USE OF GLASS CULLET IN ROADWAY CONSTRUCTION:
Laboratory Testing and Specification Development

by

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16. Abstract: The purpose of this study is to develop specifications for using glass cullet in roadway construction. Glass cullet results from collecting and crushing post consumer glass containers. Using glass cullet in roadway construction avoids expensive sorting to prevent color contamination and presents an opportunity to use glass cullet as a construction aggregate and reduce landfill requirements. A number of other states and organizations have investigated the use of glass cullet in various aspects of construction. Specifications for using glass cullet for roadway construction in the State of Texas were developed in three phases: (1) Literature Review and Identification of Available Sources and Suppliers; (2) Laboratory Testing; and (3) Specification Development. An earlier report presented findings from Phase I, literature review and identification of available sources and suppliers. This report covers Phase II, Laboratory Testing and Phase III, Specification Development.

Findings from the literature review revealed a number of states have investigated the use of glass cullet in roadway construction and several have developed applicable specifications. An extensive study was performed by the Clean Washington Center and their report served as a primary source of information for the study reported herein. Specifications for the other states were used as guidelines for developing specifications for the State of Texas. Only a limited number of suppliers were located in Texas. Samples from Texas suppliers were evaluated in limited laboratory testing and the samples obtained from Texas suppliers were found to be free of lead, a potentially toxic substance. No hazardous materials were found in the samples. Orginally, a life cycle cost analysis was planned for glass cullet as an alternative to conventional construction aggregate. However, any such life cycle cost analysis was deemed premature because the glass recycling industry is in the early stages of development.

Glass cullet received from the glass cullet supplier contained less than one percent debris. Debris consisted of paper, plastic and cork. Debris levels were varied from 0 percent to 1 percent by weight of glass cullet. Furthermore, the glass cullet with various debris levels was blended with crushed limestone at various mix proportions. Laboratory testing included triaxial, permeability, compaction, wet ball mill, gradation and stripping tests. Draft specifications were prepared for embankments, base course backfill, drainage materials and detour construction.

Both the Houston District and the Abilene District were identified as possible locations for a demonstration project. The primary Texas supplier of glass cullet is located in the Houston District. A supply of waste glass is available in the Abilene District, but requires crushing into cullet.

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IMPLEMENTATION

This project developed several products useful to the Texas Department of Transportation (TxDOT), including: draft specifications for the use of glass cullet in transportation construction projects, a report providing an overview of glass cullet in roadway projects, an assessment of glass cullet sources and suppliers in Texas, and material characteristics of glass cullet from a Texas glass cullet supplier. Procedures for enhancing the performance of glass cullet in roadway construction and possible demonstration testing were recommended.

FEDERAL/DEPARTMENT CREDIT

Prepared in cooperation with the Texas Department of Transportation, the Texas Natural Resource Conservation Commission, and the U.S. Department of Transportation, Federal Highway Administration.

AUTHOR'S DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view of policies of the Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

PATENT DISCLAIMER

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

ENGINEERING DISCLAIMER

Not intended for construction, bidding, or permit purposes. The engineer in charge of the research study was Phillip T. Nash, P.E., Texas 66985.

TRADE NAMES AND MANUFACTURERS' NAMES

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

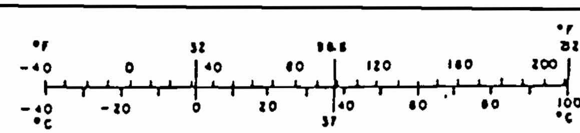
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SUMMARY

The purpose of this study is to develop specifications for using glass cullet in roadway construction. Glass cullet results from collecting and crushing post consumer glass containers. Using glass cullet in roadway construction avoids expensive sorting to prevent color contamination and presents an opportunity to use glass cullet as a construction aggregate and reduce landfill requirements. A number of other states and organizations have investigated the use of glass cullet in various aspects of construction. Specifications for using glass cullet for roadway construction in the state of Texas were developed in three phases: (1) Literature Review and Identification of Available Sources and Suppliers; (2) Laboratory Testing; and (3) Specification Development. An earlier report presented findings from Phase I, literature review and identification of available sources and suppliers *(1)*. This report covers Phase II, Laboratory Testing and Phase III, Specification Development.

Findings from the literature review revealed that a number of states have investigated the use of glass cullet in roadway construction and several have developed applicable specifications. An extensive study was performed by the Clean Washington Center and their publications served as a primary source of information for the study reported herein *(2,3,4,5,6,7)* . Specifications developed in other states were used as guidelines for developing specifications for the state of Texas. Only a limited number of suppliers were located in Texas. Samples from Texas suppliers were evaluated in limited laboratory testing and the samples were found to match well with glass cullet evaluated by the Clean Washington Center. The glass cullet samples obtained from Texas suppliers were found to be free of lead, a potentially toxic substance, and other hazardous materials. At the conclusion of Phase I, recommendations were presented for further laboratory testing and completion of the development of specifications. Originally, a life cycle cost analysis was planned for glass cullet as an alternative to conventional construction aggregate. However, any such life cycle cost analysis was deemed premature because the glass recycling industry is in the early stages of development.

Glass cullet received from the glass cullet supplier contained less than one percent debris. Debris consisted of paper, plastic and cork. Debris levels were varied from 0 percent to 1 percent by weight of glass cullet. Furthermore, glass cullet with various debris levels was blended with crushed limestone at various mix proportions. Laboratory testing included triaxial, permeability, compaction, wet ball mill, gradation and stripping tests. Draft specifications were prepared for embankments, base course, backfill, drainage materials and detour construction.

Both the Houston District and the Abilene District were identified as possible locations for a demonstration project. The primary Texas supplier of glass cullet is located in the Houston District. A supply of waste glass is available in the Abilene District, but requires crushing into cullet.

INTRODUCTION

The success of recycling collection programs has resulted in an oversupply of broken glass, or cullet, in many parts of the country *(2)*. Glass cullet is regarded as oversupplied because currently there is only one well established market for glass cullet, the glass container industry. Use of glass cullet in glass production batches is limited by a number of reasons including the following:

1. Color contamination. Glass cullet competes with virgin batch in the glass container industry at $60 per ton *(6)*. Using cullet also conserves energy and energy costs in glass making. However, supplying cullet to furnace-ready specifications requires expensive color sorting to avoid color contamination of the batch. Estimated costs of sorting the glass cullet are a substantial fraction of the supply costs.

2. Transportation costs. Cullet, because of its relatively high density, is expensive to transport long distances. Transportation costs often outweigh the market price of cullet as container batch.

A number of organizations and researchers have investigated the use of glass cullet in roadway construction *(8,9,10,11,12,13)*. Of the reports reviewed, the work by Miller and Collins *(8)*, and Larsen *(9)* are very helpful in describing technical opportunities and difficulties in using glass cullet as a construction aggregate. Miller and Collins investigated several waste materials as candidates for aggregates in a variety of construction roles. Larsen concentrated his efforts on glass cullet in pavement construction. Larsen noted poor adhesion between bitumen and glass aggregate. He cautioned against the use of glass aggregate in hot-mix asphaltic concrete. Furthermore, the glass aggregate tended to break when subjected to studded tires (not a problem in Texas) and resulted in pavement raveling. Larsen also reported difficulties with skid resistance and suggested glass aggregates only be used in low speed areas.

The Clean Washington Center conducted an investigation of glass as a construction aggregate to open new markets for cullet. The investigation was sponsored by several states and industries and performed by the Seattle office of Dames & Moore, Inc. States which participated in sponsoring this investigation included Arizona, California, Minnesota, New York and Oregon. The industries that sponsored this investigation were Browning-Ferris Industries and Waste Management of North America. The Clean Washington Center judges the study to represent the most exhaustive investigation of construction applications for cullet to date *(2)*. The four areas of concentration within the study are briefly presented below:

1. **Engineering Performance**. Cullet properties were compared to those of natural aggregate. From an engineering standpoint, cullet appears to be an excellent supplement or replacement for gravel in many construction applications.

2. **Environmental Impact**. Cullet was tested for harmful contaminants and their potential to leach over time. No appreciable environmental impact could be detected.
3. **Safety and Handling**. Since glass contains amorphous silica rather than crystalline silica, it does not pose the health risks associated with natural sand. While bottle cullet normally does not cause skin cuts, routine handling precautions are recommended.
4. **Economic Evaluation**. A number of factors such as collection, processing and transportation affect the costs of using cullet. In many cases, depending on local conditions, glass can be competitive in price or less expensive than utilizing conventional aggregates.

The Glass Feedstock Evaluation Project *(6)* is a comprehensive study and presents an excellent assessment of the use of glass cullet as construction aggregate in the United States. Items covered in the study include market conditions, sample selection and testing, environmental suitability evaluation, engineering suitability evaluation, an evaluation of equipment needed to process and handle the glass cullet, economic modeling, and safety hazards. The Clean Washington Center endorsed glass cullet as follows *(2)*:

> "Both laboratory analysis and equipment evaluation point to the technical and economic viability of using cullet as a construction aggregate feedstock. Cullet is strong, clean, safe and economical. Its benefits from an engineering standpoint include permeability, good compaction characteristics, and compatibility with conventional construction equipment. Many states, counties, municipalities and private contractors, in fact, have already approved cullet for use as construction aggregate and are conducting field trials."

