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SYMPOSIUM ON UTILIZATION OF WASTE GLASS IN SECONDARY PRODUCTS

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January 24-25, 1973
Albuquerque, New Mexico

PROCEEDINGS OF

SYMPOSIUM ON UTILIZATION OF WASTE GLASS IN SECONDARY PRODUCTS

A STUDY OF THE TECHNOLOGY, MARKETING,
AND ECONOMICS OF MANUFACTURING VALUABLE
NEW PRODUCTS FROM WASTE CONTAINER GLASS

SPONSORED BY

THE TECHNOLOGY APPLICATION CENTER, UNIVERSITY OF NEW MEXICO
THE GLASS CONTAINER MANUFACTURERS INSTITUTE, INCORPORATED
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INTRODUCTION

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FOREWORD

GLASS - A PARADOX THROUGH THE AGES

by
Richard L. Cheney, Retired President
Glass Container Manufacturers Institute, Inc.*

Many thousands of years before Christ, and even before the days of Abraham, Moses and the Prophets, there occurred a miracle in the Middle East that has become one of the great discoveries of all time. I speak of man's discovery of how to make glass.

It is probable that it took place in Mesopotamia, around 12,000 B.C., and I for one accept as indicative of what probably happened Pliny's account of the Phoenician sailors who accidently produced glass by the fusion of sand and soda in their campfire on a lonely river beach.

You may ask: Am I exaggerating the importance of the discovery of glass? I think not. The Miracle in Mesopotamia ranks with man's discovery of how to use fire and the invention of the wheel. Just consider the role glass has played, continues to play and is destined to play in the march of civilization, the advances of the sciences and man's rising standard of living.

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*Excerpts from a speech entitled "Miracle In Mesopotamia" made by Mr. Cheney in accepting the Second Annual Phoenix Award, Chicago, Ill., December 13, 1972.

If you were by some magical stroke to withdraw glass completely from the human scene, our entire social, industrial and economic fabric would shrink to unrecognizable dimensions.

Yet glass, despite its essentiality to human progress, has remained a paradox through the ages that has puzzled scientists and intrigued laymen.

Let's for a moment consider the many inherent and seemingly contradictory characteristics of glass:

It appears to be a solid -- but physicists class it as a liquid.

It is chemically inert -- yet may be fashioned into unlimited shapes.

It may be fragile as a soap bubble -- or strong enough to stop bullets.

It is made of opaque materials, but it may be transparent -- or opaque.

It transmits light more readily than any other material -- yet is totally impervious to gases and liquids.

It is among the most durable materials used by man -- yet is among the easiest of all to dispose of after use.

It is made of the most abundant raw materials on earth -- and is one of the most readily recycled industrial products.

It creates little pollution while being manufactured -- and virtually none in disposal.

The catalog could continue. The point I emphasize is that the diverse characteristics of glass are responsible for its key position in our modern world -- and even more important, it promises to make the ancient Miracle in Mesopotamia the guarantor of man's future as an industrial society.

OBJECTIVES OF SYMPOSIUM

Opening Remarks by

John H. Abrahams, Jr., General Chairman

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OPENING REMARKS

by

John H. Abrahams, Jr., General Chairman
Albuquerque Symposium on the Utilization of Waste
Glass in Secondary Products

It is my great pleasure to welcome everyone to this Symposium on the Utilization of Waste Glass in Secondary Products. In a sense, we are making history here because this event is the first of its kind ever devoted exclusively to the recycling of waste glass bottles and jars. During these two days we will be presented with virtually all of the available technology for turning used container glass into a variety of new and useful products. We also will hear for the first time the results of a comprehensive marketing and economic analysis of several of the most promising of these products.

That this event is taking place in Albuquerque -- indeed that it is taking place at all -- is a tribute to the many people and organizations who have taken such a great interest in solid waste management and who have worked to develop new methods and techniques for converting the waste glass portion of our nation's refuse into a valuable resource.

Special thanks go to the Technology Application Center (TAC) of the University of New Mexico for providing the opportunity to conduct this forum. TAC, an agency of the Institute for Social Research and Development, is sponsored by the National Aeronautics and Space Administration (NASA) and private industry. It seeks to expand the beneficial use of new technology and new products -- which sums up why we are meeting at this time.

Thanks also go to another sponsor of the Symposium, the Albuquerque Department of Environmental Health.

We in the glass container industry are convinced that the long-term solution to the present solid waste disposal problem lies in the recycling of salvageable materials from municipal refuse, such as waste container glass. This waste recycling concept was almost unheard of back in 1967 when the Glass Container Manufacturers Institute (GCMI) established an Environmental Pollution Control Program to seek answers to problems relating to solid waste management as well as air and water concerns.

One major objective of this program is to establish sound commercial uses for larger volumes of salvaged glass containers, such as in the manufacture of various secondary products. It is contemplated that the various municipal separation systems under development throughout the United States will result in increasing quantities of waste glass. As these demonstrations prove to be practical and efficient, more separation systems undoubtedly will be constructed. GCMI is cooperating with the developers of these systems to determine the quantity and quality of waste glass available, and is constructing, under partial EPA funding, a glass separation subsystem at Franklin, Ohio.

Glass container manufacturing plants, however, are unevenly distributed across the country so that transportation of this relatively heavy waste material is an important economic consideration. Thus, waste glass collected

one hundred miles or more from glass plants may be more logically used for locally manufactured secondary products which need far less processing.

Equally important are the unique physical and chemical properties of glass which make it beneficial as a raw material in many secondary products. Since glass is a non-crystalline substance with a broad and indefinite melting temperature, it can be used to create a variety of unusual and useful materials. Its decorative aspects should not be overlooked either because the moderate market for glass in artistic and hobby pursuits seems to be expanding.

With respect to the utilization of waste glass in secondary products, an enormous amount of progress has been made in a relatively short time. There now exists more than a score of new secondary products made from waste glass and its use in many other products can be envisioned. For some time now GCMI and others have been conducting extensive laboratory and field studies to determine the technical feasibility of each of the secondary products listed on the program for this Symposium.

These products have been developed not merely as a means of disposing of waste glass, but rather to capitalize on the many beneficial properties that glass can impart to various road paving and construction materials. Used in such a manner, waste glass then acquires positive values.

To determine precisely what these values might be, GCMI contracted with the Midwest Research Institute of Kansas City, Missouri in late 1970 to undertake an in-depth analysis of the economic feasibility, including marketing

potential, of manufacturing five new types of construction materials made in part from waste container glass. Comprehensive reports are now available on each.

This Symposium, therefore, is a platform from which studies on all secondary products, as well as the report recently completed by MRI can be described and discussed. We are fortunate indeed to have with us many of the men responsible for these new and exciting developments. We appreciate their interest in taking time to come to Albuquerque to present their findings and to tell how the various products are manufactured and used.

We have much to look forward to the next two days. Unquestionably, the information exchanged here in Albuquerque will add immeasurably to the body of our knowledge with respect to utilizing waste glass in secondary products. More importantly, however, its dissemination may help spur the development of viable commercial enterprises - new industries perhaps - that will someday turn waste into wealth.

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PAPERS

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ROAD SURFACING WITH WASTE GLASS

by

John H. Abrahams, Jr., Manager, Solid Waste Programs

Glass Container Manufacturers Institute, Inc.

Washington, D.C.

ROAD SURFACING WITH WASTE GLASS

by

John H. Abrahams, Jr.
Glass Container Manufacturers Institute, Inc.

Recent studies by the Glass Container Manufacturers Institute and others have shown that glass is a most versatile material and has an ever-widening range of uses. It is an ideal packaging material because of its unique physical and chemical properties and because of its environmental compatibility (3, 6). It is also shown to be one of the strongest materials: In fact, projections indicate that some day it could conceivably replace steel for bridges and tall buildings.

Early results of the GCMI program in solid waste management which began in 1967 (4), lead to the conclusion that waste glass is not a problem in either the collection or disposal of municipal refuse. Thus since continued studies in these aspects were not required, emphasis of the program subsequently shifted to the development of mechanical equipment for separating large volumes of high quality waste glass from municipal refuse for resource recovery, and on utilization of this waste in the general industrial sector (7). Further, since the automatic production of cullet for furnace use (clean, color-sorted glass free of metals) proved to be a complex task (5, 10), the development of numerous "secondary products" made from waste glass was a viable alternative.

Recent studies show the list of secondary products to be long and variable, with many of these products found to be both technically feasible and economically practical (2). Research efforts were concentrated on secondary products which promote the beneficial uses of the physical and chemical properties of waste glass rather than merely as means of disposal (1). Many of the most promising products will be described in detail at this Albuquerque Symposium of the Utilization of Waste Glass In Secondary Products.

Glasphalt

Glasphalt was developed by a research team at the University of Missouri at Rolla under a grant (1969-1972) by the Federal Environmental Protection Agency. GCMI worked closely with UMR during this period by providing crushed glass for studies and demonstrations, coordinating various technical and educational aspects, and by funding special research projects.

Examinations of most of the 33 glasphalt strips placed to date indicate that they generally are indistinguishable from normal asphalt. Skid resistance on glasphalt is good or slightly superior to normal asphalt, and all strips are reported to exhibit good reflectance characteristics which could be a favorable safety factor. In a few cases, however, some glass apparently was stripped from the surface. Details of the problems as well as the performance and conditions of the experimental strips are discussed in the following pages.

Studies 1968-70: The first field placements in 1968 consisted of several small patches in chuckholes on a parking lot at the Rolla campus. These patches are in use today with little sign of wear. Several small strips were placed on UMR campus parking lots in 1969 (Table 1) but the first commercial strip was placed October 4, 1969 on an entrance road to a parking lot at an Owens-Illinois, Inc. building in Toledo, Ohio. Two strips were placed that day, and both are still in use.

Interestingly enough, several puzzling events occurred that day which led to the realization that glasphalt may be practical for special uses not observed in regular asphalt. The day was cold, damp, and misty, and delays were encountered due to the experimental nature of the pavement, yet rolling was easy and extended.

Early thought, however, had been directed toward glasphalt as a means of disposing of a waste product. Thus a high percentage of glass was used to substitute for regular aggregate. As shown in Table 1, this substitution in 1969-70 ranged from about 51 percent of total composition to 95 percent, by weight, in addition to the 5 percent asphalt. The average was 73 percent glass, with the asphalt content varying from 4.75 to 5.8 percent.

Information in Table 1 also indicates that some stripping of the asphalt off glass surface particles did occur, but the reason was not readily apparent. Data available suggest that the raveling and wear reported at one of the Canadian tests may

TABLE I. Summary of Glasphalt Placing and Performance, 1969-1970.

