of glass up to 10 percent. In these cases, the grading of the combined natural aggregate and glass must comply with the specified grading of the aggregate used in the standard mixtures. Unofficial guidelines and specifications have been prepared, but as of September 1992, it was reported that they had not been adopted. No reports of laboratory studies were available.

## Maryland

The Maryland State Highway Administration is in the process of adopting a specification (as of September 1992) that will permit the optional use of waste glass in asphalt base courses. No upper limit will be placed on the percentage of glass, but test specimens must have a tensile strength ratio (TSR) of 85 percent or greater.

The City of Baltimore conducted a controlled experiment in the use of glassphalt in the 1970s with good results. The glass for this project was clear cullet provided to the city by the EPA free of charge. However, it is reported that the purchase of similar clean and properly graded glass was about 5 times the cost of natural available aggregate.

Use in Baltimore has continued with varying amounts of waste glass in the pavement. Watson stated that continued use in Baltimore has been partially for the pleasing sparkling of the glass in the surface under street lights or the sun.<sup>4</sup> Use in amounts of 30 to 40 percent with the maximum size of 19 mm (3/4 in) is reported. Some concern has been expressed concerning a lowered skid resistance for some of the installations in Baltimore, but no record of specific data could be found. Also, formal reports of performance evaluations could not be located. Baltimore's use is only on low-speed roads and streets, and no accidents directly attributed to the glass in the aggregate have been reported.<sup>4</sup>

## District of Columbia

The District of Columbia Department of Public Works installed an experimental section of glassphalt in the late 1970s or early 1980s. Performance was satisfactory, but at present there are no plans for further use unless such use is mandated by legislation. Developments in neighboring states are being monitored.

## Florida

The Florida Department of Transportation (FDOT) issued a research report on the "Evaluation of Crushed Glass in Asphalt Paving Mixtures" in April 1991.<sup>5</sup> This report included a summary of the available literature and a laboratory study of the characteristics of two asphalt mixtures, each containing 15 percent of glass in the aggregate. One, designated as coarse grading, had 100 percent passing the 9.5 mm (3/8 in) sieve, and the other contained 15 percent of the same glass that was further crushed so that 100 percent passed the 4.75 mm (No. 4) sieve. Results with these mixtures were compared to those with a control specimen designated as Type S-III in the FDOT specifications. The maximum size aggregate was 100 percent passing the 9.5 mm (3/8 in) sieve.

Tests showed that the Marshall stability decreased when the glass was substituted for the natural aggregate. The TSR of all glass mixtures was less than the

200

respective TRS of the control mixtures. For mixtures without antistripping additives, the percent retained TSR was 70 percent for the control mixture, 85 percent for the coarse glass mixture, and 52 percent for the fine glass mixture. Use of an antistripping additive improved the bond to some degree. Results of the boiling test showed that 25 percent of the surface of the coarse glass mixture was stripped without an antistripping additive and 10 percent stripping was present with the antistripping additive. The fine glass showed 15 percent stripping without additive and 5 percent stripping with additive. However, as indicated by the TSR results, stripping of the fine aggregate showed a greater damaging effect to tensile strength.

Recommendations included in the report were as follows:

The use of crushed glass in asphalt mixtures should be approached with caution and consideration given to economic feasibility and the possible sacrifice in mixture performance. The following technical restrictions are recommended:

1. The amount of crushed glass in the asphalt mixture shall not exceed 15 percent (by weight of the total aggregates).
2. The crushed glass shall be processed to have 100 percent passing the 9.5 mm (3/8 in) sieve and no more than 8 percent passing the 75  $\mu$ m (no. 200) sieve.
3. Asphalt mixtures containing crushed glass shall contain an antistripping additive which can be demonstrated to satisfactorily improve the moisture damage resistance of the mixture.
4. Crushed glass shall not be used in either dense-grade (FC-1 and FC-4) or open-graded (FC-2) friction course mixtures.

It is recommended that special provisions, to include the above restrictions, be developed for use by FDOT and local governments. These special provisions could be included in specific contracts involving asphalt paving where a source of crushed glass is available. However, use of the glass should be optional to the contractor to allow the most economical use of materials.