Numerous specifications or supplemental specifications include provisions for glass cullet as a construction aggregate *(6)*. A partial list is presented below:

California	Amendment to 25-1.02A (Class 1, 2 or 3 Aggregate Subbases) Amendment to 26-1.02B (Class 2 Aggregate Base) Amendment to 26-1.02C (Class 3 Aggregate Base) Amendment to provisions in Section 26, Aggregate Base
Connecticut	1.01.01 Reclaimed Waste (definition) 2.02 Roadway Excavation, Formation of Embankment and Disposal of Surplus Material
National Standard Plumbing Code	Chapter 13 Storm Drains

New Hampshire	304.2.1	Materials
	304.2.3	Processed Glass Aggregate Gradation
	304.2.4	Processed Glass Aggregate/Base Course Blends
	304.3.1	Construction Requirements--General
	304.3.5	Material Testing
Pennsylvania		Waste Glass as Pipe Backfill
		Waste Glass as Embankment Material
Washington	Part 9-03	Aggregates
	9-03.21	Recycled Material (Allows up to 15 percent glass in most aggregates listed in Part 9-03. Permits only 10 percent of the material greater than 6 mm (1/4 inch) sieve size, based upon visual examination and weight)

The possibility of using glass cullet in roadway construction avoids expensive sorting to prevent color contamination and presents an opportunity to use glass cullet as an aggregate in parts of the state where aggregate sources are scarce. The purpose of this study is to review available literature to determine the feasibility of glass cullet as an economical alternative to aggregate in roadway construction. Sources and suppliers of glass cullet in Texas are also identified. The final objective is to develop specifications for using glass cullet in roadway construction. Laboratory testing was accomplished to support specification development. Several specifications for using glass cullet in roadway construction were developed. This report covers Phases II and III of the study, and concentrates on the laboratory testing and specification development.

PROBLEM STATEMENT

Post consumer glass containers are collected as part of many Texas communities' recycling efforts. Recycling this glass to produce new containers, however, faces several obstacles, namely: a limited number of Texas reprocessing facilities, mixed glass breakage and color contamination, low glass value, and high transportation costs.

The possibility of using glass cullet in roadway construction and maintenance projects exists and is worthy of investigation. Development of Texas Department of Transportation specifications for this project would also allow Texas municipal and county transportation entities to use glass cullet generated by their communities in roadway applications.

OBJECTIVES

The primary objective of this study is to identify sound engineering and environmental uses of glass cullet in roadway construction and maintenance projects and develop specifications for each successful use of glass cullet evaluated based on current TxDOT specifications. Development of specifications is the principal goal of the research. All activities within the research program are aimed at supporting the principal goal of developing specifications.

Specifications for using glass cullet in roadway construction will be developed through the following phases:

Phase I. Literature Review and Identification of Available Sources and Suppliers. Literature will be compiled and reviewed to prepare a clear, concise summary report on using glass cullet in roadway construction. The summary report will include: a recommendation of which glass cullet uses appear the most feasible and promising; potential disadvantages or obstacles to these uses; potential effects on future recyclability; and an economic analysis comparing the use of glass cullet with currently utilized materials for the selected applications (note: the economic analysis was deleted because the glass recycling industry is in early stages of development). The summary report will also include a description of available sources and suppliers in the state of Texas. Source and supplier information is needed for the economic analysis.

Phase II. Laboratory Testing. Laboratory testing will be accomplished to provide information not available from the literature search or to assure the accuracy of information found. Testing will focus on those problem areas identified by other researchers. Potential problems include poor adhesion properties, addition of hydrated lime to improve performance, poor skid resistance, and characteristics when used as a coarse aggregate. Additional laboratory testing will be used to assess the effectiveness of various polymer matrix materials and coupling agents to enhance the performance of glass cullet as aggregate for roadway construction and/or repair. Tests on a limited scale will be conducted using glass cullet as aggregate in patching materials to repair pavement damages or install small sections of demonstration projects.

Phase III. Specification Development. Specifications will be developed for each successful use of glass cullet evaluated during the course of this study. The specifications will be designed to fit current specification formats and requirements.

Reported herein are the findings from Phases II and III, Laboratory Testing and Specification Development.

PROJECTED USES FOR GLASS CULLET

Findings of Phase 1 of this research study revealed that the feasibility of using glass cullet as a construction aggregate existed and was worth investigating. Table 1 indicates the applications in highway construction that were identified in this research for possible use of glass cullet. These applications were selected from the TxDOT Standard Specification for Construction of Highways, Streets and Bridges *(14)*.

Table 1. Possible Uses for Glass Cullet Based on Existing TxDOT Specifications.

TxDOT Specification Item No.	Description
132	Embankment Fill
247	Flexible Base
345	Asphalt Stabilized Base
400	Backfill and Bedding for Structures
508	Constructing Detours
556	Pipe Underdrains - Filter Material

Detour construction (TxDOT Specification Item No. 508) was included in this list because it involves the construction of temporary structures. Glass cullet may be a candidate material for many items involved with detours including the other items listed in Table 1 above.

A large database of laboratory results on the properties of glass cullet was available from the Clean Washington Center Study *(3,4,5)*. Information from this study were summarized in the Phase I Interim Report of this study *(1)*. It was decided that the laboratory tests that are required for uses identified in Table 1 will be performed in this research. Tables 2 to 8 indicate the tests to be performed for each identified use as per the TxDOT specifications.

Table 2. Laboratory Tests Required by TxDOT for Embankments (Item 132).

Tests Required by TxDOT Specifications	Tests Performed for This Research
TEX-104-E - Determination of Liquid Limit of Soils **TEX-105-E** - Determination of Plastic Limit of Soils **TEX-106-E** - Method for calculating PI of Soils **TEX-107-E** - Determination of Shrinkage Factor of Soils	None

Table 3. Laboratory Tests Required by TxDOT for Flexible Base (Item 247).

Tests Required by TxDOT Specifications	Tests Performed for This Research
TEX-103-E - Determination of Moisture Content of Soils **TEX-104-E** - Determination of Liquid Limit of Soils **TEX-106-E** - Method for calculating PI of Soils **TEX-107-E** - Determination of Shrinkage Factor of Soils **TEX-110-E** - Determination of Particle Size Analysis of Soils **TEX-113-E** - Determination of Moisture Density Relations of Soils and Base Materials **TEX-115-E** - Field Method for Determination of In Place Density of Soils and Base Materials **TEX-116-E** - Wet-Ball Mill Method for Determination of the Disintegration of Flexible Bases **TEX-117-E** - Triaxial Compression Test for Disturbed Soils and Base Materials **TEX-204-F** - Design of Bituminous Mixtures **TEX-460-A** - Particle Count	TEX-110-E TEX-113-E TEX-116-E TEX-117-E TEX-204-F

Table 4. Laboratory Tests Required by TxDOT for Aggregates to be Used in Asphalt Concrete. (Item 3063).

Tests Required by TxDOT Specifications	Tests Performed for This Research
TEX-106-E - Method for calculating PI of Soils **TEX-110-E** - Determination of Particle Size Analysis of Soils **TEX-217-F** - Determination of Deleterious Material and Decantation for Coarse Aggregate **TEX-404-A** - Determination of unit weight of aggregate **TEX-410-A** - LA Abrasion Test **TEX-411-A** - Soundness of Aggregate using Na_2SO_4 and $MgSO_4$ **TEX-431-A** - Pressure Slaking Test for Coarse Aggregate **TEX-432-A** - Coarse Aggregate Freeze Thaw Test **TEX-433-A** - Absorption of Dry Bulk Specific Gravity of Synthetic Coarse Aggregate **TEX-438-A** - Accelerated Polish Value Test for Coarse Aggregate **TEX-460-A** - Particle Count	TEX-110-E

Table 5. Laboratory Tests Required by TxDOT for Aggregates in Asphalt Stabilized Base (Item 345).

Tests Required by TxDOT Specifications	Tests Performed for This Research
TEX-104-E - Determination of Liquid Limit of Soils **TEX-106-E** - Method for calculating PI of Soils **TEX-116-E** - Wet-Ball Mill Method for Determination of the Disintegration of Flexible Bases **TEX-203-F** - Sand Equivalent Test **TEX-410-A** - LA Abrasion Test	TEX-116-E

Table 6. Laboratory Tests Required by TxDOT for Backfill Material in Structures (Item 400).

Tests Required by TxDOT Specifications	Tests Performed for This Research
None	None

Table 7. Laboratory Tests Required by TxDOT for Retaining Wall Backfill Material (Item 423).

Tests Required by TxDOT Specifications	Tests Performed for This Research
TEX-106-E - Method for calculating PI of Soils **TEX-117-E** - Triaxial Compression Test for Disturbed Soils and Base Materials **TEX-128-E** - Determination of soil pH	TEX-117-E TEX-128-E

Table 8. Laboratory Tests Required by TxDOT for Pipe Underdrain Filter Material (Item 556).

Tests Required by TxDOT Specifications	Tests Performed for This Research
TEX-110-E Determination of Particle Size Analysis of Soils	TEX-110-E

LABORATORY TESTING

Samples of glass cullet were received from the Houston waste glass processing center of Allwaste Recycling, Inc. Allwaste Recycling is the biggest waste glass operator in Texas, and also one of the major waste glass operators in the country. Glass cullet from Allwaste recycling was used in the laboratory testing program because their processing operation was considered as state of the art for such a facility. This glass cullet was inspected and it was noted that it contained some debris in the form of pieces of plastic, paper and cork. During field visits to the Allwaste waste glass processing center in Houston, it was observed that steps are taken to remove much of the debris coming from bottle caps, labels and corks. However Allwaste Recycling sources indicated that if the remaining debris were to be removed, the cost of glass cullet would be very high making it less viable as a road construction material.

Test Factorial

A laboratory test factorial was designed by incorporating the tests identified in Tables 2 to 8. The percent glass cullet to be used in the applications and the percent debris included in the glass cullet were selected as the test parameters. Table 9 indicates the test factorial used in the laboratory testing program. The cullet content is expressed as a percentage of the total material used and the debris level is expressed as a percentage of the weight of cullet.

Table 9. Test Factorial for Laboratory Tests on Glass Cullet.