Location of glasphalt, Organization(s) and Date of Placing	Size of Area, Tons of Glass, and Percent Glass (of total)	Weather Conditions	Rolling Time Elapsed (Mins.)	Temperature (°F) of mix	Remarks
University of Missouri at Rolla. Parking lot September, 1969	Patches and potholes. 12 sq. ft. 300 pounds 94 percent.	Hot Dry	Before: - During: -	Delivered: - Rolling: -	Small loss of glass on surface. Holding up well.
Owens-Illinois, Inc. Toledo, Ohio. Entrance Drive to Plant. October 4, 1969	18 x 50 ft. 10 x 40 ft. 2" thick 17 tons 74.3 percent	45°F Misting Windy	Before: - During: Extended	Delivered: 325° Rolling: -	Good skid resistance. Some reflectance, glitter, no raveling or cracks.
Anchor Hocking Corporation Winchester, Indiana. Parking lot and approach road. June 8, 1970	2,200 sq. ft. 3" thick 45 tons 82 percent	85°F Sunny Clear	Before: - During: -	Delivered: - Rolling: -	No deterioration. Some reflectance, glitter, good skid resistance.
University of Missouri at Rolla. Campus service road. July 10, 1970	525 x 20 ft. 1 1/2" thick 60 tons 59.4 percent	85°F Hot Dry	Before: 5-15 During: 30	Delivered: 275-300° Rolling: 220-275°	Good skid resistance, some reflectance, glitter, minor raveling.
Glass Container Corporation of Canada, Toronto. Access road to Dominion Glass Company. August 29, 1970	500 x 18 ft. 3" thick - -	55°F Sunny Cold	Before: - During: -	Delivered: - Rolling: -	Good skid resistance, some reflectance, glitter, normal wearing.
Borough of Scarborough, Toronto, Canada. Street October 17, 1970	600 x 26 ft. 1" thick 70 tons 65 percent	35°F -	Before: 5 During: 180	Delivered: 260° Rolling: -	Good skid resistance; light reflectance, glitter. Raveling, with surface wear(studded tires).
Glass Container Corporation Fullerton, California. City street in industrial park. October 26, 1970	600 x 40 ft. 3" thick 300 tons 63 percent	80°F Normal	Before: 30 During: -	Delivered: 300° Rolling: 250-180°	Good skid resistance, some reflectance, glitter, stripping of surface particles.
Brockway Glass Company, Brockway, Pa. Entrance road and parking lot. October 28, 1970	490 x 24 ft. Road 1" thick Lot 5" thick 95 tons 51.4 percent	54-56°F Sunny Windy	Before: 5-10 During: 10-15	Delivered: 300° Rolling: 260°	Good skid resistance, normal wear, minor raveling. Heat retention. Good binding to subgrade.
Owens-Illinois, Inc. Toledo, Ohio. Stopping lane November 16, 1970.	245 x 9.5 ft. 1" thick 15 tons 94 percent	30-40°F Cloudy	Before: 30 During: 60	Delivered: 240° Rolling: 200°	Sealer. Good performance, no deterioration.

be related to the long period (3 hours) spent in the rolling operation. With the exception of the strip placed in Brockway, Pennsylvania, an anti-strip agent or hydrated lime was added in small amounts to each batch as recommended by UMR to bind the asphalt to the glass. The volume of traffic on these experimental strips was only moderate, ranging up to about 2,225 vehicles a day (Scarborough strip, October 17, 1970), so that traffic had a negligible effect on the condition of the glasphalt.

Indications of heat retention characteristics of glasphalt, however, were vaguely evident on several occasions during these early tests, and became more noticeable during 1971.

Studies 1971: The largest number of glasphalt strips were placed in 1971, some 15 locations in all, including one in Toledo with five distinct courses. Of these 15 locations, 5 were major streets in cities, carrying heavy vehicular traffic ranging between 6,000 and 13,500 vehicles a day. The average area of the strips increase from about 9,600 square feet in 1970 to about 13,000 in 1971, with the largest being 50,000 square feet.

Experimentation with variations of composition continued throughout 1971, with the most notable change being the smaller percentage of glass used in the mix, as shown below:

Amount of Glass in Glasphalt Mix

	Average Percentage	Highest Percentage
1970	73	95
1971	46	63

These lower percentages in 1971, however, do not include the two subgrades in the full depth glasphalt placement in Toledo.

Also not included in the 46 percent figure are the 2 percent and 8 percent values used in the Albuquerque strip placed October 19, 1971. These low percentages were used to "sweeten" the fine aggregate, and probably represent the proportion which could be used on a regular basis because of the relatively small amount of waste glass potentially available. No anti-strip agent was used in the Albuquerque mix, however.

As noted in Table 2, some problems of raveling and loss of surface glass were encountered, and are being followed closely. For example, cores have been collected recently from the parking lot in Vancouver, Washington for thorough investigation. The strip on the fairgrounds at Des Moines was perhaps the thinnest layer of glasphalt ever placed, averaging less than an inch thick after some supply and rolling problems. Since it was placed in an area of little or no traffic and some glass was loosening on the surface, the area was overlaid in August 1972 with 1-1/2 inch Type A asphaltic concrete.

Most of the strips placed in 1971, however, demonstrated good skid resistance (some better than normal), good reflectance without driver hindrance, and normal wearing conditions with no deterioration. The weather did not seem to be the factor that it was in 1970 when some strips were placed in damp 30 to 40 degree Fahrenheit weather. Almost all of the Charles Street

strip in downtown Baltimore, Maryland, however, was placed in a driving rainstorm which started only 15 minutes after rolling began.

Two significant winter observations were made on various glasphalt strips which probably will help determine the direction of glasphalt studies in the future. A limiting factor is that tire chains and studs seem to break up some of the glass particles on the surface, particularly those over 1/2 inch across. A strong positive factor is that snow appears to melt faster on glasphalt than on normal asphalt. This aspect probably is related to the fact that glasphalt requires less heat and retains it longer than normal asphalt.

For example, in Burnaby, B.C., the contractor noted that rolling was easy and needed only one-half to one-third the normal time, after initial cooling. Furthermore, recent observations showed that deterioration due to tire studs was no greater on the glasphalt than on normal asphalt nearby. In Vernon, B.C., an additional 45 minutes for cooling was allowed before rolling, indicating that less heat input could have been tolerated. Furthermore, softening during the summer was attributed to an excess of asphalt not needed because of the high percentage of glass used.

The five course pavement with glass aggregate throughout, placed by the City of Toledo with state funds, used an estimated 1,450 tons of crushed glass provided by Owens-Illinois, Inc. Nearly 77 percent of this amount was used in the two base layers

TABLE 2. Summary of Glasphalt Placing and Performance, 1971.

Location of Glasphalt, Organization(s), and Date of Placing	Size of Area, Tons of Glass, and percent Glass(of total)	Weather Conditions	Rolling Time Elapsed (Mins.)	Temperature (°F) of mix	Remarks
Louisiana Coca-Cola Bottling Company, New Orleans, La. Parking lot. March 19, 1971	170 x 60 ft. 1" thick 70 tons 65 percent	70°F Clear	Before: - During: -	Delivered: 250-225° Rolling: 140°	Good skid resistance, good reflectance, glitter, wear normal, minor raveling.
City of Des Moines, Iowa Isolated surface road on fair grounds. May 15, 1971	300 x 12 ft. 1 1/2 - 3/4" 10 1/2 tons 47 percent	75°F Windy Clear	Before: 5 During: 30	Delivered: 275-300° Rolling: 200-225°	Some stripping due to lack of use - overlaid on 8-15-72.
Lucky Lager Brewery, San Francisco, Calif. Parking lot. May 20, 1971	7,300 sq. ft. 1 1/2" thick 70 tons 47 percent	-	Before: - During: -	Delivered: - Rolling: -	No known problems.
University of Missouri at Rolla. Campus Parking lot May 27, 1971	12,000 sq. ft. 2" thick 60 tons 37.8 percent	55°F Rain before rolling.	Before: 20 During 30	Delivered: ±275° Rolling: ±240°	No skid tests. Good reflectance, no deterioration, except some loss of surface glass due to poor mechanical compaction(equipment problem).
City of Burnaby, B.C. City street, one lane road in each direction. June 18, 1971	700 x 20 ft. 1 1/2" thick 135 tons 63 percent	60°F Overcast Showers	Before: 10-25 During: 1/2 normal	Delivered: 280° Rolling: ±250;±200°	Good skid resistance. Some shattering due to chains and studs. Heat retention good. Some raveling
Thatcher Glass Company, Elmira, N.Y. (Big Flats) Entrance Drive. July 6, 1971	58 x 9 ft. 1 1/2" thick 2 tons 52 percent	80° Sunny Clear	Before: 10 During: -	Delivered: 275° Rolling: -	Better than normal skid resistance, good reflectance, glitter;good heat retention; wear normal, some raveling.
City of Omaha, Nebraska. City street. August 6, 1971	283 x 60 ft. 3/4" thick 70 tons 18.75 percent	86° Partly Cloudy	Before: 8 During: 140	Delivered: 295° Rolling: -	Good skid resistance. No deterioration.
City of Baltimore, Md. Downtown city street. August 19, 1971	6,500 sq. ft. 1" thick - 60 percent	70-75°F Constant rain	Before: - During: -	Delivered: 275° Rolling: -	Good reflectance, glitter. No deterioration.
City of Azusa, California City street August, 1971	300 x 40 ft. 1 1/2" thick 80 tons 43 percent	-	Before: - During: -	Delivered: - Rolling: -	Light reflectance, glitter. Some raveling.
Lucky Lager Brewery Vancouver, Washington. Parking Lot September 16, 1971	10,000 sq. ft. 1 1/2" thick - 40 percent	-	Before: - During: -	Delivered: - Rolling: -	Some raveling: High air voids due to low asphalt content.

TABLE 2 (Continued). Summary of Glasphalt Placing and Performance, 1971

Location of Glasphalt, Organization(s), and Date of Placing	Size of Area, Tons of Glass, and percent Glass (of total)	Weather Conditions	Rolling Time Elapsed (Mins.)	Temperature (°F) of mix	Remarks
Coca-Cola Company, Vernon, B.C. Parking lot September, 1971	200 x 60 ft. 3" thick 100 tons 66 percent	45°F Damp	Before: 50 During: Normal	Delivered: 200°+ Rolling: 180°-	Good skid resistance and reflectance. Softening in summer due to excess asphalt. Retained heat longer
Labatt Breweries, London, Ontario. Industrial yard. September 27, 1971	3,160 sq. ft. 1-2" thick 70 tons 40 percent	70°F Dry	Before: 10 During: 30	Delivered: 300° Rolling: 275°	No skid tests, good reflectance, glitter. No deterioration.
Brooks Products, Inc. Holland, Michigan. Loading-parking area. September 28, 1971	50,000 sq. ft. 1 3/4" thick 108 tons 40 percent	70°F Sunny	Before: - During: -	Delivered: 295° Rolling: -	No deterioration, used some regular and some hydrated lime. No skid tests.
Owens-Illinois, Inc. Toledo, Ohio, City street. October 5, 1971 Leveling Layer:	1,000 x 24 ft. 1 - 1 1/4" thick 94 tons 47 percent	50°F Clear	Before: 60 During: 60	Delivered: - Rolling: -	Better than normal skid resistance.
Base Layer:	800 x 24 ft. 1 1/4" thick 34 percent				Total glass in five layers ~ 1,500 tons.
Upper Base Layer:	600 x 24 ft. 3" thick 38 percent				Aggregate 88% passing 1"
Aggregate Base Layer:	400 x 24 ft. 9" thick 25 percent				Aggregate 82% passing 1"
Glass Subgrade:	200 x 24 ft. 6" thick 50 percent				Aggregate 98% passing 3/4"
City of Albuquerque, N.M. Entrance to parking lot at Levi-Strauss Plant. October 19, 1971.	220 x 40 ft. 2" thick 3 tons 2 to 8 percent	57°F 10 mph Wind	Before: 10 During: 110	Delivered: 300° Rolling: 275°	Good skid resistance, same reflectance as asphalt. No deterioration.

which were only 200 feet and 400 feet long, compared to the 1,000 foot length of the surface layer. With large amounts of glass used in this fashion the process is mostly a disposal method, since glass in the lower courses need not be clean. This section of roadway has been in place over one year, and is standing up well.

Studies 1972-73: Most of the tests in 1972 were full-scale demonstrations placed on major thoroughfares and congested parking areas. The five largest areas averaged over 44,000 square feet. The volume of waste glass used averaged 45 percent, compared to 46 percent in 1971. Weather conditions during all the placements were generally good, and no extreme conditions were noted for temperature mixes or rolling times.