In a telephone conversation on September 1, 1992, it was indicated that FDOT is proceeding with the development of special provisions for use by cities and counties within the state on an optional basis. There are no plans to permit its use on heavily traveled or high-speed highways.

## Indiana

A joint highway research project was conducted by the Department of Civil Engineering of Purdue University, and a report was published in May 1991.<sup>6</sup> The study synthesized information obtained from a number of sources concerning the use of a number of waste materials, including waste glass. The sources of information included the results of a questionnaire submitted to all state highway agencies in the United States. Possible uses of glass and potential problems associated with its use were discussed and summarized by the author of the report as follows:

Unmarketable glass can be used in highway construction in place of conventional aggregate in asphalt pavement (glasphalt) and in unbound base layers and as a filler material in embankment construction. As previously stated, all these uses have technical, economic, and environmental implications, which must be addressed prior to extensive use of glass in INDOT facilities.

Although glasphalt has been used at a number of locations in the past, long-term performance evaluations have not been conducted,<sup>[2]</sup> therefore correlations between laboratory test results and field performance are severely lacking. The major areas where potential problems in the use of glasphalt have been identified and further investigation is required include:

- the effect of moisture on glass-asphalt mix;
- type and quantity of the most suitable antistripping agent (presently 1 percent hydrated lime is used);<sup>[2]</sup>
- the glass content ([Hughes, Ref. 1] recommends 15 percent to be the upper limit) and most appropriate glass gradation;
- optimum asphalt content and evaluation procedures for asphalt.

The use of waste glass in concrete pavement or structures is not feasible due to alkali-aggregate reaction, and consequent expansion of glass, and reduction in the concrete strength. The problem needs to be further investigated to find the remedial measures.

The use of glass as an aggregate/fill materials in unbound base layers/ embankment is feasible if gradation/size meets the INDOT specifications.

It is likely that unmarketable waste glass, available for highway construction, may be contaminated with foreign materials which may include: (a) durable materials (e.g.; ceramics, pottery, mirror, Pyrex, etc.); (b) nondurable (e.g.; wood/metal pieces, cardboard container covers, etc.); or (c) hazardous materials (e.g.; chemically contaminated glass, small batteries, etc.). If the glass contains durable materials, it may be acceptable. However, glass contaminated with the other two categories of materials, depending upon the level of contamination, may require secondary sorting in the case of nondurable materials and pre-treatment (or may even be rejected) in case of hazardous materials. Both secondary recovery and pre-treatment would increase the cost of waste glass. The environmental acceptability of waste glass will depend on the level of contamination, to be determined prior to its use in highway construction.

Based on the results of feasibility studies summarized above, rational conclusions can be drawn regarding the economic feasibility of the use of glass in INDOT facilities. The use of glass in:

- asphalt and concrete pavements will be uneconomical (the cost will be at least 10 to 20 percent higher than the conventional materials);
- unbound base layers and embankment may be economically justified (however, it will depend on many factors which include: current and projected quantities of recyclable waste glass, crushing and transportation costs, and availability and cost of conventional aggregates);
- highways will reduce landfill costs.

Finally, an adequate and consistent supply of glass is an important factor which will influence its use in the highway industry. The EPA publication on "Char-

acterization of Municipal Solid Waste in the United States: 1990 Update" comments as follows on the production trends of waste glass:

Generation of glass has continued to decline from 1986 to 1988. In fact, glass containers would disappear from the waste stream if a trend line analysis were followed. The consultants elected not to use that projection, but to assume that glass containers will continue to be made. The projected generation for 2000 was, however, lowered by 23 percent based on the historical data.

The report further stated that the comments reported raised serious concerns about the adequate and consistent supply of recyclable glass.