Cullet Content (%)	Debris Level (%)	Triaxial Test Tex-117-E	Permeability Test ASTM D-2434	Compaction Test Tex-113-E	Wet Ball Mill Test Tex-116-E	Gradation Test Tex-110-E	Stripping Test on HMAC Tex-530-C
0 (control)	0.0	X		X	X	X	X
5	0.0					X	X
5	0.5	X		X			
5	1.0						
10	0.0			X		X	
10	0.5	X		X			
10	1.0	X		X			
20	0.0					X	
20	0.5	X		X	X		
20	1.0						
50	0.0		X			X	
50	0.5		X				
50	1.0		X				
100	0.0		X		X	X	
100	0.5						
100	1.0						

A glass cullet content of 5 percent was earmarked for use as an aggregate substitute in hot mix asphalt concrete. Glass cullet contents of 10 and 20 percent were earmarked for structural fill such as base materials, subbase materials and structural backfill. Glass cullet contents of 50 and 100 percent were earmarked for applications such as drainage filter material, non-structural embankment fill and pipe bedding and backfill materials. Therefore, tests were conducted not only on glass cullet, but blends of glass cullet and a conventional granular material as well.

Crushed limestone from the Fordyce Company Brownwood pit was used as the conventional granular material. This is a source of flexible base material approved by TxDOT. The gradation of crushed limestone is given in Table 10 and plotted in Fig. 1. The gradation indicates that the material is deficient in the sizes finer than the #40 sieve.

Table 10. Gradation of Limestone From Fordyce Company Brownwood Pit.

Sieve Size	Percent Passing	Individual Percent Retained	Cumulative Percent Retained
1.5 in.	100.00	0.00	0.00
1.25 in.	98.37	1.63	1.63
7/8 in.	88.37	10.00	11.63
5/8 in.	74.89	13.48	25.11
3/8 in.	53.86	21.03	46.14
#4	45.26	8.60	54.74
#10	31.84	13.42	68.16
#20	14.83	17.01	85.17
#40	4.70	10.13	95.30
#60	2.63	2.07	97.37
#100	1.03	1.60	98.97
#200	0.27	0.76	99.73

Preliminary Evaluation of Glass Cullet from Allwaste Recycling, Inc.

Tests were performed on the glass cullet received from Allwaste Recycling Inc. to determine its debris level and the gradation. In order to find the debris level in glass cullet, debris was first removed using a simple but effective procedure. First, glass cullet was dried in an oven at 140 °F for 24 hours. This was necessary to loosen the debris such as paper which were stuck onto the glass particles. Then cullet was soaked in water for 24 hours. Much of the debris was paper and it floated on water. The debris was then removed by washing over a #200 sieve. It was possible to remove virtually all the debris from glass cullet in this manner. It was revealed that debris level in glass cullet was 0.62 percent by weight of cullet. In the Clean Washington Center study *(2)*, debris level was estimated on a volumetric basis using the American Geological Institute Visual Method *(15)*. Gradation data on glass cullet is shown in Table 11 and Fig. 2.

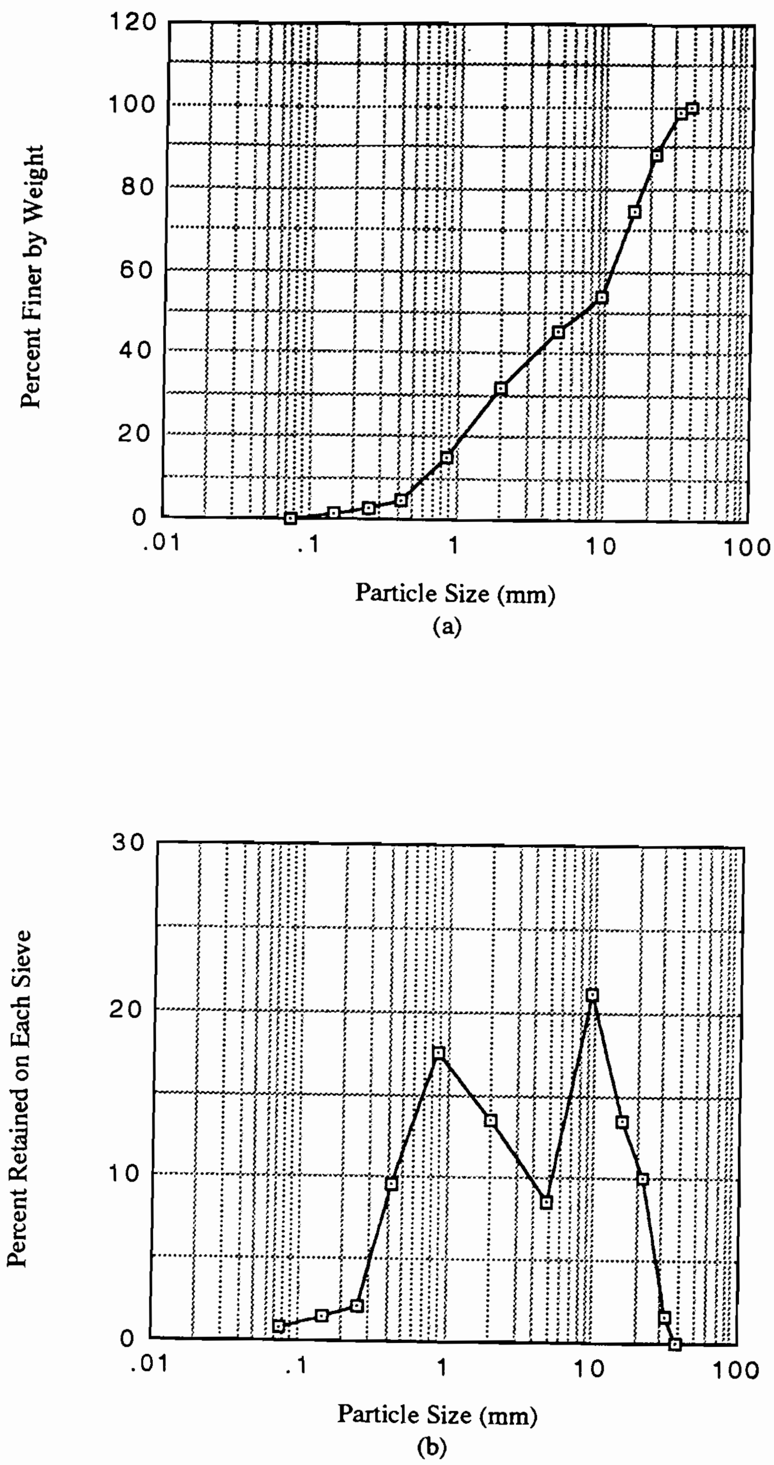


Fig. 1. Gradation of Limestone from Fordyce Company, Brownwood Pit (a) Cumulative Percent Passing (b) Individual Percent Retained.

Table 11. Gradation of Glass Cullet from Allwaste Recycling, Inc.

Sieve Size	Percent Passing	Individual Percent Retained	Cumulative Percent Retained
3/8 in.	96.20	3.80	3.80
#4	62.80	33.40	37.20
#10	28.76	34.04	71.24
#20	12.77	15.99	87.23
#40	5.63	7.14	94.37
#60	3.14	2.49	96.86
#100	1.33	1.81	98.67
#200	0.47	0.86	99.53
Pan	-	0.47	100.00

Blending of Glass Cullet and Crushed Limestone

Four blends of glass cullet and limestone were used in the laboratory test program. These gradations are given in Table 12 and plotted in Fig. 3. The gradation of Blends 1 and 2 nearly met the master grading requirements for Grade 1 flexible base materials *(14)* except for the #40 sieve size. Even this sieve size may have satisfied the gradation criteria had the original crushed limestone met the requirements for the same #40 sieve size.

Table 12. Gradations of Blended Crushed Limestone-Glass Cullet Mixes.

Sieve Size	Blend 1: 5% Glass Cullet and 95% Limestone	Blend 2: 10% Glass Cullet and 90% Limestone	Blend 3: 20% Glass Cullet and 80% Limestone	Blend 4: 50% Glass Cullet and 50% Limestone
1.5"	0	0	0	0
1.25"	1.549	1.470	1.304	0.815
7/8"	11.049	10.470	9.304	5.815
5/8"	23.855	22.600	20.088	12.555
3/8"	44.023	41.910	37.672	24.970
#4	53.863	52.990	51.232	45.970
#10	68.314	68.470	68.776	69.700
#20	85.777	85.850	86.006	86.465
#40	95.254	95.210	95.114	94.835
#60	97.345	97.320	97.268	97.115
#100	98.955	98.940	98.910	98.820
#200	99.720	99.710	99.690	99.630