One exception to the good weather conditions is noted relative to the farmers market in Michigan, where the air temperature was only 30 degrees Fahrenheit when the first pass was made to roll the topping. The contractor felt it could be worked more easily than normal asphalt under these conditions, and noted that no joints were visible.

Good skid resistance was noted on most of the glasphalt placed in 1972, with only one strip (in Michigan) indicating less than normal resistance. Good reflectance was noted on most strips, and most contractors reported that there was no deterioration except where some asphalt was worn off surface glass particles.

TABLE 3. Summary of Glasphalt Placing and Performance, 1972 to Date

Location of glasphalt, Organization(s), and Date of Placing	Size of Area, Tons of Glass, and percent Glass (of total)	Weather Conditions	Rolling Time Elapsed (Mins.)	Temperature (°F) of mix	Remarks
Town of Hempstead, L.I. Parking lot, recycling area May 11, 1972	15 x 15 ft. 1 5/8" thick 1 ton 40 percent	60°F Sunny Windy	Before: 5 During: 17	Delivered: 150° Rolling: 140°	No performance tests. No deterioration, except some glass particles exposed.
City of South Burlington, Vermont. Vt.116 and City Street. May 24, 1972	2218 x 22 ft. 1" thick 50 tons 15 percent	75°F Sunny Warm	Before: 5 During: ±50	Delivered: 300° Rolling: 250°	Good skid resistance, good reflectance, no deterioration, excellent condition.
J.F. Kennedy Airport Port Authority of New York Road to hanger May 24, 1972	200 x 24 ft. 1 1/2" thick 22 1/2 tons 44.8 percent	70°F Dry Sunny	Before: 0 During: -	Delivered: 260° Rolling: 260°	No tests. Good condition.
Town of North Hempstead, L.I. Circle drive to Roslyn incinerator. August 2, 1972	70 x 12 ft. 2" thick 5.4 tons 45 percent	85°	Before: 20 During: 45	Delivered: 275° Rolling: 200°	Good skid resistance, good reflectance, good condition, no deterioration.
City of Flint, Michigan Major street (12th Street) August 24, 1972	2390 x 11 ft. 1 3/8" thick 125 tons 55 percent	75°F Ideal	Before: 3 During: 60	Delivered: 270° Rolling: 250°	Less than normal skid resistance, considerable reflectance, no deterioration, asphalt worn off exposed glass.
City of Royal Oak, Michigan and Beautification Council. Farmers Market parking lot. Binder October 16, 1972	50,889 sq. ft. 1 1/2" binder 87 tons 25 percent	60°F Cloudy Overcast Damp	Before: 30-40 During: 15-20	Delivered: 290° Rolling: -	Good reflectance, no skid tests, good condition. Placed after heavy rain.
Topping October 17, 1972	50,889 sq. ft. 1" topping 246 tons 50 percent	45°F Clear	Before: 30-40 During: 15-20	Delivered: 290° Rolling: -	Good reflectance, no skid tests, no deterioration. First morning pass at 30°F.
Thatcher Glass Company Elmira, N.Y. (Big Flats) Parking lot. October 24, 1972	1,900 sq. ft. 3" Base 10 tons 84 percent	60°F	Before: 0 During: 30	Delivered: - Rolling: 75°	Kopper System with cold aggregate. Used shatter-guard cullet and 16 percent asphalt. Normal top coat applied.
Emhart Corporation, Windsor, Connecticut. Parking lot, access road. September 28, 1972	45,000 sq. ft. 1" thick 150 tons 50 percent	70°F	Before: 10 During: -	Delivered: ±290° Rolling: ±275°	No tests. Good condition. Easy to work and rake.
Joe G. Maloof-Distributor, Albuquerque, New Mexico. Recycling parking lot. January 11, 1973	1,500 sq. ft. 2" thick 6 tons 5 percent	50°F Clear	Before: 5 During: 15	Delivered: 300° Rolling: -	No tests.

One test of particular interest was conducted by the Thatcher Glass Company, which makes a plastic-clad bottle named "shatterguard." Both plastic and glass were crushed and placed in a base layer, using a Kopper System of cold aggregate along with 16 percent asphalt. No anti-strip agent was used.

No performance data are yet available on the most recent glasphalt study, January 12, 1973, in Albuquerque. Only 5 percent glass was used in the mixture which contained no anti-strip agent, similar to the glasphalt study in Albuquerque in October, 1971.

New Technology: Recent studies by the Colorado School of Mines under a GCMI contract have shown that glasphalt could extend the asphalt paving season because of its slower rate of cooling. This occurs apparently because the plate-like shape of the glass fragments allow better heat absorption, and because of their horizontal configuration which tends to transmit heat laterally rather than vertically. The laboratory studies conducted by CSMRI confirm the various indications of heat retention experienced with a number of the strips placed over the last several years.

With this special use of glasphalt, the economics of the system will change. Since it is believed that northern cities could extend their paving or patching season several months each year, the waste glass becomes a special ingredient which could

demand a higher price, and need not compete with the local rock aggregate priced in the $2 to $5 a ton range.

This same pricing situation is believed to be true for other proposed uses of waste glass in road surfacing material, such as slurry seal and anti-skid road sprays.

Other Materials

Glasphalt has been emphasized in this summary because more than 30 strips are in place, some for more than 3 years. Several other factors must be considered, however, when evaluating the use of waste glass in road surfaces. Two big factors, of course, are the availability of waste glass and the general economics. Glasphalt could absorb all the waste glass potentially available (about 11 million tons of glass containers) with only minimal effect on the general aggregate market. The economics are questionable, however, because regular aggregate usually is available for about $2 to $5 a ton.

The advent of municipal systems to separate large volumes of waste glass may change the economics, since municipalities could accumulate a surplus of glass-rich material. In addition, recent studies at the University of Missouri at Rolla under a GCMI grant have shown that glasphalt can tolerate some foreign material mixed in with the glass as discharged from the proposed separation systems (8).

An alternate approach to disposal of waste glass is to emphasize the beneficial use of the glass in making a product. Most of the secondary products developed or promoted by GCMI, in fact, are in this category. A beneficial use implies of course that a certain value can be placed on the waste glass, and assumes that a market for the product, or for its use, can be developed. Accordingly, the waste glass is no longer considered a disposal item. Instead, it becomes a raw material and can theoretically establish its own price in competition with other materials.

This procedure was followed in an in-depth study made by the Midwest Research Institute under a GCMI contract, to determine the market potential of five secondary products made from waste glass (9). Using the figure of $12 a ton for waste glass, it was determined that the following products were economically feasible: thixatropic construction panels (11) developed by the Colorado School of Mines Research Institute, glass wool, terrazzo, slurry seal, and foamed glass. GCMI has published brochures describing the technical and economic feasibility of each of these secondary products.

Slurry Seal: Slurry Seal consists of a stable suspension of crushed rock aggregate in liquid emulsified asphalt with about 0.1 percent to 2 percent of Portland cement or lime generally applied cold in a thin layer over a sound road base. It acts as: a positive sealer for any pavement which is absorbing water; a retardant to stop asphalt pavements from raveling and spalling; a filler for pavements which have a "popcorn" surface; an armor

coat for pavement needing protection; a long-life durable surface; a skid-resistant surface which will aid in reducing accidents; and as a filler and leveler of potholes.

Laboratory studies demonstrated that a workable slurry containing 40 percent waste glass is technically feasible, and that such a mixture was equal to or superior to the performance of slurries containing the best natural stone. This was demonstrated in two field tests conducted by Slurry Seal, Inc. in Waco, Texas and New Orleans, Louisiana. Economic evaluation shows that slurry seal using ground glass at $10 a ton in a 40/60 mixture would cost about the same as conventional surfaces.

Important advantages provided by the hardness and angularity of the glass are the superior skid resistance and the extended life of the slurry seal. Economic advantages are readily available to municipalties which recover scrap glass in their waste disposal procedures. Futhermore, laboratory studies show that glass-rich mixtures (75 percent glass along with other inorganics) obtained from municipal refuse separation systems being developed can be used successfully in slurry seal reducing the price of reclamation to a minimum.

Glass in Plastic Asphalt Mixtures: There is a great interest along coastal areas for reliable and long lasting bridge sealants which would prevent de-icing materials from penetrating bridge decks. There are several patented formulas in use which could utilize waste glass as aggregate and can be used on concrete,

steel, or asphalt surfaces. These materials also are reported to have excellent adhesion to aggregate, exceptional toughness, low temperature properties, and good handling properties.

One product on the market is a "concresive epoxy asphalt" consisting of aggregate, epoxy resins, asphalt, and epoxy resin hardness. Another is a thermo-plastic asphalt material developed by the National Aeronautics and Space Administration (NASA) and Stanford Research Institute.

SRI has conducted studies utilizing waste products such as ground rubber, sulfur, and fibers, as fillers in thermo-plastic asphalt. Test patches have been placed on Route I-99 in California and proved successful. These mixtures are designed for resurfacing, pothole patching and, possibly, base course application.

Currently SRI is conducting laboratory studies under a GCMI contract using waste glass as an aggregate. Optimum formulations of thermo-plastic compounds are being compiled and tested using waste glass. Preliminary results indicate that materials containing 10 percent and 20 percent glass frit are tougher than thermo-plastics with other fillers. As such they are less deformable but still have good flexibility. Studies at SRI also show that glass in the mix appears to act as a processing aid.

Surface Sprays: Several commercial materials are available for spraying directly over roads to renew the surface, increase skid resistance, and provide numerous other benefits. These materials are applied cold or at only slightly elevated temperatures and they generally cure in a matter of hours. Studies using waste glass as the aggregate in some of these materials are contemplated.

The surface sprays are similar to the thermo-plastic materials in several respects. For example, they both provide a barrier against road chemicals on bridge decks. Like the thermo-plastics, the surface sprays do not have an asphalt base, and thus will not cause a failure by oxidation of the binding media.

One commercial material consists of a layer of calcined bauxite aggregate spread on a layer of asphalt-epoxy resin which binds it to the road. Cost is one problem with this process since the bauxite grit is imported and sells in the range of $200 a ton. The advantage, of course, is its extreme hardness. Glass (5-6 on the Moh scale) is softer, but still generally harder than most aggregate material, and far less costly than the imported bauxite.

Replacement of Limestone Dust: Waste glass ground to 200 mesh is being used commercially in Cleveland to replace limestone dust as a filler. The waste glass has been used economically, in 50-ton batches, for over two years, is accepted as a substitute,

and presents no problems in handling. The company substitutes the waste glass primarily when a "tight" mix is needed for curbs and similar hard mixes, and the firm reportedly hopes to continue its use in the future.

Glass as a Pozzolan: Glass ground to 325 mesh can be defined as a pozzolan using ASTM specifications, as shown in a recent study by the Colorado School of Mines Research Institute. Pozzolans are materials added to concrete to control or eliminate deleterious reactions between cement and certain reactive aggregates. Using ground glass as a pozzolan could mean the eventual utilization of glass fragments in concrete, and the partial replacement of cement by glass to actually strengthen the concrete.

In fact, the development of glass as a pozzolan may create a situation whereby local aggregate formerly not usable because of deleterious action may become acceptable in concrete with the addition of finely ground glass. In some Midwestern states, siliceous aggregates react with highly basic cements, causing the weakening of concrete roads.

The economics of using ground glass would be comparable to that of cement. The cost of grinding glass to the 200 to 325 mesh size range is about $1 a ton, so that the cost of ground waste glass from a municipal separation system could be in the $10 to $20 a ton range. Color sorting would be unnecessary.

Summary

Laboratory and field studies have demonstrated that waste glass can be used satisfactorily as an aggregate in road paving and resurfacing materials such as asphalt, slurry seal, and plastic compounds. Glasphalt is the best known of these materials and has withstood extensive laboratory and field testing. It has been shown to be a good means for disposal of large quantities of waste glass from municipal refuse.