## Washington

The Washington State Department of Transportation (WSDOT) made a study of the use of recycled materials in highway construction.<sup>7</sup> This included a review of information regarding the use of waste glass. The discussion and conclusions reached by the authors of the report were as follows:

### Waste Glass in Asphalt Concrete Pavement (Glasphalt)

There have been sporadic attempts to use waste glass in asphalt concrete pavement since the late 1960s. One of the most complete studies on the "Use of Domestic Waste Glass for Urban Paving" was conducted by Malisch, et al., from the University of Missouri-Rolla, for the U.S. Environmental Protection Agency and reported in 1975.<sup>[15]</sup> With the large increase in waste glass from the various recycling programs implemented across the nation, there has been a clear increased interest and activity in incorporating waste glass in ACP [asphalt concrete pavement], particularly from the late 1980s on. Although there are quite a few short experimental sections of "glasphalt" constructed across the country, New York DOT has used a considerable amount of waste glass in their ACP in the New York City urban area over the last 4+ years. Connecticut,<sup>[2]</sup> New Jersey, Virginia, and Florida DOTs have conducted smaller special studies on the use of waste glass in ACP over the last few years.

In reviewing all of this information there was a very common set of findings that governs the use of glass in highway construction:

1. Glass crushes more easily than construction-quality aggregate.
2. Asphalt does not adhere as well to the very smooth glass surface as it does to construction-quality aggregate.
3. Many east coast references indicated that waste glass sources contained as much as 20 percent "commingled" waste such as aluminum cans, soil and ceramics.

To mitigate these potential problems there is a fairly common set of recommendations or limitations in almost all of the references for the use of waste glass in highway construction:

1. To minimize the crushing problem associated with glass, its use is limited to a maximum of 15 percent of the total aggregate volume, using

only glass crushed fine enough to pass a 9.5 mm (3/8 in) sieve. Glass this size or smaller does not crush as easily as the larger sizes, and thus better meets the durability needs of construction aggregate.

2. To minimize stripping problems (adhesion loss of asphalt to glass or aggregate) all sources recommended the use of antistrip agents, specifically the addition of hydrated lime, to the glass waste during ACP production. Hydrated lime is the most universally successful antistripping agent used by the paving industry today. WSDOT has a concern in this specific area. All of the references to stripping potential had judged that potential based on the conditioning of a laboratory sample in a warm water bath for 24 hours. This is a fairly easy conditioning process used in the southern and east coast states. WSDOT and most other northern tier states use a more aggressive conditioning process that requires freezing the sample for 24 hours before the warm bath. This conditioning correlates better to pavement distress found in the northern states from freeze-thaw cycles. It is likely that potential stripping problems associated with glass will be accentuated by this conditioning procedure.
3. WSDOT has been assured by representatives of the waste glass industry that contamination or commingling of other waste stream materials is not a problem in Washington State. Grading requirements such as the restriction to 9.5 mm (3/8 in) maximum size, as mentioned above, and an additional requirement for a maximum of, say 7 percent passing the 75 µm (number 200) sieve would likely insure that the waste glass material is reasonably contaminant free.

In addition to those specific items noted above, most references indicated a general concern, in varying degrees, about long-term asphalt stripping problems, loss of surface friction, rutting, etc. Because of these general concerns there is a fairly consistent consensus that "glasphalt" not be used on high-speed, heavy-volume highways. Its use is usually limited to wearing and base courses on lower-speed and lower-volume streets or highways, and only as base courses on high-speed or high-volume highways.

Some conclusions in the WSDOT report that apply to the use of glass are as follows:

Waste glass could be used in asphalt concrete pavement in Washington for lower-speed and lower-volume streets and highways or in the asphalt base layers of higher-volume highways, or in bike paths or walkways, with the following limitations:

1. The waste glass be reasonably clean, with 100 percent passing the 9.5 mm (3/8 in) sieve and no more than 7 percent passing the 75 µm (number 200) sieve.
2. A maximum of no more than 15 percent by volume of waste glass should be used in ACP.
3. The use of any waste glass in ACP will require the use of an antistrip additive such as hydrated lime slurry or equal.
4. The use of waste glass should be considered experimental at the present time.
5. The use of any waste glass in ACP will require a full laboratory work-up.

*Glass in Concrete* Alkali-silica reactivity (ASR) is a widespread problem in the United States. This is essentially a chemical reaction between certain forms of silica in glass (or some aggregates) and alkalis (sodium or potassium) from the cement. The result is a gel product that absorbs moisture and expands, which finally leads to the destruction or disintegration of the concrete.