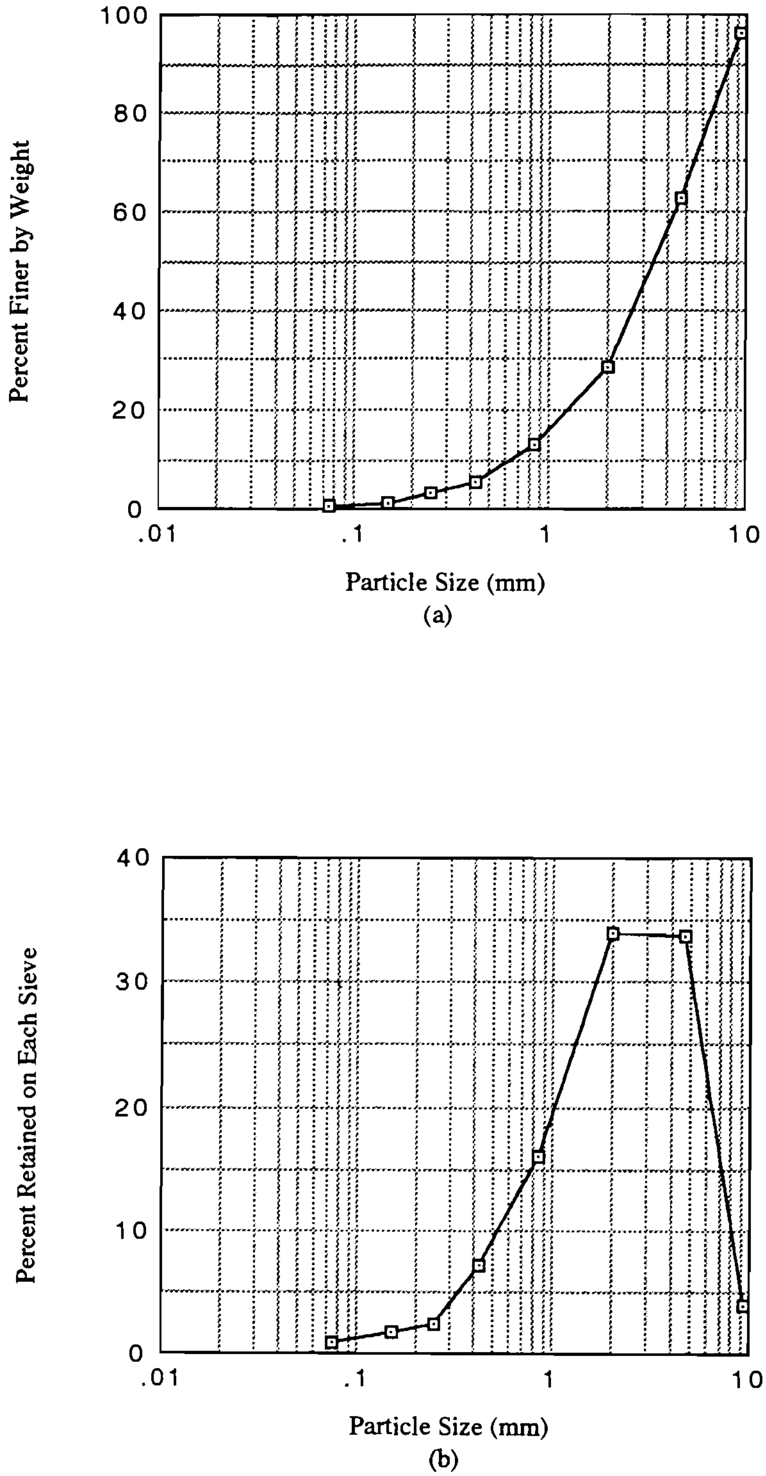


Fig. 2. Gradation of Glass Cullet Received from Allwaste Recycling, Inc., Houston (a) Cumulative Percent Passing (b) Individual Percent Retained.

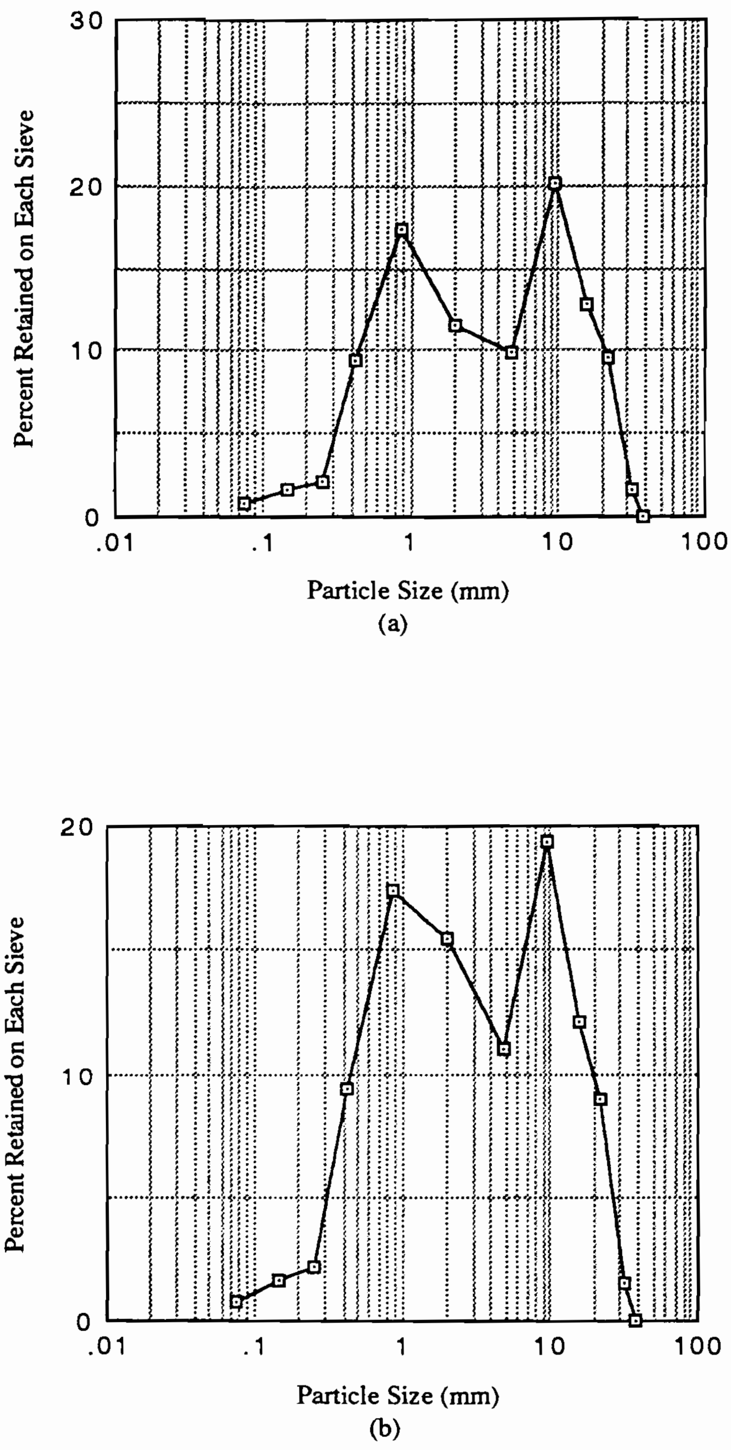
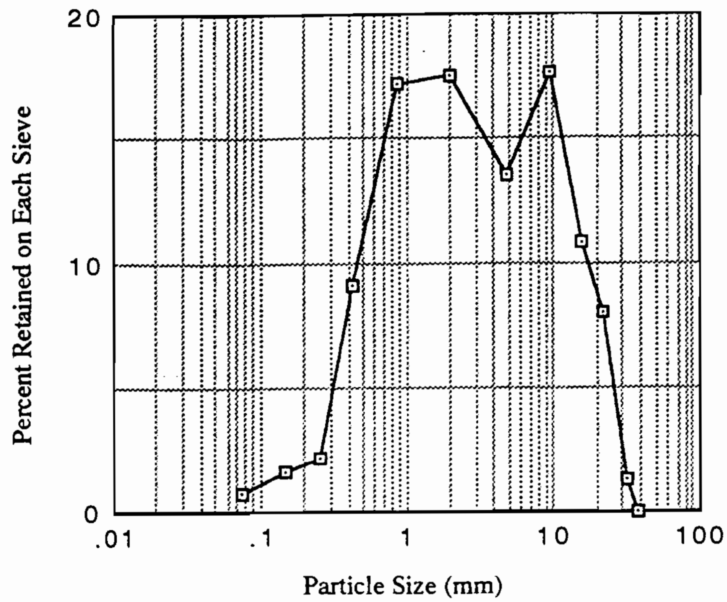
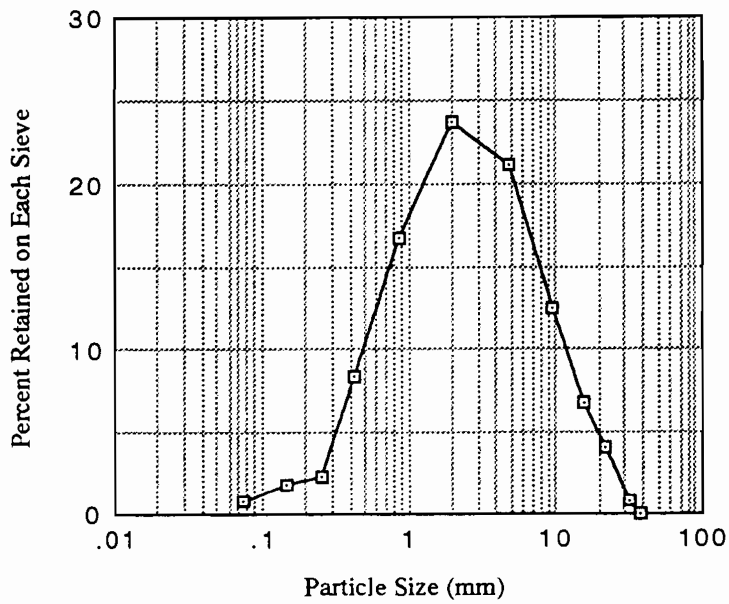


Fig. 3. Gradations of Limestone-Glass Cullet Blends: (a) Blend 1 (b) Blend 2.



(c)



(d)

Fig. 3 Continued. Gradations of Limestone-Glass Cullet Blends: (c) Blend 3 (d) Blend 4.

Laboratory Tests Performed on Materials Containing Glass Cullet

Compaction Test

TxDOT standard test procedure Tex-113-E was adopted for this test *(16)*. Tests were conducted at the laboratories of Texas Tech University Civil Engineering Department. The compaction test was performed for 100% limestone aggregate (control test), and blends of glass cullet and limestone with 5, 10 and 20 percent glass cullet in the total mix. For 10 percent glass cullet blend, tests were performed at 0, 0.5 and 1.0 percent debris by weight of cullet to evaluate the effect of debris level on compaction characteristics. Tests were also performed for 5 and 20 percent cullet blends at a debris level of 0.5 percent. A control test with only limestone was performed to compare the effects of having glass cullet in the material. This test factorial enables the evaluation of the effects of glass cullet, different quantities of glass cullet and the debris level on compaction characteristics of the material. Compaction test for 100 percent cullet was not performed since it was envisaged that 100 percent glass cullet will not be used as a structural fill material. Compaction specimens were subjected to 112 blows per layer for four layers using a hammer falling from a height of 18 inches. Results from the compaction test are shown in Table 13. The related compaction curves are illustrated in Figs. 4-9.