Materials and methods, however, which utilize the beneficial properties of glass seem to have a better potential for competing with standard aggregates and fillers. For example, the extreme durability of glass helps to increase the skid resistance of the surface layers; and its heat retention properties allow cold weather paving in thick layers. The development of markets for these beneficial uses of waste glass could someday increase its value to a point where cullet for secondary products would command nearly the same price as the higher quality cullet used in glass furnaces for making new bottles.

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LABORATORY AND FIELD EXPERIENCE WITH ASPHALTIC CONCRETES CONTAINING GLASS AGGREGATES

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INTRODUCTION

The use of waste glass as an aggregate in asphaltic mixtures has been investigated at the University of Missouri-Rolla since 1969 with financial support provided by the U.S. Environmental Protection Agency and the Glass Container Manufacturers Institute. Laboratory studies have been conducted to determine the Marshall properties of asphaltic paving mixtures containing glass (glasphalt) and to investigate the effects of non-glass components in glass-rich fractions separated from raw or incinerated refuse. In cooperation with private companies, citizens groups and governmental agencies at the state and city level, field installations of asphaltic concrete containing glass aggregates have been placed at numerous locations throughout the United States and Canada. The first of these was placed on a parking lot entrance by Owens-Illinois in October of 1969, and since then glasphalt pavements have been used on state highways, city streets and parking lots.

In this paper, construction procedures and performance data for several glasphalt pavements are described along with results of laboratory tests to assess the effects of non-glass components in glass-rich fractions mechanically separated from municipal refuse.

CONSTRUCTION AND PERFORMANCE OF GLASPHALT PAVEMENTS

Questions have been raised concerning possible health hazards involved in the use of glass aggregates, especially in the crushing operation, special equipment requirements for glasphalt pavements and the performance of glasphalt pavements. Several field installations of glasphalt are described below followed by a discussion of these points.

Field Experience with Glasphalt Pavements

A. University of Missouri-Rolla

A road to the University general services building and central receiving area was paved with glasphalt on July 10, 1970. Traffic density on this road is approximately 700 vehicles per day with approximately 10 percent being heavy trucks. The portion paved was 525 feet long and 20 feet wide with a thickness of 1 1/2 inches. It was placed over an existing surface treatment in which chuck-holes had been patched with cold mix prior to tacking with a diluted SS-1 emulsion.

The glass used for this project was donated by member companies of the Glass Container Manufacturers Institute and was a relatively coarse mixture of drain cullet and clean broken bottle glass. The mix was designed to include 63 percent glass, 33 percent fine sand and 4 percent hydrated lime.

During construction, the material was mixed in an ordinary batch plant at 275 F with an asphalt content of 5.75 percent

(total weight basis) using an 85-100 penetration asphalt cement. Aggregate gradation based upon hot bin analysis is given in the first column of Table 1. After placing half of the pavement the supply of coarse glass was nearly exhausted and the gradation was modified to produce a finer mixture as shown in the second column of Table 1. This gradation with an asphalt content of 5.5 percent was used for the remainder of the paving. Marshall properties of laboratory compacted field samples for both mixtures are also given in Table 1.

A conventional paver and 2 ton roller were used for placing and compaction. Both mixtures were tender and it was necessary to defer breakdown rolling until the mixture temperature had dropped to 225 F. The finished pavement, immediately after placing, is shown in Figure 1. Sawed samples of the compacted pavement were taken 3 days after compaction and at one year intervals thereafter. The results of density determinations for these samples are given in Table 2.

A British Portable Skid Tester was used to measure the skid resistance of the pavement at approximately 1 to 3 month intervals for the first year and at approximately 6 month intervals thereafter. Measurements were made in the wheel tracks at 10 different places for each mixture and variations in the average British Pendulum number with time are shown in Figure 2.

The pavement surface is in good condition after 30 months of service as shown in Figures 3 and 4. Alligator

TABLE 1

AGGREGATE GRADATION AND MARSHALL PROPERTIES FOR GLASPHALT FIELD INSTALLATIONS

GRADATION:	Percent Passing						
	Rolla		Fullerton	Burnaby	Baltimore	South Burlington	
Sieve	Coarse Mix	Fine Mix				Sample 1	Sample 2
3/4 inch	100	100	99.2	100	100	100	100
1/2 inch	98.5	99.8	92.6	99.8	100	99	99
3/8 inch	93.1	99.3	86.2	92.5	98	80	79
No. 4	75.1	86.9	66.6	61.8	78	66	58
No. 8	49.4	57.7	54.2	42.8	54	52	48
No. 16	38.0	44.1	30.5	29.7	33	42	39
No. 30	30.4	35.2	17.8	19.4	23	31	29
No. 50	15.1	17.2	12.2	11.2	16	15	14
No. 100	5.8	6.0	8.5	6.3	11	--	--
No. 200	4.6	4.6	6.4	4.1	7	3	3
MARSHALL PROPERTIES:							
Stability, lbs.	840	710	1770	540	1000	1090	940
Flow, .01 inch	13	8	13.5	6.6	11	9	9
Unit Wt., pcf	141.5	139.1	140.5	140.3	142.8	146.1	147.5
Air Voids, %	2.01	4.20	4.9	5.7	3.7	2.9	1.8
VMA, %	14.88	16.34	15.9	15.9	18.1	18.3	17.6

Figure 1—Rolla Glasphalt Road Immediately After Placement

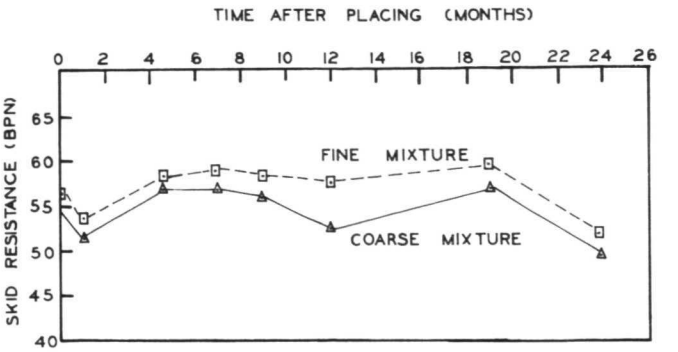

Figure 2—Variations in Skid Resistance With Time for Rolla Glasphalt Road

Figure 3—Rolla Glasphalt Road after 30 Months of Service

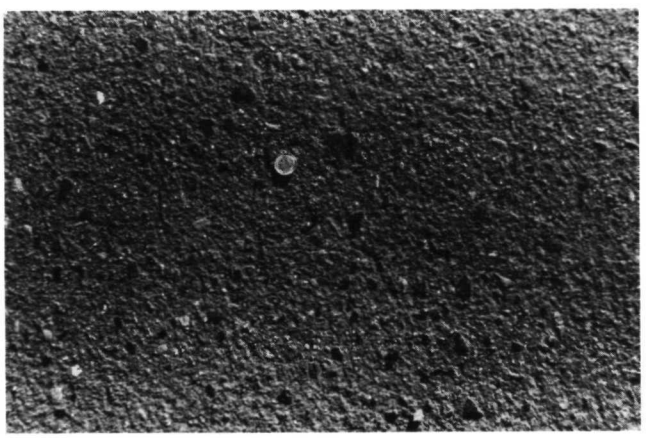

Figure 4—Surface Texture of Rolla Glasphalt after 30 Months of Service

TABLE 2

RESULTS OF DENSITY TESTS FOR ROLLA GLASPHALT

	Coarse Sample		Fine Sample	
	Density	% Comp.	Density	% Comp.
Plant Sample (50 blow comp.)	2.268	----	2.229	----
After paving	2.203	97.1	2.178	97.7
After 1 year	2.204	97.2	2.189	98.2
After 2 years	2.224	98.0	2.190	98.2

cracking has occurred in one limited area, Figure 5, but this is thought to be due to a base failure.

B. Glass Containers Corporation (California)

A street in the Fullerton Air Industrial Park in Fullerton, California, was paved with glasphalt on October 26, 1970. The street was 600 feet long and 40 feet wide. Thirty feet of the width was paved with a 3-in. thick layer of glasphalt with the other 10 feet of width being paved with conventional asphaltic concrete. The base course was a 7 1/2 in. thick layer of crushed rock equivalent to California Division of Highways Class 2 aggregate base. The subgrade was a silty sand which had been compacted to at least 90 percent of maximum density as determined in the laboratory in accordance with the requirements of the California Standard Specifications.

All of the glass used for this pavement was obtained by crushing clean non-returnable bottles in a hammermill. The glass was blended with rock dust and hydrated lime in a mixture consisting of 63 percent glass, 36 percent rock dust and 1 percent hydrated lime.

The design asphalt content chosen was 5.5 percent (total weight basis) with a 60-70 penetration asphalt cement being used. The gradation of the aggregate based on hot bin analyses and results of Marshall tests on a sample taken at the plant are given in Table 1.

The material was mixed in a batch type plant with a 4000 lb. pugmill and the hydrated lime was added by hand at the pugmill. The 3-in. thick layer was placed and compacted

with an 8-10 ton tandem roller. Initial attempts at compaction resulted in excessive crawl even at temperatures of 220 F. Breakdown rolling was carried out at temperatures of 220 F and below.

Tests conducted on cores removed from the compacted pavement indicated a unit weight of 131.4 pcf or 93.5 percent compaction as shown in Table 3. This low unit weight is believed to be due to the difficulties in compacting the mixture at temperatures above 220 F. Table 3 also shows that little further increase in density had occurred after one year when additional cores were obtained.

On March 2, 1971, skid tests were conducted on the glasphalt pavement by the California Division of Highways. The towed trailer method (ASTM E-274) was used at a test speed of 25 mph and the skid number at 25 mph ranged from 61 to 69 which converts to 54 to 62 at 40 mph.

After one year of service, the pavement surface exhibited some raveling caused by the fracture of larger glass particles at the surface. However, the overall condition of the surface was good as shown in Figure 6, and its performance has been considered satisfactory.

C. Burnaby (British Columbia)

A 700 foot section of Royal Oak Avenue in Burnaby, British Columbia, was paved with glasphalt on June 18, 1971. The 20 foot wide existing asphalt pavement was tacked with a diluted emulsion before placing a 1 1/2 inch overlay. Traffic density on the road is 6000 vehicles per day (both lanes) at a maximum posted speed of 30 mph, with deceleration and

Figure 5—Alligator Cracking in Rolla Glasphalt Road

Figure 6—Surface Texture of Fullerton Glasphalt Road after One Year of Service

TABLE 3

RESULTS OF DENSITY TESTS FOR FULLERTON GLASPHALT

	Density	Percent Compaction
Plant Sample (75 blow compaction)	2.252	-----
After paving	2.106	93.5%
After 1 year	2.112	93.8%

acceleration occurring at the intersection with Moscrop Avenue.

The project was a cooperative effort between the Municipality of Burnaby and the Dominion Glass Company, with testing being carried out by the Department of Highways, B.C. Provincial Government.

Approximately 90 tons of bottles were crushed and blended with conventional aggregates to produce the combined gradation given in Table 1. The combined aggregate consisted of approximately 67 percent glass, 31 percent conventional aggregate and 2 percent hydrated lime with 4.75 percent (total weight basis) of 85-100 penetration asphalt cement added to the mix.

Results of Marshall Tests on plant samples given in Table 1 indicate that the stability and flow values are low while air voids are high.

The glasphalt was delivered to the job site at temperatures between 270 and 290 F. Breakdown rolling was carried out at 230 to 270 F with an 8 ton tandem roller, and subsequent rolling was done with a 7 ton pneumatic roller at temperatures from 180 to 230 F. The mix was tender and required a cooling period before rolling.