Due to the alkali-silica reactions, the use of glass as an aggregate substitute in portland cement concrete is prohibited by many agencies.<sup>[2, 6]</sup>

*Waste Glass in Unbound Surfacing* A number of agencies have adopted specifications for the use of glass in unbound base materials as an alternative to its use in pavements.<sup>[2]</sup> A general special provision has been developed by WSDOT which allows the use of glass chard in a wide range of untreated base materials in Washington State. A copy of this proposed GSP is included as Appendix E [Appendix B of this report].

## Synthesis of the National Cooperative Highway Research Program

A synthesis on the "Use of Waste and By-Products in Highway Construction" is being prepared by the National Cooperative Highway Research Program under Project 20-5, Topic 22-10. This synthesis is expected to be available late in 1992 or early 1993. It will contain information concerning the use of waste glass in various highway applications. A preliminary review of an unpublished first draft of this synthesis did not reveal significant use by state highway agencies not covered in this report.

## DISCUSSION

The term *glasphalt* was first used to describe the glass-asphalt mixture used in a test section placed by Owens-Illinois in 1969.<sup>15</sup> This test section and a number of others were placed in the early 1970s. The aggregates in most of these early trials contained from 54 to 68.5 percent crushed glass graded so that 100 percent passed the 12.5 mm (1/2 in) sieve. Various combinations of natural sand or rock dust plus hydrated lime made up the balance. The percentage of hydrated lime varied from 1 to 4 percent.

In later installations, such as is now customary in New York City and other cities and towns, the glass content is usually 10 to 20 percent. The term *glasphalt* is generally used to describe all such installations. However, with such wide variations in the aggregate composition, similar performance should not be expected in all cases. Thus, the reference to *glasphalt* as a generic term for a class of pavement is questioned. The amount and grading of the glass as well as the grading of the combined aggregate should always be considered in any performance evaluation.

The early evaluations of the use of glass as aggregate in asphalt pavements were made from the standpoint of assessing the feasibility of using waste glass as a



means of conserving energy and natural resources by the use of waste materials. The literature search conducted in conjunction with the earlier VTRC report by Hughes identified a number of limitations to the use of glass as a replacement for a major proportion of the aggregate in an asphalt mixture.<sup>1</sup>

Because of the high cost of collecting and crushing the glass, it was generally concluded that the most favorable use of recycled containers was for the manufacture of new containers by the glass industry and that use in asphalt mixtures was not economically feasible as an alternate source of aggregate. However, within the last few years, increasing recycling efforts and an increased amount of unsorted glass unsuited for recycling by the glass industry dictate the need for reevaluation of this approach primarily from the standpoint of nonharmful disposal of the waste glass. When public works agencies responsible for roads and streets and trash collection can avoid immediate landfill costs, as well as preserve landfill capacity, such avoided costs may outweigh the added cost of crushing and handling the materials for highway construction and maintenance operations. Thus, there is renewed interest in cooperative efforts between waste management and highway personnel to develop the most cost-effective overall effort.

Most of the state highway agencies contacted in this survey recognize the need to provide means for optional use in some highway application. However, reported or perceived problems relating to possible stripping, aggregate crushing, and lack of skid resistance make it desirable to limit such optional use of glassphalt to less traveled roadways and possibly to applications other than the surface mixture.

In assessing the potential use of recycled glass in highways, the present-day emphasis is: How can the material be utilized in highway construction procedures without detriment to long-term performance? Thus, proven or perceived differences in behavior of asphalt mixtures with glass as a part of the aggregate from mixtures containing natural aggregates with similar grading must be kept in mind.