Table 13. Compaction Test Results on Limestone and Limestone/Glass Cullet Blends.

Test No.	Material Composition	Optimum Moisture Content (%)	Dry Density kg/m^3 (lb/ft^3)
1	100% limestone with 0% debris	5.8	2402.8 (150.0)
2	95% limestone and 5% cullet (Blend 1) with 0.5% debris	6.6	2322.7 (145.0)
3	90% limestone and 10% cullet (Blend 2) with 0.5% debris	6.6	2305.1 (143.9)
4	80% limestone and 20% cullet (Blend 3) with 0.5% debris	6.6	2313.1 (144.4)
5	90% limestone and 10% cullet (Blend 2) with 0% debris	6.0	2338.7 (146.0)
6	90% limestone and 10% cullet (Blend 2) with 1% debris	5.6	2351.5 (146.8)

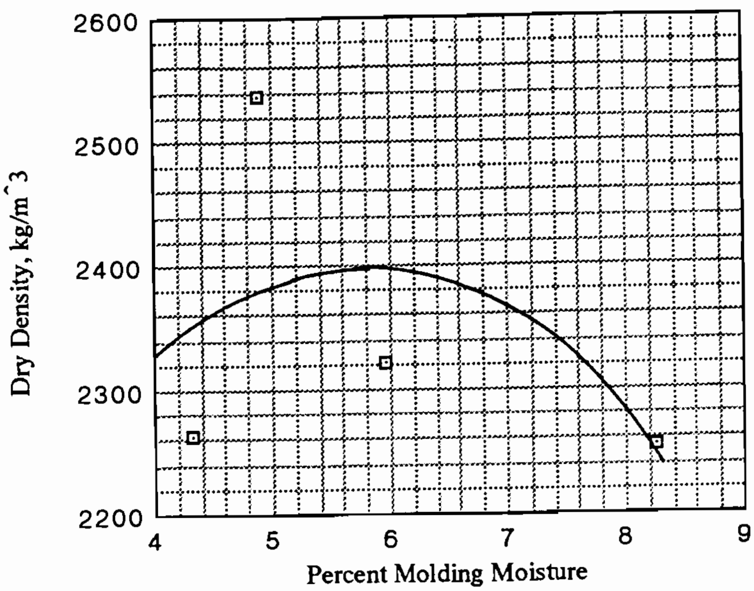


Fig. 4. Compaction Curve for 100% Limestone.

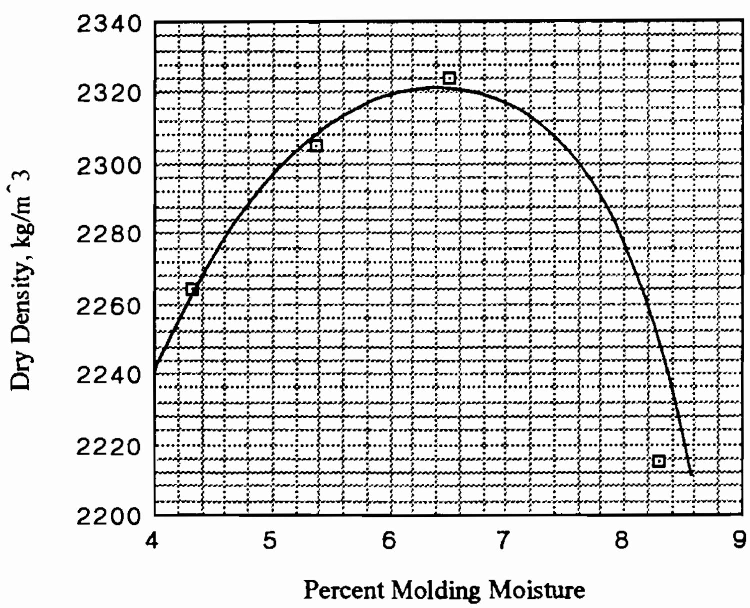


Fig. 5. Compaction Curve for Blend 1 With 0.5% Debris.

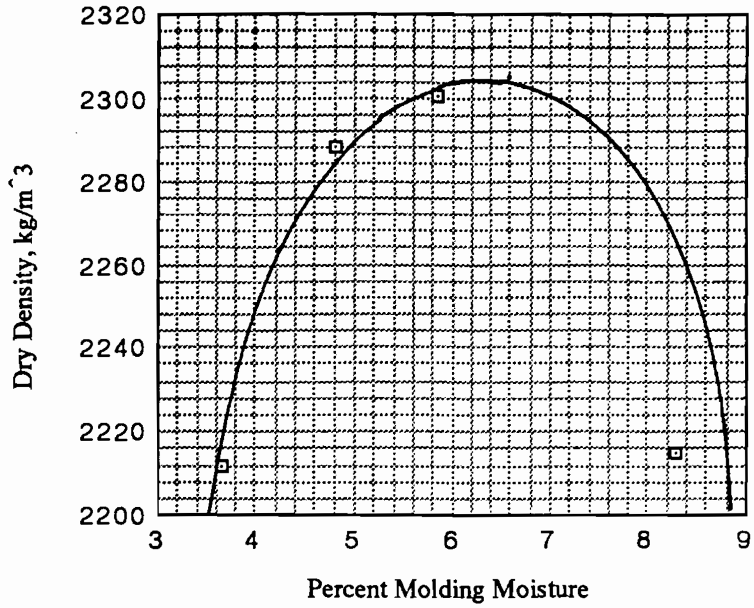


Fig. 6. Compaction Curve for Blend 2 With 0.5% Debris.

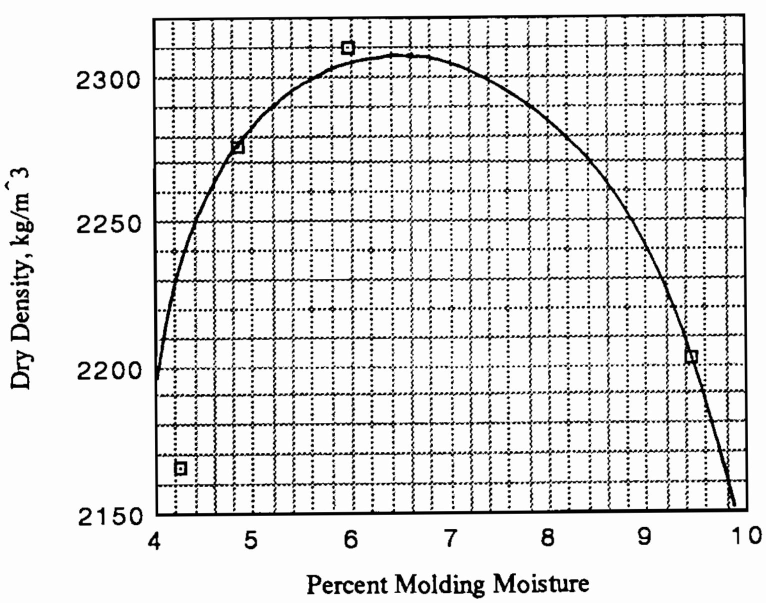


Fig. 7. Compaction Curve for Blend 3 With 0.5% Debris.

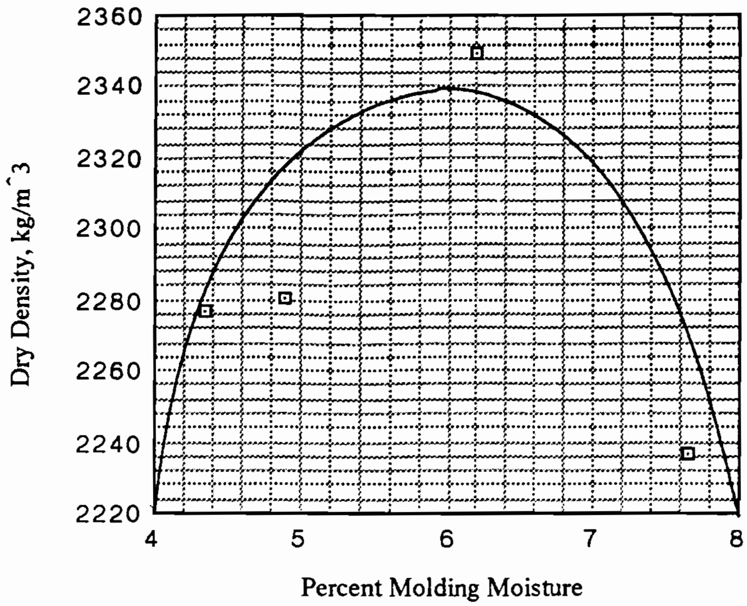


Fig. 8. Compaction Curve for Blend 2 With 0% Debris.

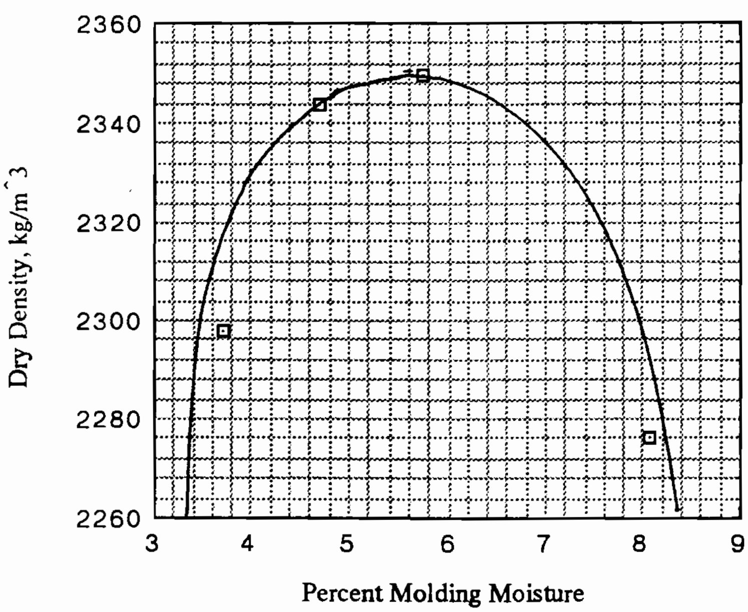


Fig. 9. Compaction Curve for Blend 2 With 1.0% Debris.