Seven cores were cut from the compacted pavement and the density ranged from 96.4 to 98.5 percent of the laboratory density with an average density of 97.0 percent.

On September 16, 1971, skid tests were conducted on the glasphalt pavement as well as a conventional asphalt pavement placed during the same time period. The British Portable

Tester results given in Table 4 show that the conventional asphaltic concrete yielded higher skid numbers than the glasphalt.

Inspection of the pavement on March 30, 1972, indicated that severe raveling had occurred in the wheel paths as shown in Figure 7. Loose, uncoated glass particles were prevalent along the shoulder and the pitting shown in Figure 8 was extensive. One pot hole had developed. This deterioration was attributed primarily to heavy studded-tire traffic resulting from an abnormally severe winter. However, low pavement density and insufficient asphalt content may also have contributed to the condition.

On May 23, 1972, additional skid tests were conducted on the glasphalt and conventional asphalt pavements. Results of these tests are shown in Table 4 and they show a substantial increase in skid resistance for the glasphalt over the values measured in September. This was probably due in part to the raveling which was previously mentioned. The glasphalt had higher average skid numbers for these measurements than the conventional asphalt pavement.

D. Baltimore, Maryland

The 200 block of Charles Street between Lexington and Saratoga Streets in Baltimore was paved with glasphalt on August 19, 1971. The total area paved was 1450 square yards with a 1-in. overlay of glasphalt being placed over an existing 1-in overlay of conventional asphaltic concrete that was

TABLE 4

RESULTS OF BURNABY SKID TESTS

		British Pendulum Number		
		Glasphalt Pavement		Asphalt Pavement
Date	Location	Range	Average	Average
Sept. 1971	Outer Wheel Path	45.7-52.1	49.4	57.7
Sept. 1971	Between Wheel Paths	48.7-56.5	53.3	64.2
Sept. 1971	Inner Wheel Path	45.4-54.5	48.5	54.3
May 1972	Outer Wheel Path	55.7-70.3	64.0	56.4
May 1972	Between Wheel Paths	54.0-66.0	59.3	60.5
May 1972	Inner Wheel Path	55.0-68.2	64.1	58.4

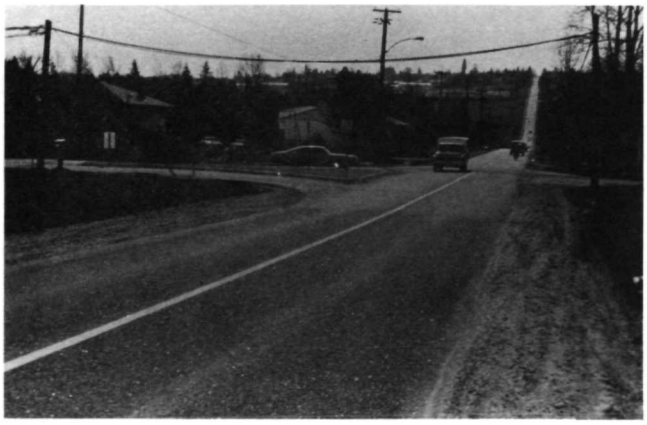

Figure 7—Raveling of Burnaby Glasphalt Road after One Winter

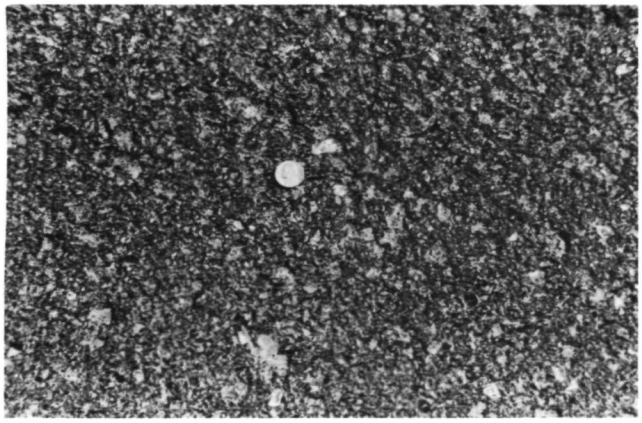

Figure 8—Surface Pitting of Burnaby Glasphalt Road

beginning to wear thin in spots. Charles Street is a main artery bisecting the city and a traffic count taken on October 18, 1971, indicated that 12, 579 vehicles passed over the glasphalt block in a 24-hour period.

Over 50 tons of glass containers collected at a city operated reclamation center were crushed for use in the glasphalt. The glass was blended with slag, limestone dust and hydrated lime such that the combined aggregate consisted of approximately 64 percent glass, 31 percent slag, 4 percent limestone dust and 1 percent hydrated lime.

The gradation of the combined aggregate and the laboratory Marshall properties of a mixture containing 6.5 percent (total weight basis) of an 85-100 penetration asphalt cement are given in Table 1.

After over a year of service, the street is wearing well and has shown no signs of raveling, shoving or rutting, or cracking. No skid resistance measurements have been made.

E. South Burlington, Vermont

A 0.42 mile section of VT Route 116 in the city of South Burlington, Vermont was paved with a one inch thickness of glasphalt on May 24, 1972. This portion of VT 116 had a 1970 average daily traffic count of 4,370 vehicles and is classified as being a fairly heavily travelled suburban connecting street with speeds generally less than 40 mph.

Approximately 50 tons of glass containers were crushed at a commercial stone crushing plant to a maximum size of 3/8 in. The bottles and jars were not washed and the only

preparation consisted of removing the metal caps. Crushed stone, with a 4-in. maximum size was fed into the crusher at the same time as the glass to assist in the crushing operation and to keep the bottles on the various inclined belts used to feed the two crushers involved. The primary crusher was a Universal hammermill and the secondary crushing was accomplished with a Tornado impact crusher.

Various combinations of the amount of stone versus the amount of glass feeding into the primary crusher were tried, with highest production being achieved when the weight of stone and weight of glass were about equal. The end product contained approximately 50 percent glass and 50 percent stone with the gradation shown in Table 5.

A mix design satisfying the requirements of the Vermont Highway Department's Type III bituminous pavement was developed using the Marshall procedure. The aggregate used consisted of 30 percent glass-stone mixture, 39 percent sand, 10 percent 3/8-in. stone, 20 percent 1/2-in. stone and 1 percent hydrated lime by weight. The actual glass content of the mix was thus about 15 percent by weight. The combined gradation as produced in the field and the Marshall properties of specimens with an asphalt content of 6.8 percent are shown in Table 1. The asphalt cement had an absolute viscosity of 500$\pm$ 100 poises at 140 F (approximately 120 penetration).

The mixture was produced in a 6-ton fully automated batch plant in 5-ton batches with the 100 pounds of hydrated lime being added manually. The mixture was hauled approximately 3

TABLE 5

GRADATION OF CRUSHED STONE-GLASS MIXTURE FOR VERMONT GLASPHALT

Sieve	Percent Passing
3/8 inch	100
No. 4	75
No. 8	44
No. 16	26
No. 30	17
No. 50	11
No. 200	5.5

Figure 9—Rolling of South Burlington Glasphalt Road

miles to the job site, layed with a Barber-Greene SA41 track paver and rolled with an 8-10 ton tandem roller. Figure 9 shows the pavement during rolling operations. Traffic was allowed on the finished mat as soon as the rolling operation was completed and no laydown problems were experienced other than minor flushing of the surface in some areas. No further flushing or bleeding has occurred since the day the road was paved.

Potential Health Hazards

Concern with health hazards attendant to the use of waste glass in asphaltic concrete has centered primarily on the crushing process, with the fear being expressed that glass dust might enter the workers' lungs and cause abrasions or cuts to do serious damage. The booklet entitled Threshold Limit Values of Airborne Contaminants (8), published by the American Conference of Governmental Hygienists in 1971 lists glass dust along with limestone and portland cement as "inert" or "nuisance" dusts. In contrast to fibrogenic dusts which cause scar tissue to be formed in lungs when inhaled in excessive amounts, so-called "nuisance" dusts have a long history of little adverse effect on lungs and have not been found to produce significant organic disease or toxic effect when exposures are kept under reasonable control. Thus, while excessive "nuisance" dust of any kind may be harmful, there is no differentiation made between limestone dust or glass dust.

In the more than 20 glasphalt installations placed to this date there has been only one report of a health hazard and this occurred during the crushing of glass bottles for use in an Omaha, Nebraska installation. A three-roll Pioneer crusher normally used for crushing gravel with a maximum size of 1-in. was used and bits of glass flew from the crusher, resulting in several workers being cut. However, roll crushers, hammermills and jaw crushers have been used for other installations with no reported safety hazards. The procedure of blending stone with the glass to be crushed, as described for the Vermont project, might be used if a trial crushing run indicates that flying glass will be a problem.

Equipment Requirements

Conventional equipment for laydown and rolling has been used in all of the glasphalt pavements placed to date, without the need for modifications in the pavers or rollers. A mechanical dust feeder on the batch plant would be desirable since hydrated lime is necessary to control stripping and manual addition of the lime may result in delays or inconvenience in the mixing process.

Performance of Glasphalt Pavements

A British Portable Tester was used to measure skid resistance on the Rolla and Burnaby installations. After two years of service, the average British Pendulum Number (BPN) for the Rolla Street was 49.5 for the coarse mixture and 52.0 for the fine mixture. Natural rubber sliders were used for

these measurements rather than ASTM E249 synthetic rubber sliders. Tests conducted by Kummer and Moore (4) show that the synthetic rubber sliders give BPN values that are 10 to 15 percent higher than numbers obtained with natural rubber sliders. In "Tentative Skid Resistance Requirements for Main Rural Highways" (3), Kummer and Meyer list tentative minimum skid resistance requirements for various testing methods and test speeds. These requirements for the British Protable Tester are given in Table 6. A 10 percent correction for use with data obtained with natural rubber sliders has been applied to these figures and is shown in the table. Based upon these corrected figures, the minimum recommended BPN for both coarse and fine mixtures is above this minimum value.

The average BPN measured in the wheel paths of the Burnaby glasphalt road was 48.9 after 3 months of service but had risen to 64.0 after 11 months of service. Measurements were also made on an adjacent conventional asphalt pavement which had been placed at the same time and the average values obtained in the wheel paths were 56.0 and 57.4 after 3 and 11 months respectively.

The Fullerton road was tested using the ASTM towed trailer (ASTM E274). The tests were conducted at 25 mph and yielded skid numbers (SN) ranging from 61 to 69. These values, converted to 40 mph were 54 and 62 respectively, which are well above minimum requirements shown in Table 6.

TABLE 6

RECOMMENDED MINIMUM SKID RESISTANCE REQUIREMENTS

Mean Traffic Speed (mph)	Skid Number		British Pendulum Number	
	SN*	SN_{40}+	BPN_{SR}‡	BPN_{NR}ξ
0	60	--	--	--
10	50	--	--	--
20	40	--	--	--
30	36	31	50	45
40	33	33	55	50
50	32	37	60	55
60	31	41	65	59

* Measured at mean traffic speed.

+ Measured at 40 mph

‡ Measured in accordance with ASTM E 303 using ASTM E 249 rubber

ξ Corrected for use of natural rubber sliders as suggested by Kummer and Moore

These skid tests show that pavements containing glass aggregate have generally maintained adequate skid resistance levels under the service conditions described and for the time periods indicated. The Burnaby road, however, did have a reading slightly below the recommended minimum value after 3 months of service.