This survey and review of recently published literature generally confirm the observations concerning glassphalt cited by Hughes in the initial VTRC report,<sup>1</sup> which were:

1. Lime or other antistripping agents are needed in the mixtures to attain and retain proper adhesion of the asphalt to the glass.<sup>[8-10]</sup>
2. The glass should be crushed to pass a 9.5 mm (3/8 in) sieve. Larger particles, especially those that are elongated, have a tendency to crush during construction.<sup>[9-11]</sup>
3. Glass particles cool more slowly than aggregate because of the differences in their thermal conductivity. This may be an advantageous property in cold weather as it allows more time for compaction.<sup>[12]</sup> However, in warmer weather, the mixtures may tend to be unstable under the construction rollers; consequently, the rolling patterns may need to be revised.<sup>[12]</sup>
4. Performance in a number of cases was reported as adequate.<sup>[9, 13, 14]</sup> However, the loss of glass from the surface was reported in a Canadian trial.<sup>[12]</sup>
5. The surfaces tested appeared to have adequate skid resistance.<sup>[9, 13, 15]</sup>

6. Except for situations where the disposal of the glass is likely to be costly or the landfill space is limited, glasphalt does not appear to be economically feasible. The cost of conventional aggregates in most areas is less than the cost of collecting and crushing the glass.<sup>[13, 15, 16]</sup>
7. Estimates are that 1 million bottles would be required for 1 lane mile of 76-mm-thick pavement (3 in) when the aggregate is 20 percent crushed glass.<sup>9</sup> It was also estimated by a different source that 29.4 billion glass containers were used and discarded in the United States during 1966.<sup>[11]</sup>

These observations are based primarily on results of studies in which about two thirds of the aggregate was glass. However, present efforts are more likely to be directed to using glass as an additional component of the aggregate in the range of 10 to 20 percent.

The Hughes evaluation was based on tests made with 5 and 15 percent of glass with a nominal top size of 9.5 mm (3/8 in).<sup>1</sup> He concluded that mixtures with up to 15 percent glass with a grading approximately that of a coarse sand in an overall grading for a VDOT S-5 surface mixture would perform satisfactorily without serious loss of quality as measured by laboratory tests. The grading of the S-5 mixture without glass used by Hughes is shown in Table 2 and that of the recycled glass is shown in Table 3. The grading of the mixed aggregate containing the glass

Table 2  
GRADING OF BASIC S-5 MIXTURE WITHOUT GLASS

Sieve Size	Percent Passing
12.5 mm (1/2")	100
9.5 mm (3/8")	95
4.75 mm (No. 4)	58
2.36 mm (No. 8)	39
1.18 mm (No. 16)	29
600 $\mu$ m (No. 30)	19
300 $\mu$ m (No. 50)	10
150 $\mu$ m (No. 100)	6
75 $\mu$ m (No. 200)	4.7

Table 3  
GRADING OF RECYCLED GLASS

Sieve Size	Percent Passing
12.5 mm (1/2")	100
9.5 mm (3/8")	98
4.75 mm (No. 4)	70
2.36 mm (No. 8)	32
1.18 mm (No. 16)	19
600 $\mu$ m (No. 30)	10
300 $\mu$ m (No. 50)	6
150 $\mu$ m (No. 100)	4
75 $\mu$ m (No. 200)	2.9

was very close to, but not identical with, the S-5 mixture without glass. The FDOT study used glass from the same source as that used by Hughes for the coarse material and crushed portions of the same glass for the tests designated as fine material. A report by Petrarca and Chesner summarized the placing of a demonstration project for the town of Hempstead, New York.<sup>17</sup> They reported that laboratory tests on glass mixtures with as much as 40 percent glass had Marshall stability values essentially the same as mixtures with 100 percent natural aggregate of the same grading. However, the mixture placed on the road contained 15 percent glass in the aggregate. Other reports of laboratory evaluations were not found. The grading of the aggregate in these tests was similar to that used in the Virginia tests<sup>1</sup> and the coarse aggregate in the Florida test.<sup>5</sup> Thus, at present, there are insufficient data with which to establish an upper limit of the amount of glass and the grading that can be used without appreciably affecting performance. Additional research is needed.

Intuitively, a number of highway engineers recommend that if glass is to be used in an asphalt mixture it should be in a base course or intermediate layer to avoid changing surface characteristics of the pavements. However, no record of performance evaluations of the material in base course could be found. There is a possibility that stripping damage in the base course would be greater than in surfaces. For this reason, consideration should be given to limiting use by VDOT to low-speed and low-volume roadways. General use should also be limited to the surface courses of such roadways until field trials or other tests can evaluate the behavior in bases. Long-term difficulties with surface courses could be much more easily corrected than failures in the base courses.