Texas Triaxial Test

The Texas Triaxial Test was performed at the Lubbock district laboratory of the Texas Department of Transportation, according to TxDOT standard laboratory procedure Tex-117-E *(16)*. This test was performed to determine the shearing resistance of the granular material containing glass cullet. The test consists of applying an axial load to a molded cylindrical specimen to failure at several lateral pressures. It was decided to test the specimens with glass cullet contents of 5, 10 and 20 percent and keeping the debris level constant at 0.5 percent by weight of the glass cullet material. A 10 percent cullet-90 percent limestone blend was also tested with 1 percent debris in cullet because the gradation of 10/90 percent cullet/limestone blend met the master grading requirements for Grade 1 flexible base material *(14)*.

Due to the excessive work load in the TxDOT laboratories, only three specimens were made at the optimum moisture content instead of the usual seven. Prior to testing, the specimens were subjected to capillarity overnight. The three specimens were tested until failure at lateral pressures of 0 and 15 psi. The results from these tests are shown in Tables 14-16.

Table 14. Maximum Corrected Stress for Glass Cullet With 0.5 % Debris.

Lateral Pressure kPa (psi)	Blend 1: 5% Cullet and 95% Limestone kPa (psi)	Blend 2: 10% Cullet and 90% Limestone kPa (psi)	Blend 3: 20% Cullet and 80% Limestone kPa (psi)
0	73.1 (10.6)	35.9 (5.2)	60.7 (8.8)
0	62.7 (9.1)	40.0 (5.8)	40.0 (5.8)
103.42 (15)	1147.3 (166.4)	1143.2 (165.8)	1183.8 (171.7)

Table 15. Maximum Corrected Stress for Blend 2 With 1.0 % Debris.

Lateral Pressure kPa (psi)	Blend 2: 10% Glass Cullet and 90% Limestone kPa (psi)
0	37.9 (5.5)
0	55.9 (8.1)
103.42 (15)	1183.1 (171.6)

Table 16. Maximum Corrected Stress for 100 % Crushed Limestone.

Lateral Pressure kPa (psi)	0% Glass Cullet and 100% Limestone kPa (psi)
0	25.5 (3.7)
0	70.3 (10.2)
103.42 (15)	1236.9 (179.4)

Texas Degradation (Wet-Ball Mill) Test

This test was performed at the laboratories of Texas Tech University Civil Engineering Department according to the TxDOT standard test procedure Tex-116-E *(16)*. Three aggregate blends were used to compare the effect of glass cullet on the aggregate degradation potential. Aggregates comprising of 100 percent limestone, 100 percent glass cullet and a 10/90 percent blend of glass cullet and limestone were tested. The results indicating the Wet Ball Mill (WBM) value and the maximum increase of material passing the #40 sieve are given in Table 17.

Table 17. Results from Wet Ball Mill Tests on Various Aggregate Blends.

Test No.	Material Composition	WBM Value	Max. Increase of Material Passing #40 Sieve
1	100% limestone	27.5	57.42
2	100% glass cullet	10.9	22.62
3	10% cullet and 90% aggregate blend with 0.5% debris	37.1	14.94

Permeability Test (ASTM D-2434)

The permeability test was performed according to the ASTM D-2434 test procedure *(17)*. This test was aimed at evaluating the use of glass cullet as a filter material in underdrains. It was envisaged that a high percentage of glass cullet could be used in such material and therefore, the material tested consisted of both 100 percent glass cullet as well as a 50/50 blend of glass cullet and conventional granular material. Only the 50/50 blend satisfied the gradation requirements stipulated for Type B filter materials in TxDOT specification in item 556(2) for pipe underdrain filter material. The pH value of the water entering and leaving the glass cullet material in this test equipment was measured to assess the change in the chemical characteristics of water. Results from this test are shown in Table 18.

Table 18. Permeability and pH Value Test Results.

Test No.	Material Composition	Permeability at 20 °C (cm/sec)	pH of Water Before Test	pH of Water After Test	Change in pH
1	50% cullet and 50% limestone with 0% debris	0.083	7.296	8.118	0.822
2	50% cullet and 50% limestone with 0.5% debris	0.011	7.296	7.780	0.484
3	100% cullet with 0% debris	0.051	7.296	7.360	0.064

Evaluation of Stripping in Asphalt Concrete With Glass Cullet as an Aggregate

This test was performed according to the TxDOT standard test procedure Tex-530-C *(16)*. The asphalt concrete mix design was performed according to TxDOT QC/QA standard procedure 3063 for asphalt stabilized base with Type A gradation. Therefore, the mix design incorporated the Type A gradation recommended for asphalt stabilized bases in the mix design procedure 3603.

Mix Design for Type A Coarse Base

The mix design was performed according to TxDOT standard test procedure Tex-204-F *(16)*. These tests were conducted at the Lubbock district laboratories of the Texas Department of Transportation. The mix design was performed using an aggregate blend of 5 percent glass cullet and 95 percent limestone by weight of total aggregate mix. Also, the standard anti-stripping agent used by the Lubbock district, Kling Beta 2550, was included in the mix design. Results from the mix design are given in Table 19.

Table 19. Data from Mix Design Based on Aggregate Blend 2 (95% Limestone/5% Glass Cullet).

Parameter	Design Value
Optimum Asphalt Content, percent	3.9
Effective Specific Gravity	2.663
VMA at Optimum Asphalt Content, percent	13.0

Asphalt Stripping Test

The Asphalt Stripping Test was performed according to TxDOT standard test procedure Tex-530-C *(16)*. The tests were conducted at the Lubbock district laboratories of TxDOT. The performance of four anti-stripping agents were evaluated in the presence of glass cullet in the aggregate. The four anti-stripping agents were hydrated lime, Kling-Beta 2550, Siloxane and a mix of Kling-Beta 2550 and Siloxane in equal proportions. Kling-Beta 2550 is the antistripping agent currently being used by the Lubbock District of TxDOT. The results from these tests which were provided by TxDOT laboratory personnel are given in Table 20.

Table 20. Results from the Antistripping Tests on Hot Mix Asphalt.

Test No.	Mix	Antistripping Agent Used	Percent Antistripping Agent Used	Estimated Percent Stripping
1	95% Limestone and 5% cullet	Lime	0.5	10
2	95% Limestone and 5% cullet	Kling-Beta	0.5	5
3	95% Limestone and 5% cullet	Siloxane	0.5	0
4	95% Limestone and 5% cullet	Kling-Beta & Siloxane	0.25+0.25	7

Discussion of Test Results

Evaluation of Glass Cullet Received from Allwaste Recycling Inc., Houston

The glass cullet tested in this laboratory test program came from the Allwaste plant in Houston. Allwaste Recycling, Inc. is currently in the business of providing clean waste glass cullet to the glass container manufacturing industry. They primarily provide clear and amber glass to the glass container manufacturers. The price of plant ready glass cullet run as high as $60 per ton. Allwaste recycling has small scale suppliers who provide them with color sorted glass. The current market price for color sorted glass containers appear to be around $30 per ton. This glass is cleaned, crushed, and again cleaned at the Allwaste plant in Houston before they are shipped to the glass container manufacturing facility. Currently, the glass recycling market supply infrastructure is geared towards this scenario.

The gradation of glass cullet tested in this research (Table 11) shows a maximum cullet size of 5/8 inches. Much of the glass cullet (approximately 70 percent) was retained on the #10 sieve. It was also observed that the fine fraction (passing #40 sieve) was quite low (less than 5 percent). Debris in the glass cullet was found to be 0.62 percent by weight of glass cullet. Debris in glass cullet can be in the form of paper, plastic, metal caps etc. This glass cullet sample had much of its debris in the form of paper.

Tests on Material Containing Glass Cullet

Compaction Test

The compaction test was performed to evaluate the effect of glass cullet and debris level in glass cullet on the compaction parameters. The results given in Table 13 show that the addition of up to 20 percent glass cullet did not have any noticeable effect on the optimum moisture content and the dry density of the material. It can be expected that the optimum moisture content would decrease with increasing glass cullet content. However, this was not observed since the optimum moisture content for 100 percent crushed limestone using the best fit curve was calculated at 5.8 percent. It is believed that if there was not much scatter in the plot (Fig. 4) for 100 percent limestone, the optimum moisture content for crushed limestone may have been even higher than for aggregate blends containing glass cullet.

Texas Triaxial Test

Results from the Texas Triaxial Test give the maximum corrected stress for the sample tested. No appreciable change in the maximum corrected stress was observed for samples with different amounts of glass cullet up to 20 percent. Therefore, it was concluded that glass cullet up to 20 percent can be mixed with conventional granular material for use in structural fills without compromising the strength of the material. Such applications may include base and subbase layers as well as load bearing structural backfill. Furthermore, no appreciable change was observed in the triaxial strength for different levels of debris in the glass cullet.