Surface Deterioration

Raveling has been a problem on the Burnaby glasphalt road. Pronounced raveling was noted in the wheel paths after the first winter, and glass aggregates which had been dislodged from the pavement had no asphalt remaining on the surface. Raveling on the Fullerton pavement was less severe and was confined primarily to the loss of large particles at the surface. Little raveling had occurred on the Rolla, Baltimore and South Burlington pavements.

In a laboratory study of raveling characteristics of hot mix asphalt paving mixtures, Gallaway and Vavra (1) found that increasing voids in the pavement (lower densities) resulted in increased raveling. In their studies, raveling was not found to be significant except where the void content was 10 percent and higher for specimens made with good aggregates. Specimens made with poor aggregates showed significant raveling at all void contents, but the raveling definitely increased with increasing void content. Based upon field density tests of the Burnaby glasphalt, the void content of the compacted pavement was 8.67 percent. Since this is below the 10 percent figure suggested by Gallaway and Vavra,

it is unlikely that inadequate density alone accounts for the raveling which occurred, although it may have contributed to the severity of the problem. The major cause of this raveling thus appears to be the studded-tire traffic on the road. A similar, though not as severe, form of surface deterioration appeared on a glasphalt street in Scarborough, Canada, subjected to studded-tire traffic. The material lost from the surface in this case was primarily coarse glass particles which had fractured and then been dislodged from the surface. Since an adjacent section of the Burnaby road paved with conventional aggregate asphaltic concrete did not exhibit as much surface deterioration as the glasphalt under similar traffic conditions, it appears that glasphalt is less resistant to studded-tire damage. Performance results from the Vermont glasphalt after a winter of service should be helpful in confirming this observation.

The void content of the compacted pavement at Fullerton was higher than 10 percent, but the lower traffic volume and absence of studded-tire traffic at this site may account for the absence of extensive raveling.

Excessive Deformations and Pot Holes

There was little deterioration of other types occurring in the glasphalt pavements described. One pot hole had developed in the Burnaby road and alligator cracking due to a base failure was found in one area of the Rolla road. There was no rutting, shoving, or other evidence of low stability in any of the other pavements containing glass aggregates.

Summary of Construction and Performance

Based upon existing threshold limit values for airborne contaminants, inhalation of glass dust during crushing or subsequent use of glass aggregates does not pose a health hazard when exposures are kept under reasonable control. With some types of crushing equipment, flying glass may be a hazard and require modifications in the crushing procedure to prevent injury to workmen.

Conventional equipment may be used for laydown and compaction of glasphalt pavements. A mechanical dust feeder is desirable at the batch plant so that hydrated lime can be added to the mixture without undue delays or inconvenience.

Performance of existing glasphalt pavements has been satisfactory in most instances, but pavements subjected to heavy studded-tire traffic have not performed well. Skid resistance has been adequate for the conditions described and the time periods indicated with the exception of the 3 month readings taken on the Burnaby road. There has been little rutting, shoving, or other evidence of problems caused by low stability.

LABORATORY TESTS ON MIXTURES CONTAINING GLASS SEPARATED FROM MUNICIPAL REFUSE

In initial laboratory and field development and testing of glasphalt mixtures, relatively clean glass was used. It was obtained either from recycling centers at which containers had been hand-sorted or from glass container manufacturers' in-house waste. There were few non-glass components present in the glass. However, practical utilization of substantial volumes of waste glass in glasphalt will require the use of waste-separation facilities capable of mechanically separating larger quantities of glass from refuse. Several such systems are being developed and one of the materials separated is a fraction consisting primarily of glass but also containing non-glass components such as metals, bone, plastics, etc. These glass-rich fractions have been used in laboratory specimens of glasphalt and tests (6) have demonstrated that mixtures containing up to 76 percent of the glass-rich material can be designed to satisfy requirements for stability, flow, and void content specified by the Asphalt Institute.

In order to minimize costs associated with the utilization of waste glass in asphalt paving, it would be desirable to use the glass-rich fraction without further processing by blending it into a conventional asphaltic concrete. If the properties were not appreciably affected by the presence of the glass-rich fraction, little alteration in the design would be necessary. To study the effects of replacing conventional

aggregate with glass-rich fractions or clean glass, an asphaltic concrete was designed using conventional aggregates. It was then modified by substituting clean glass and glass-rich fractions for portions of the conventional aggregate without altering the volume fractions of aggregate and asphalt. The mixtures were tested to determine changes in stability, flow, and void content and to assess the effect of the replacement upon compactibility.

Materials

A. Glass-Rich Fractions

The glass-rich fractions were obtained from two sources. One source was the Hydrasposal-Fibreclaim system designed by the Black-Clawson Company (2) to separate raw refuse into recyclable components. The glass-rich fraction from this process had the gradation shown in Table 7 with most of the material ranging in size from minus 3/8 in. to plus No. 16. Approximately 83 percent by weight of this material was glass with the balance consisting of ferrous and non-ferrous metals, organic materials, plastics, stone and other non-glass components.

The second source of glass-rich fractions was a system developed by the U.S. Bureau of Mines for separating incinerator residue into recyclable components (7). The gradation of the coarse glass-rich fraction from this process is shown in Table 7. Only material passing the 1/2 in. sieve and retained on the No. 8 sieve was used in this study and it was approximately 68 percent glass with the remainder consisting

TABLE 7

AGGREGATE GRADATION AND MARSHALL PROPERTIES FOR CONTROL MIXTURE

Sieve Size	Percent Passing
1/2-inch	100
3/8-inch	90
No. 4	65
No. 8	48
No. 16	35
No. 30	23
No. 50	14
No. 100	8
No. 200	4
Marshall Properties	
Stability, lbs.	1830
Flow, .01-inch	8
Air Voids, %	3.3
Voids in Mineral Aggregate, %	15.6

of glass, ferrous and non-ferrous metals and other non-glass components.

B. Conventional Aggregates

Coarse aggregate (material retained on a No. 8 sieve) used for control mixtures was a crushed limestone locally available in the Rolla area. It was sieved into three size fractions which were recombined to obtain the desired gradation. Fine aggregate (material passing a No. 8 sieve) was a Meramec River sand which had been sieved into six size fractions and recombined to yield the desired gradation.

C. Asphalt and Hydrated Lime

The asphalt cement was an 85-100 penetration material produced from a West Texas crude. Reagent grade hydrated lime was added to the mixtures containing glass aggregates to control stripping.

Test Procedures

A mixture containing conventional limestone and sand aggregates was tested at varying asphalt contents using the Marshall design method (ASTM D 1559). The aggregate gradation and Marshall properties at an effective asphalt content of 5.4 percent are given in Table 8. This mixture served as a control for comparison with mixtures containing clean glass or glass-rich fractions.

The predominant size fractions present in each glass-rich fraction were determined from the sieve analysis data. For the Black Clawson product, the major size fractions present

TABLE 8

GRADATION OF GLASS-RICH FRACTIONS FROM BLACK CLAWSON AND BUREAU OF MINES SEPARATION SYSTEMS

	Percent Passing	
Sieve Size	Black Clawson	Bureau of Mines
1-inch	100	99
3/4-inch	100	97
1/2-inch	100	85
3/8-inch	97	72
No. 4	70	31
No. 8	29	6
No. 16	16	1
No. 30	5	0
No. 50	2	
No. 100	0	

were materials retained on the No. 4, 8, and 16 sieves. Using the same gradation employed in the control batch, mixtures were made in which 0, 10, 30, and 50 percent by volume of the conventional aggregates retained on the No. 4, 8, and 16 sieves were replaced by clean glass and the Black Clawson glass-rich fraction. A constant volume of asphalt was used in each mixture. Three specimens were made for each addition level and type of glass employed, using standard Marshall methods for compaction. The unit weight, stability, and flow were then measured and the air voids and voids in the mineral aggregate were calculated.

For the incinerator residue, the major size fractions present were materials retained on the 3/8 in., No. 4 and No. 8 sieves. Again using the same gradation employed in the control batch, mixtures were made in which 0, 10, 30, and 50 percent by volume of the conventional aggregates retained on the 3/8 in., No. 4, and No. 8 sieves were replaced by clean glass and the coarse incinerator residue. Three specimens were made for each addition level and type of glass employed, using a constant volume of asphalt, and mixture properties were determined.

A preliminary assessment of changes in compactibility caused by replacing conventional aggregate with clean glass or the Black Clawson fraction was made using a technique developed by Lefebvre and Robertson (5). In this technique, specimens are made using two compaction efforts and a Com-

paction Resistance Index is calculated based upon the density of these specimens. Specimens of the control, 50 percent clean glass replacement and 50 percent Black Clawson glass replacement mixture were molded and three of each were compacted at two different compaction efforts. The Compaction Resistance Index was then computed.

Test Results

The Marshall test results are shown in Figs. 10 and 11. An analysis of variance technique was used to determine the statistical significance of changes in properties with increasing addition levels and the data were also analyzed for linear quadratic and cubic regression trends. In the test series using Black Clawson glass-rich fractions and clean glass, the addition of increasing amounts of Black Clawson material resulted in decreasing stability, air voids and voids in the mineral aggregate (VMA) and increasing flow. However, the maximum decrease in air voids and VMA was only one percent and the maximum increase in flow was .015 in., all at the 50 percent addition level. A substantial decrease in stability accompanied increasing addition levels of the Black Clawson material. This would be expected since the smoother surface texture of glass as compared to the crushed limestone it replaced would decrease the internal friction in the mixture. However, the stability at a 50 percent replacement was still well above minimum requirements established by the Asphalt Institute.

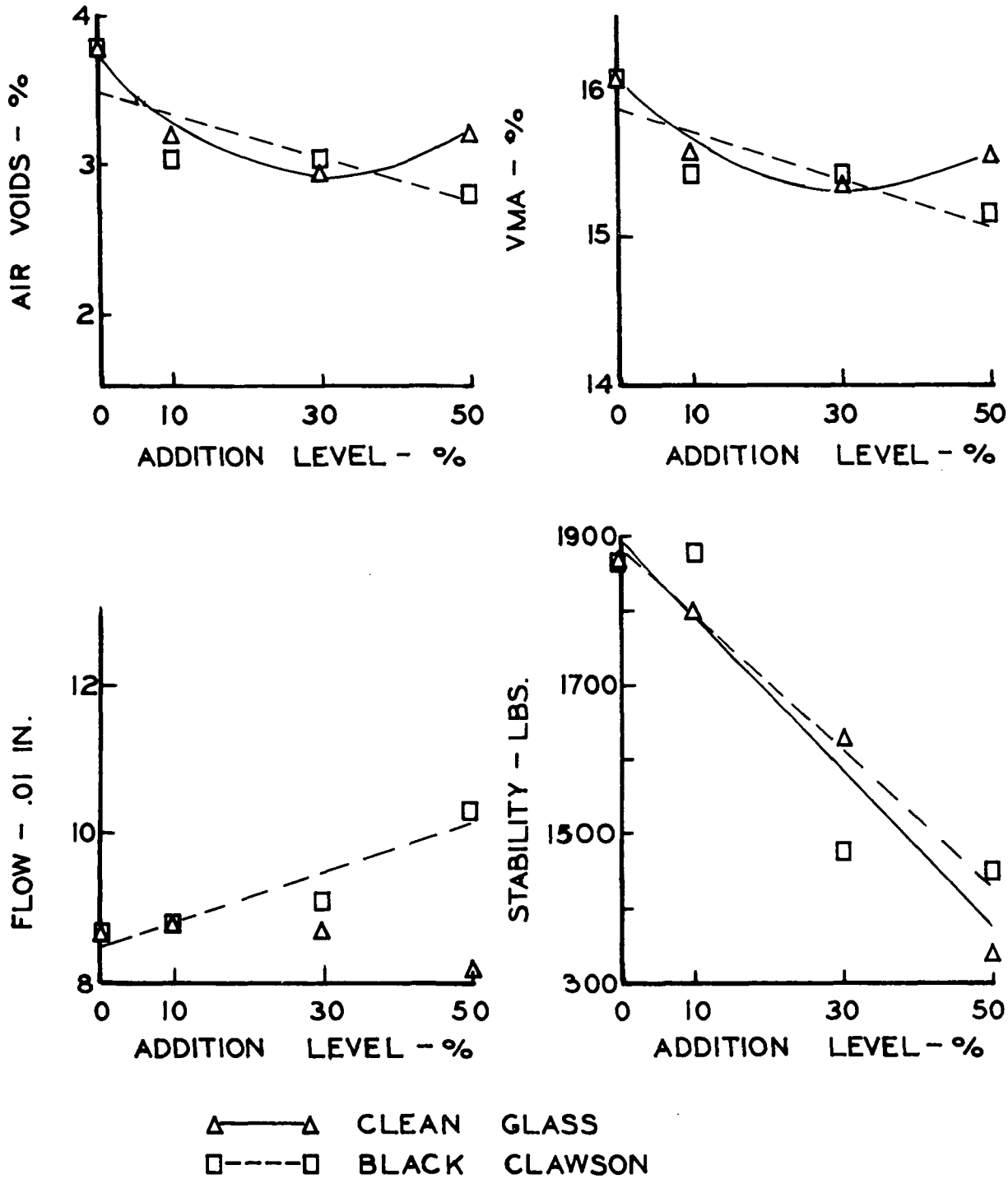

Figure 10—Effect on Marshall Properties of Replacing Conventional Aggregate with Black Clawson Glass-Rich Fraction and Clean Glass