Highway engineers generally believe that a better place for disposal of the glass waste would be in fills, embankments, or aggregate bases, where it must only be stable and nondegradable. It is also considered that glass used in this manner need not be crushed to as small a size as is needed for asphalt mixtures. The proposed special provision of the WSDOT included as Appendix C lists 17 possible uses for such material. Washington limits the amount of glass in the blended aggregate for such purposes to a maximum of 15 percent. As stated, ConnDOT permits up to 25 percent glass in aggregate base courses, but information was not obtained as to how the material was placed or blended with other aggregates.

Although haul distances would greatly affect cost, the use of waste glass in fills and embankments appears to offer the optimum procedure for disposal of the waste glass. Much larger volumes can be used; less crushing would be required; minor contamination from paper labels and ceramic particles would be of no concern. With initial inspection to avoid the use of crushed bottles that may have contained hazardous materials, contamination of ground waters would not be likely.

No attempt was made in this survey to update the economic analysis reported by Hughes. However, it is evident that the costs of placing waste glass in landfills have accelerated greatly in the last 2 years. Costs in Northern Virginia have been stated to be as high as \$55 per ton, and conversations with persons in New York and Connecticut indicated costs as high as \$70 per ton in some areas.

Thus, any use of waste glass that avoids such costs is likely to be cost-effective from the overall standpoint provided the performance of the facility in which it is used is not appreciably diminished. However, procedures need to be developed whereby the highway agency can be compensated for any increased costs incurred by the use of glass and possibly share a portion of the avoided costs.

## CONCLUSIONS

1. Legislative pressures are increasing at both the national and state levels for use of recycled waste materials in highway construction. Such pressures are generated by the growing concern for landfill space and the increasing costs of placing waste material in such landfills.
2. Although not cost-effective as a replacement for natural fine aggregate in asphalt mixtures, waste glass can be used in a number of highway construction applications with satisfactory performance. If procedures are developed to compensate highway agencies properly for added costs, the use of such material in highway application will provide a viable alternative to disposal in landfills. The cost of otherwise disposing of such material often makes such use in highway projects the least costly alternative.
3. The preferred use of waste glass in highway construction is in embankments and fills.
4. To date, relatively limited laboratory data and documented records of long-term field performance are available regarding the characteristics and optimum design of asphalt mixtures containing glass. Thus, the present use of such mixtures should be confined to low-volume and low-speed roads. More research studies as well as field experimental projects are needed before waste glass is used as a portion of the aggregate in heavily trafficked asphalt concrete pavements.

## RECOMMENDATIONS

1. VDOT should develop special provisions for the use of waste recycled glass with soil and rock as fill material in embankments and as a portion of the aggregate in unbound aggregate bases.
2. Specifications permitting the optional use of glass in asphalt mixtures should be developed. Such use should be permitted only in mixtures to be applied on roadways carrying a low volume of traffic at legal speeds of 40 miles per hour or lower. Such mixtures should contain a maximum of 15 percent waste glass. Grading controls should be 100 percent passing the 9.5 mm (3/8 in) sieve and a

maximum of 6 percent passing the 75  $\mu\text{m}$  (No. 200) sieve, with the TSR of the mixture being 0.9 or better. A job-mix formula for grading and asphalt content should be established by the contractor using the Marshall method of design for each mixture to be supplied.

3. VDOT should cooperate with glass recycling centers, aggregate producers, asphalt paving contractors, and others who may be concerned in developing information regarding the location and quantity of recycled glass in specific areas of the state and cost analysis data that can be used to develop optimum methods of use for specific locations.

### ACKNOWLEDGMENTS

Appreciation is expressed to the following, who provided information by telephone and copies of available reports.

• New York	James J. Murphy	(518) 457-3240
	Gary Frederick	(518) 457-4582
• Connecticut	Donald A. Larsen	(203) 258-0301
• Maryland	Dr. Haleem Tahir	(301) 321-3538
• New Jersey	Eileen Connolly	(609) 530-2315
• District of Columbia	Nat Kalchef	(202) 673-2155
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• TRB	Scott Sabol	(202) 334-3242
• BFI (Fairfax)	David Minter	(703) 550-2421
• Environmental Council	Michael Clower	(703) 324-5436
• Fairfax		
• Northern Virginia Planning District Commission	Rob Arner	(703) 642-0700

Thanks are also extended to Ann McDaniel for typing the initial drafts of the report and to Linda Evans for editing it.