Wet Ball Mill Test

Results from the Wet Ball Mill Test (Table 17) provide information regarding the disintegration potential of the material in the presence of water. The Wet Ball Mill Value for 100 percent glass cullet material is quite low indicating that it does not break that easily while subjected to moving loads in the presence of water. The amount of material in glass cullet that pass through the #40 sieve before the test was a low 5 percent. A Wet Ball Mill Value of 10.9 is quite favorable for use as in a flexible base. This is probably due the fact that the glass cullet does not have particles larger than 5/8 inches. The Wet Ball Mill values for conventional crushed limestone and a blend of 90 percent/10 percent limestone-glass cullet mix were found to be 27.5 and 37.1 respectively. Considering the hardness values of crushed limestone and glass cullet, one would expect to see a reduction in the Wet Ball Mill value when limestone is blended with glass cullet. However, an increase in the Wet Ball Mill Value to 37.1 indicate that glass cullet probably enhances the degradation potential of limestone. The reason for this phenomenon may be that the sharp glass cullet particles are driven into the limestone particles thus enhancing the degradation of limestone. Nevertheless, aggregate blends of glass cullet and crushed limestone proved to be within TxDOT specifications wet ball mill test results *(14)*.

Permeability Test

Results from the Permeability Test (Table 18) show that 100 percent glass cullet aggregate which did not meet the Type B underdrain filter material gradation requirement as in TxDOT specification Item 556.2(2), has a permeability comparable to the 50/50 percent cullet/limestone blend which satisfied the gradation requirements *(8)*. The increase in the pH value was more noticeable for material containing limestone. The pH for 100 percent glass cullet virtually remained the same. This is probably an indication that the pH increase in tests 1 and 2 were due to the presence of limestone.

Hot Mix Asphalt Concrete Stripping Test

This test was performed to determine the degree of stripping in asphalt concrete between glass cullet particles and the asphalt cement. Researchers from the Chemical

Engineering Department at Texas Tech University tested the effectiveness of a new silane based material, siloxane, as an antistripping agent. In the asphalt stripping test Tex-530-C, the amount of stripping is determined by the naked eye. This makes the test a subjective one. Therefore, the test was performed by experienced professionals in the TxDOT district laboratory in Lubbock. The stripping test results (Table 20) indicate that while hydrated lime and Kling Beta 2550 led to stripping, the mix which contained Siloxane as the antistripping agent showed no stripping at all. Therefore, Siloxane appear to be a very good antistripping agent when glass cullet is used as aggregate in asphalt concrete.

SPECIFICATIONS FOR USING GLASS CULLET

During the first phase of the research program *(1)*, a number of state DOT's were contacted to determine their experience with the use of glass cullet in roadway construction, and if they have developed specifications for the use of glass cullet. Several other state DOT's were identified to have experimented with glass cullet use in roadway construction. A number of these state DOT's already had specifications developed for such use *(18,19,20,21,22,23,24,25,26)*. These findings are presented in the Phase I report of this research *(1)*.

Based upon state DOT specifications found in the Phase 1 research and laboratory test results reported in the previous section, several specifications were developed for using glass cullet in roadway construction. A list of specifications developed is given in Table 21 and detailed specifications as additions or amendments to existing specification items are given in the appendix.

Table 21. Specifications Developed for Use of Glass Cullet In Roadway Construction

Specification Item	Description of Use
132	Embankments
247	Flexible Base
301	Asphalt Antistripping Agent
340	Hot Mix Asphaltic Concrete Pavement
345	Asphalt Stabilized Base (Plant Mix)
400	Excavation and Backfill Structures
423	Retaining Wall
556	Pipe Underdrains
Other	Open Graded Base Course

DEMONSTRATION PROJECT

Both the Houston District and Abilene District are possible locations for a demonstration project. Allwaste Recycling is located in Houston and can be used as a nearby source of glass cullet thus alleviating expensive transportation costs. Texas Tech researchers met with TxDOT personnel from the Houston District to discuss possible demonstration projects. Several potential applications were identified including projects requiring base material, leveling course, bond breaker and pipe underdrains. Using glass cullet as a backfill material was not considered viable because of requirements within the Houston District to stabilize backfill with cement. Cement reacts adversely with glass *(10)*. Engineers from the Houston District are willing to include glass cullet as a material in a construction project.

The Abilene District is another possible location for a demonstration project. Although there is no glass recycling facility near Abilene, a significant quantity of waste glass is reported to be available in close proximity. A glass crushing operation would be required either at the construction site or nearby in order to produce cullet for the demonstration project. Otherwise, the waste glass must be shipped to a crushing facility for processing and then returned to Abilene for application. The Project Director, Mr. David Casteel, is the Design Engineer for the Abilene District and is familiar with the specifications developed within this research program.

CONCLUSIONS AND RECOMMENDATIONS

In the previous phase of research, a literature review was completed on the use of glass cullet in roadway construction, available sources and suppliers in Texas were identified and samples from Texas suppliers were compared with samples used in investigations by other states. A laboratory test plan was presented and accepted along with recommendations for specification development.

With TxDOT approval of recommendations from Phase 1, glass cullet from a Texas glass recycling facility was characterized in laboratory testing and specifications for using the cullet as a construction material were developed. TxDOT agencies were contacted for possible demonstration projects and the two districts contacted (Houston and Abilene) have expressed their willingness to use cullet in planned construction projects.

Recommendations from laboratory testing and specification development are as follows:

- Include the draft specifications developed within this research in TxDOT construction practices

- Select a construction project for demonstrating the use of glass cullet in roadway construction and complete the necessary design and construction

- Evaluate the long term performance of projects using glass cullet as a construction material

- Develop procedures to improve the performance of glass cullet as a construction material

It should be noted that much of the existing glass recycling efforts are all geared towards the glass container manufacture. Since such glass recycling efforts require color sorting of glass, the existing cullet prices are not realistic for the potential highway construction market for which expensive color sorting is not required. It can also be anticipated that when new markets for glass cullet such as roadway construction is developed, the glass recycling level in Texas would potentially increase from the current 10 percent rate and possibly drive down the cullet prices even more.

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APPENDIX

Specifications for Using Glass Cullet in Roadway Construction

<u>Note:</u>
The following specifications need to be added to the relevant sections of the prevailing TxDOT Standard Specifications for Construction of Highways, Streets and Bridges. These amendments/additions were based on the contents and format of the 1993 issue of the specification.

Item 132

EMBANKMENTS

132.2 Material.

Type E. This material shall consist of suitable recycled waste material such as crushed waste container glass cullet (referred to as glass cullet), which are free from vegetation and other objectionable matter and reasonably free from lumps of earth. The glass cullet shall also be free of hazardous products and the contractor is responsible for furnishing the engineer with documentation certifying that the glass cullet complies with Class 3 industrial waste requirements in accordance with 30 TAC 335.507. The source shall be approved by the engineer prior to use.

This material shall be suitable for forming a stable embankment and, when tested in accordance with Test Methods Tex-104-E, Tex-105-E, Tex-106-E, and Tex-107-E, Part II, and Tex-110-E shall meet the following requirements:

The liquid limit shall not exceed	45
The plasticity index shall not exceed	15
The bar linear shrinkage shall not be less than	2

The glass cullet material shall conform to the following grading unless shown otherwise in plans.

Sieve Size	Cumulative Percent Retained on Sieve
5/8 in.	0
3/8 in.	0-10
No. 4	30-50
No. 10	50-75
No. 40	80-90
No. 200	90-100

Glass cullet may be used as an embankment material but only in combination with Type A, Type B, Type C or Type D embankment materials approved by the engineer. The maximum percentage of glass cullet in the embankment material mix shall not exceed 20 percent by weight of mix.

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet used as an embankment material shall not exceed 5 percent as estimated using the American Geological Institute Visual Method.

132.3 Construction Methods

(1) General.

Since all glass cullet material used in embankments shall not exceed 5/8 in., the material should be relatively safe to handle. However, precautions shall be taken for the safety of the construction personnel. When glass cullet is used in combination with other types of approved embankment materials, they shall be mixed thoroughly until a uniform mix is achieved to the satisfaction of the engineer.

Embankment material containing glass cullet shall not be used on the surface of the embankment unless it is indicated in plans or without the approval of the engineer.

Item 247

FLEXIBLE BASE

247.2 Material.

(2) Physical Requirements.

(e) Type D. Type D flexible base material shall be recycled waste material such as crushed waste container glass (glass cullet) used in combination with Type A, Type B or Type C flexible base materials. Glass cullet shall be free from vegetation and other objectionable matter and reasonably free from lumps of earth. The glass cullet shall also be free of hazardous products and the contractor is responsible for furnishing the engineer with documentation certifying that the glass cullet complies with Class 3 industrial waste requirements in accordance with 30 TAC 335.507. The source shall be approved by the engineer prior to use. Glass cullet shall only be used as flexible base in pavements that will be surfaced prior to opening for traffic.

The percentage of glass cullet used in Type D flexible base material shall not exceed 20 percent by weight of the total mix.

The glass cullet material shall conform to the following grading unless shown otherwise in plans.

Sieve Size	Cumulative Percent Retained on Sieve
5/8 in.	0
3/8 in.	0-10
No. 4	30-50
No. 10	50-75
No. 40	80-90
No. 200	90-100

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet used as a flexible base material shall not exceed 5 percent as estimated using the American Geological Institute Visual Method.

(f) Type E. As shown on the plans.

247.3 Construction Methods

(1) General.

Precautions shall be taken for the safety of the construction personnel handling glass cullet. Glass cullet shall be mixed thoroughly with other approved sources of flexible base material until a uniform mix is achieved to the satisfaction of the engineer.

Item 301

ASPHALT ANTISTRIPPING AGENTS

301.2 Materials.

(2) **Liquid Antistripping Agent.**

When glass cullet is used as an aggregate in asphalt stabilized bases, lime and some liquid antistripping agents may not perform adequately. An antistripping agent such as a silane based compound may be used effectively in these instances.

Item 340

HOT MIX ASPHALTIC CONCRETE PAVEMENT

340.2 Material.

(1) Aggregate

For Type A and Type B asphalt concrete for pavement base layers, crushed waste container glass (glass cullet) may be used as a part of the virgin coarse and fine aggregate. The percent weight of glass cullet in the aggregate mix shall not exceed 5 percent of the total weight of the aggregate.