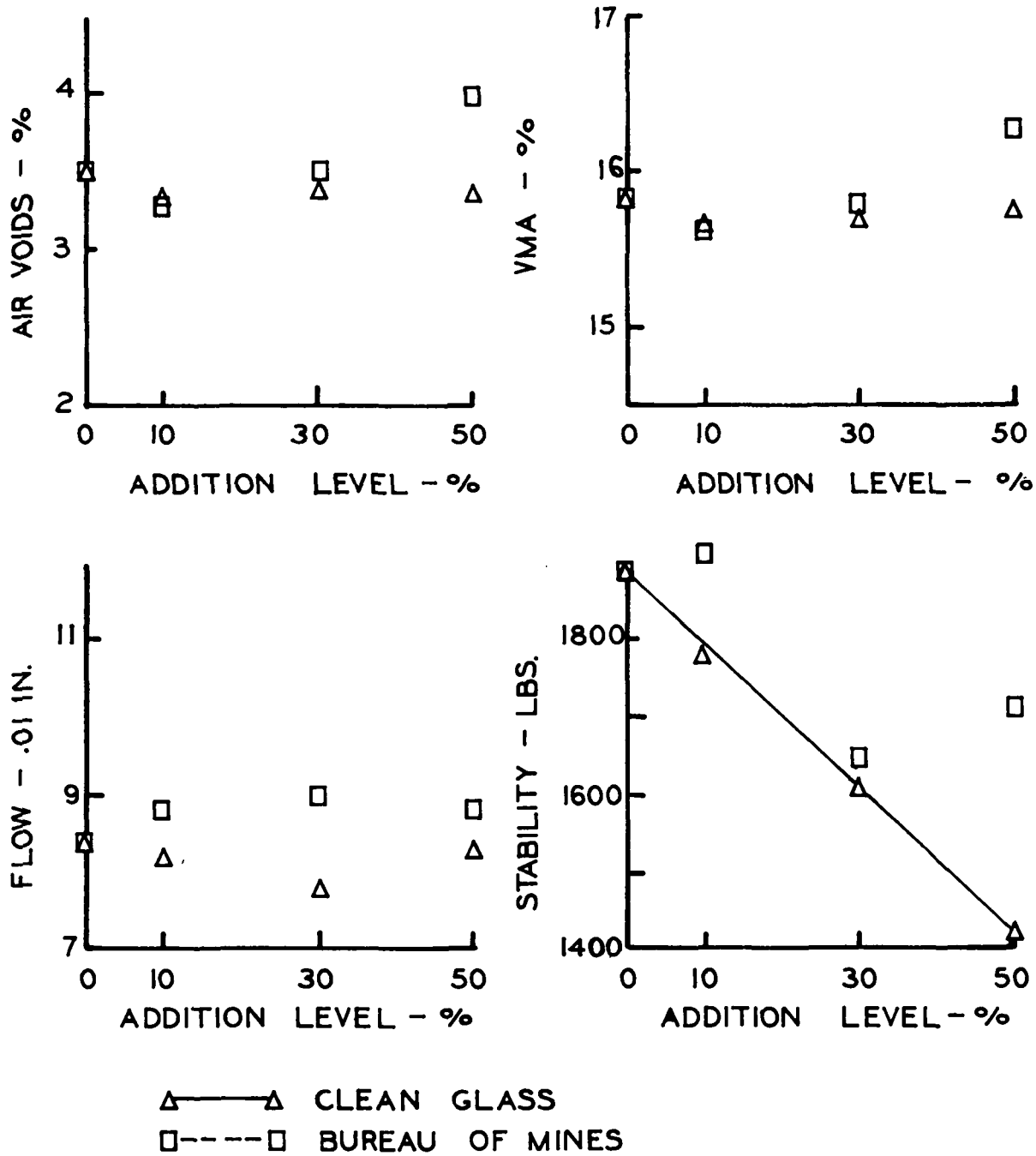

Figure 11—Effect on Marshall Properties of Replacing Conventional Aggregate with Bureau of Mines Glass-Rich Fraction and Clean Glass

The clean glass replacement in the same test series resulted in a similar trend for stability decrease but there was no statistically significant change in flow. The air voids and VMA both dropped initially with increasing addition levels of the glass but then rose at a higher addition level. The changes were of the same magnitude produced by the glass-rich fraction.

In the test series using Bureau of Mines coarse residue there was no statistically significant effect upon stability air voids, VMA, or flow when increasing amounts of the residue were added to the control mixture. The graph shows a trend toward decreasing stability with increasing amounts of residue up to 50 percent replacement but the analysis of variance revealed no statistically significant differences. The clean glass replacement in the same test series indicated no effect upon air voids, VMA or flow but there was a linear decrease in stability with increasing additions of clean glass which was similar to the trend noted in the Black Clawson series. There was little difference in the effects of clean glass and the Bureau of Mines residue on voids or flow.

Table 9 shows results of the tests for compaction resistance on the control mixture and mixtures in which 50 percent of the aggregate retained on the No. 4, 8, and 16 sieves was replaced with clean glass or Black Clawson residue. There was no difference between the control mixture and the mixture in which clean glass had been substituted for conventional aggregate. However, substitution of Black Clawson material for conventional aggregate caused an increased

TABLE 9

COMPACTION RESISTANCE INDICIES FOR SPECIMENS CONTAINING CONVENTIONAL AGGREGATE, CLEAN GLASS, AND BLACK CLAWSON GLASS

	Treatment		
Replication	Conventional Agg.	50% Clean Glass (No. 4,8&16 sieves)	50% Black Clawson (No. 4,8&16 sieves)
1	4.66	5.24	6.60
2	4.97	5.08	7.36
3	5.36	4.87	7.91
Average	5.00	5.06	7.29

resistance to compaction which would indicate that some difficulties in achieving adequate densities might be encountered in the field. The acceptable range of compaction resistance index values, however, has not yet been defined due to a lack of correlation between laboratory results and field compaction experience.

Significance of Laboratory Studies

One way in which glass-rich fractions might be most efficiently utilized in an asphaltic mixture is to replace portions of the conventional aggregate in a suitable asphaltic mixture without appreciably altering the mix design. The results of these laboratory studies, utilizing medium to coarse glass to replace up to 50 percent of the same size conventional aggregate, indicate that the flow, air voids and VMA weren't changed to any great extent by the replacement. This was true whether clean glass or fractions containing up to 32 percent non-glass components were used. The stability was decreased by additions of clean glass or Black Clawson glass-rich fractions but, for the mixtures tested, stabilities were still well above minimum requirements specified by the Asphalt Institute. By simply blending glass-rich fractions into an acceptable conventional aggregate mixture it may be possible to use them without further processing or extensive modifications in mixture design to keep Marshall properties within specified limits.

Further studies of this type are being conducted using fine glass-rich fractions from incinerator residues. Also,

additional experimental data relative to the effect of glass-rich fractions on compactibility is being obtained. The results of this work should be of value in determining the most economical and efficient means for using waste glass in asphalt paving.

ACKNOWLEDGMENTS

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WASTE GLASS IN ROAD CONSTRUCTION

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ABSTRACT

Crushed waste glass, cullet, was substituted for stone aggregate in all five courses of the two northbound lanes in a section of Westwood Avenue, Toledo, Ohio. The two southbound lanes are of black top with conventional material. The traffic load is 10,000 vehicles per day with 22% being heavy trucks. The GLASPHALT® top layer of paving material has worn as well as the conventional pavement. Both skid tests show all the lanes to be approximately the same, possibly the GLASPHALT® material is a little better. Core samples show good adhesion between glass and asphaltic cement, with very few voids. Dynaflect deflection tests were taken after six months of use. No appreciable difference between the test strip and conventional road were found.

WASTE GLASS IN ROAD CONSTRUCTION

Pollution problems and the necessity of preserving the environment has caused an impetus in reuse or secondary uses of materials formerly disposed of in dumps as solid waste. The glass industry has taken a positive approach in several of their research efforts. Extensive work has been directed toward primary reuse or putting waste glass back into furnaces to make new glass containers. The use of waste glass for such operations may be costly due to transportation or handling operations.

The interest in secondary uses for waste glass has expanded in the last decade.[1] The use of glass as a substitute for stone aggregate in the top layer of road construction has been reported in many articles.[2] The first GLASPHALT® material test strip was placed at the entrance to the Owens-Illinois Technical Center parking lot at Toledo, Ohio on October 4, 1969. Several other strips have been placed in this country and in Canada. A second test strip was placed in front of the Owens-Illinois Technical Center in November of 1970. The strips placed at Owens-Illinois both show good wear characteristics.

The idea of using glass as a stone aggregate for complete road building was suggested to the Highway Department, State of Ohio early in 1971. The use of glass recovered from trash as an aggregate substitute appeared to be most favorable, especially in urban areas where, because of high population density, more waste glass is generated. Waste container glass makes up about 6% of the solid waste stream; however, the percentage has been found to be somewhat greater in cities. Waste glass is not troublesome because it is an inert material and does not degrade. Many places use this as a good

landfill material. The suggested use of such landfill material for highway construction was agreed upon by the State of Ohio on a test basis. Systems are presently designed or being designed which separate the components of solid waste into paper, metals, and glass.[3] The disposal of such recovered glass into road construction was the goal of this project. The experiment was called The Westwood Project because Westwood Avenue in Toledo was the roadway selected for this test.

Westwood Avenue is a major north-south artery in Toledo and carries maximum traffic. It is a four lane pavement with turning lanes at major intersections. The traffic count for this roadway is about 10,000 vehicles per day with 20% being heavy truck traffic. It is estimated that the 1990 traffic count will approximate 17,000 vehicles per day. The road construction is typical, 6'' subbase, 9'' base, 3'' bituminous cement aggregate base, 1-1/4'' asphaltic cement leveling course, and a 1-1/4'' asphalt surface course. The decision to use glass in all five courses of the two northbound lanes required using about 1500 tons of waste glass as a substitute for stone aggregate.