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## Appendix A

### NYS DOT SPECIFICATIONS FOR HOT-MIX ASPHALT CONCRETE PAVEMENT WITH CRUSHED GLASS

**SCOPE.** This specification covers the requirements for the addition of crushed glass to asphalt concrete mixes. The provisions of Section 403—Hot Mix Asphalt Concrete Pavement—shall apply except that the Contractor has the option of blending crushed glass in the following mixes:

- Asphalt Concrete — Type 1 Base
- Asphalt Concrete — Type 3 Binder
- Asphalt Concrete — Type 6 Top\*
- Asphalt Concrete — Type 7 Top\*
- Asphalt Concrete — Truing and Leveling

If the Contractor chooses the crushed glass option, the following modifications to the Standard Specifications shall apply:

#### MATERIAL REQUIREMENTS

A. Crushed glass. Crushed glass shall be subject to the approval of the Regional Materials Engineer prior to its use. The crushed glass shall contain no more than 1 percent (by weight) contaminants and shall meet the following gradation:

Sieve Size	Percent Passing
3/8"	100
1/4"	90–100
No. 200	0–20

Note: The gradation requirements may be modified upon approval of the Regional Materials Engineer.

B. Composition of Mixture. Crushed glass may be included in the mixture up to 5 percent, maximum, of the total aggregate weight. The crushed glass, aggregate, and added asphalt cement shall meet the requirements specified in Table 401-1, Composition of Bituminous Plant Mixtures, for aggregate gradation, asphalt cement content, asphalt cement grade, and temperature range.

#### CONSTRUCTION DETAILS

**Plant Equipment.** The crushed glass shall be proportioned from a separate feed bin approved by the Regional Materials Engineer. In addition, all requirements per-

\*For shoulders.

taining to aggregate shall apply to crushed glass, including the equipment requirements for automatic proportioning and recording stipulated for aggregate in subsection 401-3.02.

**METHOD OF MEASUREMENT.** The provisions of subsection 401-4 shall apply.

**BASIS OF PAYMENT.** The provisions of subsection 403-5 shall apply.

**Appendix B**

**WSDOT PROPOSED SPECIAL PROVISION  
FOR RECYCLED GLASS IN BASE AGGREGATES**

Aggregate base shall conform to the provisions in Section 9-03 of the Standard Specifications and these Special Provisions. Aggregate base blended with reclaimed glass may be processed and used as:

- 9-03.9(1) Ballast
- 9-03.9(2) Shoulder Ballast
- 9-03.9(3) Crushed Surfacing Base Course
- 9-03.10 Aggregate for Gravel Base
- 9-03.12(1)A Gravel Backfill for Foundations, Class A
- 9-03.12(1)B Gravel Backfill for Foundations, Class B
- 9-03.12(2) Gravel Backfill for Walls
- 9-03.12(3) Gravel Backfill for Pipe Bedding
- 9-03.12(4) Gravel Backfill for Drains
- 9-03.13 Backfill for Sand Drains
- 9-03.13(1) Sand Drainage Blanket
- 9-03.14 Gravel Borrow
- 9-03.15 Bedding Material for Rigid Pipe
- 9-03.16 Bedding Material for Flexible Pipe
- 9-03.17 Foundation Material Class A and B
- 9-03.18 Foundation Material Class C
- 9-03.19 Bank Run Gravel for Trench Backfill

Blended material must conform to all specifications in Section 9-03 for these items except that the Los Angeles Wear requirement for Ballast, Shoulder Ballast, and Crushed Surfacing Base Course is waived.

These blended materials shall not be used within 1 foot of finished grade under the traveled lanes of a roadway.

No more than 15 percent of a blended material shall consist of reclaimed glass. When tested as a mixture, no more than 10 percent of the material retained on a specified sieve 1/4 in or larger shall be glass, based upon visual examination and weight.

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