The glass cullet material shall conform to the following grading unless shown otherwise in plans.

Sieve Size	Cumulative Percent Retained on Sieve
5/8 in.	0
3/8 in.	0-10
No. 4	30-50
No. 10	50-75
No. 40	80-90
No. 200	90-100

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet used as a flexible base material shall not exceed 5 percent as estimated using the American Geological Institute Visual Method.

340.3 Paving Mixtures.

(1) Mixture Design.

The mixture of aggregate, asphalt material and additives proposed for use shall be evaluated for moisture susceptibility in the mixture design stage only by Test Method Tex-531-C, unless otherwise shown in plans. Production verification testing using Test Method Tex-530-C may be required when shown on plans. When production verification testing is required, the engineer will determine the location and frequency of testing and will perform the test. The contractor may choose to use either lime or a liquid antistripping agent to reduce the moisture susceptibility of the aggregate. The addition of antistripping agents shall be in accordance with Item 301, "Asphalt Antistripping Agents". The engineer may waive testing for moisture susceptibility if a similar design, using the same materials, has proven satisfactory.

When the antistripping additive type and rate is shown on the plans, then the moisture susceptibility testing and requirements shall be waived.

Item 345

ASPHALT STABILIZED BASE (Plant Mix)

345.2 Material.

(1) Aggregate.

(a) Description. The aggregate shall be composed of one or more virgin (not previously used in construction) aggregates and/or reclaimed asphalt pavement (RAP). Samples of each aggregate shall be submitted for approval in accordance with Item 6, "Control of Materials".

Crushed waste container glass (glass cullet) may be used as a part of the virgin aggregate. The percent weight of glass cullet in the aggregate mix shall not exceed 5 percent of the total weight of the aggregate.

The glass cullet material shall conform to the following grading unless shown otherwise in plans.

Sieve Size	Cumulative Percent Retained on Sieve
5/8 in.	0
3/8 in.	0-10
No. 4	30-50
No. 10	50-75
No. 40	80-90
No. 200	90-100

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet used as a flexible base material shall not exceed 5 percent as estimated using the American Geological Institute Visual Method.

345.3 Asphalt Stabilized Mixtures.

(1) Mixture Design.

The mixture of aggregate, asphalt material and additives proposed for use shall be evaluated for moisture susceptibility in the mixture design stage only by Test Method Tex-531-C, unless otherwise shown in plans. Production verification testing using Test Method Tex-530-C may be required when shown on plans. When production verification testing is required, the engineer will determine the location and frequency of testing and will perform the test. The contractor may choose to use either lime or a liquid antistripping agent to reduce the moisture susceptibility of the aggregate. The addition of antistripping agents shall be in accordance with Item 301, "Asphalt Antistripping Agents".

The engineer may waive testing for moisture susceptibility if a similar design, using the same materials, has proven satisfactory.

When the antistripping additive type and rate is shown on the plans, then the moisture susceptibility testing and requirements shall be waived.

Item 400

EXCAVATION AND BACKFILL FOR STRUCTURES

400.4 Shaping and Bedding.

Waste material such as crushed waste container glass (glass cullet) may be used as utility bedding. Glass cullet used for utility bedding shall be free from vegetation and other objectionable matter and reasonably free from lumps of earth. The glass cullet shall also be free of hazardous products and the contractor is responsible for furnishing the engineer with documentation certifying that the glass cullet complies with Class 3 industrial waste requirements in accordance with 30 TAC 335.507. The source shall be approved by the engineer prior to use.

Utility bedding material may comprise of up to 100 percent of glass cullet material. The glass cullet material shall conform to the following grading unless shown otherwise in plans.

Sieve Size	Cumulative Percent Retained on Sieve
5/8 in.	0
3/8 in.	0-10
No. 4	30-50
No. 10	50-75
No. 40	80-90
No. 200	90-100

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet when used as an utility bedding shall not exceed 5 percent as estimated using the American Geological Institute Visual Method.

Precautions shall be taken for the safety of the construction personnel handling glass cullet. When glass cullet is to be used in combination with other types of materials, they shall be mixed thoroughly until a uniform mix is achieved to the satisfaction of the engineer.

400.5 Backfill.

(1) General

Waste materials such as crushed waste container glass (glass cullet) may be used for many types of backfill operations. Glass cullet used as backfill material shall be free from vegetation and other objectionable matter and reasonably free from lumps of earth. The glass cullet shall also be free of hazardous products and the contractor is responsible for furnishing the engineer with documentation certifying that the glass cullet complies with Class 3 industrial waste requirements in accordance with 30 TAC 335.507. The source shall be approved by the engineer prior to use.

The maximum allowable glass cullet content in backfill material shall be in accordance with the type of backfill. Backfill which will support any portion of the roadbed or embankment shall include a glass cullet content not more than 20 percent of the combined mix by weight. Backfill which does not support any portion of the roadbed or embankment may include a glass cullet content of up to 100 percent of the combined mix.

The glass cullet material shall conform to the following grading unless shown otherwise in plans.

Sieve Size	Cumulative Percent Retained on Sieve
5/8 in.	0
3/8 in.	0-10
No. 4	30-50
No. 10	50-75
No. 40	80-90
No. 200	90-100

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet used as an embankment material may depend on the type of backfill. The debris level of glass cullet used in backfill which will support any portion of the roadbed or embankment shall not exceed 5 percent as estimated using the American Geological Institute Visual Method. The debris level of glass cullet used in backfill which does not support any portion of the roadbed or embankment shall not exceed 10 percent as estimated using the American Geological Institute Visual Method.

Since all glass cullet material used in embankments shall not exceed 5/8 in., the material should be relatively safe to handle. However, general precautions shall be taken for the safety of the construction personnel. When glass cullet is used in combination with other materials, they shall be mixed thoroughly until a uniform mix is achieved to the satisfaction of the engineer.

Embankment material containing glass cullet shall not be used on the surface of the embankment unless it is indicated in plans or without the approval of the engineer.

(2) Bridge Foundations, Retaining Walls, And Culverts.

Glass cullet may be used as backfill in retaining walls and culverts in combination with other backfill materials which are approved for 100 percent use as backfill. The percent of glass cullet used in different applications and the allowable debris level in glass cullet shall be based on the criteria indicated in 400.5.1 above.

(3) Pipe.

Glass cullet may be used as backfill in pipeline applications in combination with other backfill materials which are approved for 100 percent use as backfill. The percent of glass cullet used in different applications and the allowable debris level in glass cullet shall be based on the criteria indicated in 400.5.1 above.

Item 423

RETAINING WALL

423.2 Material.

Backfill Material

(1) Backfill for spread footing retaining walls shall be in accordance with Item 132, "Embankment", Types B or D, unless otherwise shown on the plans.

(2) Backfill for MSE walls may include crushed waste container glass (glass cullet) except when cement stabilized backfill material is used. The backfill material shall be free from organic or otherwise deleterious materials, and shall conform to the following gradation limits as determined by Test Method Tex-110-E.

The use of glass cullet as a structural backfill shall be limited to a maximum of 20 percent of the total backfill material, by weight. In non-structural backfill applications, up to 100 percent of glass cullet may be used.

The glass cullet material shall conform to the following grading unless shown otherwise in plans.

Sieve Size	Cumulative Percent Retained on Sieve
5/8 in.	0
3/8 in.	0-10
No. 4	30-50
No. 10	50-75
No. 40	80-90
No. 200	90-100

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet used as backfill may depend on the type of retaining wall backfill. The debris level of glass cullet used in structural retaining wall backfill shall not exceed 5 percent as estimated using the American Geological Institute Visual Method. The debris level of glass cullet used in non-structural retaining wall backfill shall not exceed 10 percent as estimated using the American Geological Institute Visual Method.

Since all glass cullet material used in embankments shall not exceed 5/8 in., the material should be relatively safe to handle. However, general precautions shall be taken for the safety of the construction personnel. When glass cullet is used in combination with other materials, they shall be mixed thoroughly until a uniform mix is achieved to the satisfaction of the engineer.

Embankment material containing glass cullet shall not be used on the surface of the embankment unless it is indicated in plans or without the approval of the engineer.

Item 556

PIPE UNDERDRAINS

556.2 Material.

(2) Filter Material. Filter material for use in backfill trenches under, around and over underdrains shall consist of hard, durable, clean sand, gravel, crushed stone, crushed shell, crushed waste container glass (glass cullet) or other materials specified on the plans and shall be free from organic matter, clay balls or other deleterious matter. Unless other wise shown in the plans, crushed limestone will not be permitted.

Up to 100 percent of glass cullet may be used as a filter material in pipe underdrains. The glass cullet material shall conform to the following grading unless shown otherwise in plans.

Sieve Size	Cumulative Percent Retained on Sieve
5/8 in.	0
3/8 in.	0-10
No. 4	30-50
No. 10	50-75
No. 40	80-90
No. 200	90-100

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet used as a filter material in pipe underdrains shall not exceed 5 percent as estimated using the American Geological Institute Visual Method.

556.3 Construction Methods

Precautions shall be taken for the safety of the construction personnel handling glass cullet. When glass cullet is to be used in combination with other types of materials, they shall be mixed thoroughly until a uniform mix is achieved to the satisfaction of the engineer.

Other Recommended Uses

OPEN GRADED BASE COURSE

Material

Crushed waste container glass may be used as aggregate in open graded drainable base courses. The use of glass cullet in this application shall be governed by Item 345, "Asphalt Stabilized Base". It is recommended that glass cullet shall be used in combination with other approved granular base material. The percent glass cullet in such mixes shall not exceed 5 percent of the total aggregate by weight.

The master gradation to be used in the open graded base course shall be as follows:

Sieve Size	Cumulative Percent Passing
1.5 in.	100
1.0 in.	95-100
1/2 in.	25-60
No. 4	0-10
No. 8	0-5