The pavement test section was approximately 1000 feet long, and divided into five sections of 200 feet each. The first 200 feet section had a waste glass replacement for aggregate in all layers as shown in Figure 1. Each successive 200 feet test section had one less layer of pavement using waste glass aggregate; in these test sections regular stone was used where needed. The top layer was 1-1/4'' of No. 404 with glass replacing aggregate. This 1000 feet of GLASPHALT® paving extended from Hartwell to Hawkins Avenues in the two northbound lanes of Westwood Avenue.

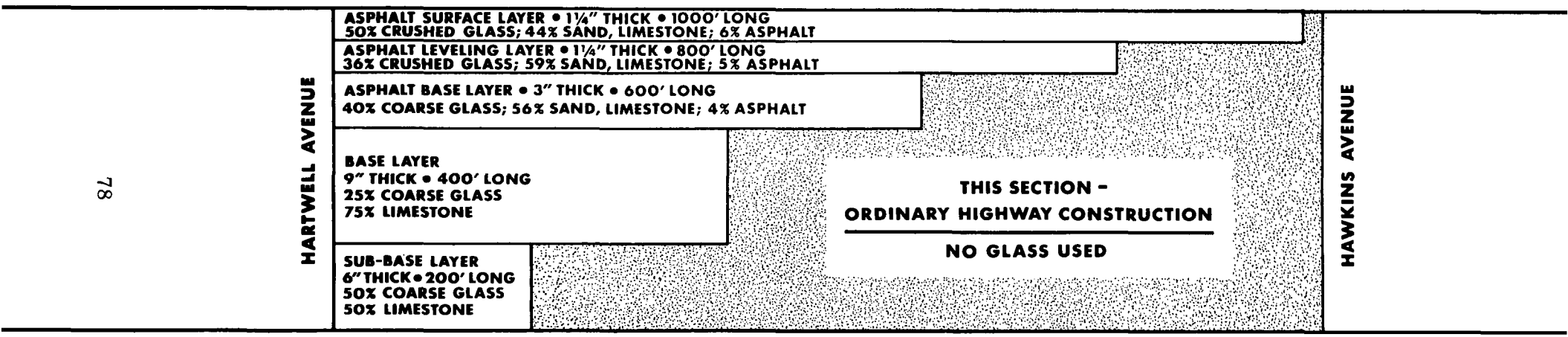
The glass used would be considered a typical mixture with various colors and thicknesses. The mixed color recovered glass has very little

Figure 1

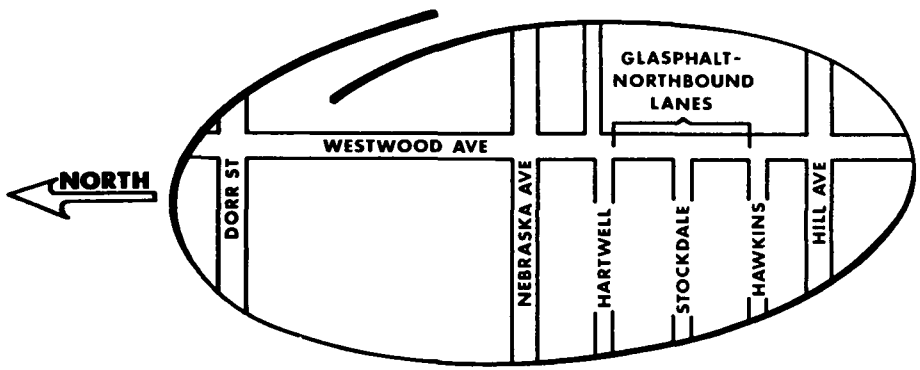
WORLD'S LARGEST "GLASPHALT®" INSTALLATION

TOLEDO, OHIO • OCTOBER 1971

Cross-Section View* of Northbound Westwood Avenue Lanes Between Hartwell and Hawkins Avenues



*ALL PERCENTAGE FIGURES ARE APPROXIMATE.



NOTE: 1450 TONS OF WASTE GLASS SUPPLIED BY OWENS-ILLINOIS, INC. UTILIZED IN PROJECT

demand in the glass container industry because color mixed glass causes problems in glass container manufacturing.[4] The waste glass used in this test, while similar in thickness and size to that recovered from trash, was cullet from the Libbey plant of Owens-Illinois in Toledo and therefore much cleaner than what would be expected of glass recovered from a solid waste stream.

To substitute glass for stone aggregate in all five road courses required that the glass fulfill the requirements of conventional aggregate for a complete roadbed. For all materials used in the Westwood project, sizing and other necessary tests were carried out in order to comply with the Ohio State highway regulations.[5] The subbase, commonly called No. 310 by the State of Ohio was composed of 50% limestone and 50% glass which agreed with State specifications for No. 310 stone subbase sizing. This combination was blended by front end loaders placing the mixtures into piles and then mixing portions of the piles into new piles. The material was loaded into trucks and spread on the first 200 feet of the roadbed. The remaining subbase was composed of regular 310.

The next layer is an aggregate base referred to as No. 304, composed of 75% limestone and 25% glass. This was also mixed using front end loaders and spread on the first 400 feet of roadbed with the remainder placed with regular 304 material.

The bituminous base course was composed of 40% glass and the remainder was stone, sand, and asphalt. Figure 2 gives the size and approximate percentages of the materials used. This bituminous mix, State specification 301, was blended at an asphalt plant and trucked from the plant to the roadbed site. The material was placed with conventional equipment and rollers. This strip was 600 feet in length and two lanes wide. The

Figure 2

COURSE	STATE DESIGNATION	SIZE	%	MATERIAL
SUB-BASE	#310	-3/4"+200M	50	GLASS
		-3/4"+200M	50	STONE
AGGREGATE	#304	-1"+1/2"	25	GLASS
		-1"+1/2"	75	STONE
BITUMINOUS BASE	#301	-3/4"+1/2"	40	GLASS
		-1"+3/4"	10	STONE
		-3/4"+1/2"	23	STONE
		-1/4"+200M	23	SAND
			4	ASPHALT CEMENT
ASPHALT LEVELING COURSE	#402	-7/16"+1/4"	16	GLASS
		-1/4"+200M	20	GLASS FINES
		-3/4"+1/2"	38	STONE
		-1/4"+200M	21	SAND
			5	ASPHALT CEMENT
SURFACE	#404	-7/16"+1/4"	27	GLASS
		-1/8"+200M	23	GLASS FINES
		-7/16"+1/4"	24	STONE
		-1/8"+200M	20	SAND
			6	ASPHALT CEMENT

remaining roadway for this course was composed of regular No. 301 mix. The leveling course usually referred to as No. 402 had 36% glass, 59% stone and sand, with 5% asphalt as the binder. This layer was 800 feet long. The top layer, GLASPHALT® paving material, was composed of 50% glass, 44% aggregate and sand, with 6% asphalt and was 1000 feet in length.

All the materials were mixed in a conventional asphalt mill. No special handling or equipment was required either in crushing or placing this material upon the road. A diagram of the crushing plant is shown in Figure 3. Standard jaw crushers, impact crushers, and hammer mills were used with standard screening devices in order to handle this waste glass--just as one would handle stone aggregate in a normal road building operation. Some difficulty was anticipated in the crushing of glass for aggregate replacement. The crushing plant operators reported no more dust problems with this material than with normal limestone crushing. The gradations, sieve size measurements, for the asphaltic blended items (Nos 301, 402, and 404) are shown in Figures 4, 5, and 6. The shaded area is the zone in which the material sized must fall. The line is the actual measurement of material used in this project. The values are approximate for the material prior to blending. The crushing operation on the glass did not make as many fines as are normally produced in stone crushing. In most cases, glass which would be recovered from municipal sites would probably have most of the breaking or crushing already accomplished. In this experiment, sand was added to the glass aggregate mixtures because sufficient fines were not produced in the glass crushing.

The State Highway Department testing engineers suggested what percentages of glass aggregate should be blended with stone to accomplish what was

Figure 3

CRUSHING PLANT

FLOW DIAGRAM

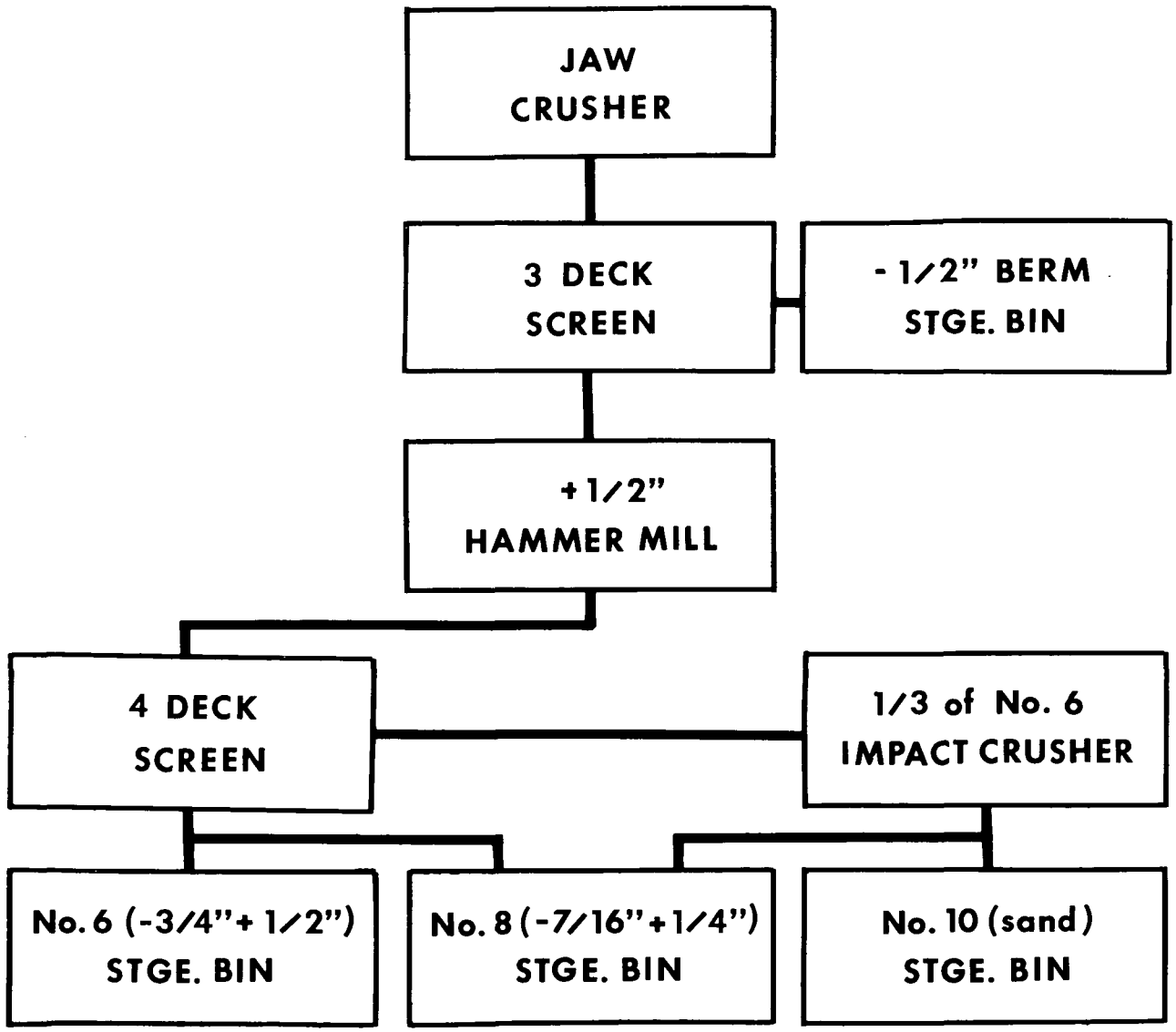
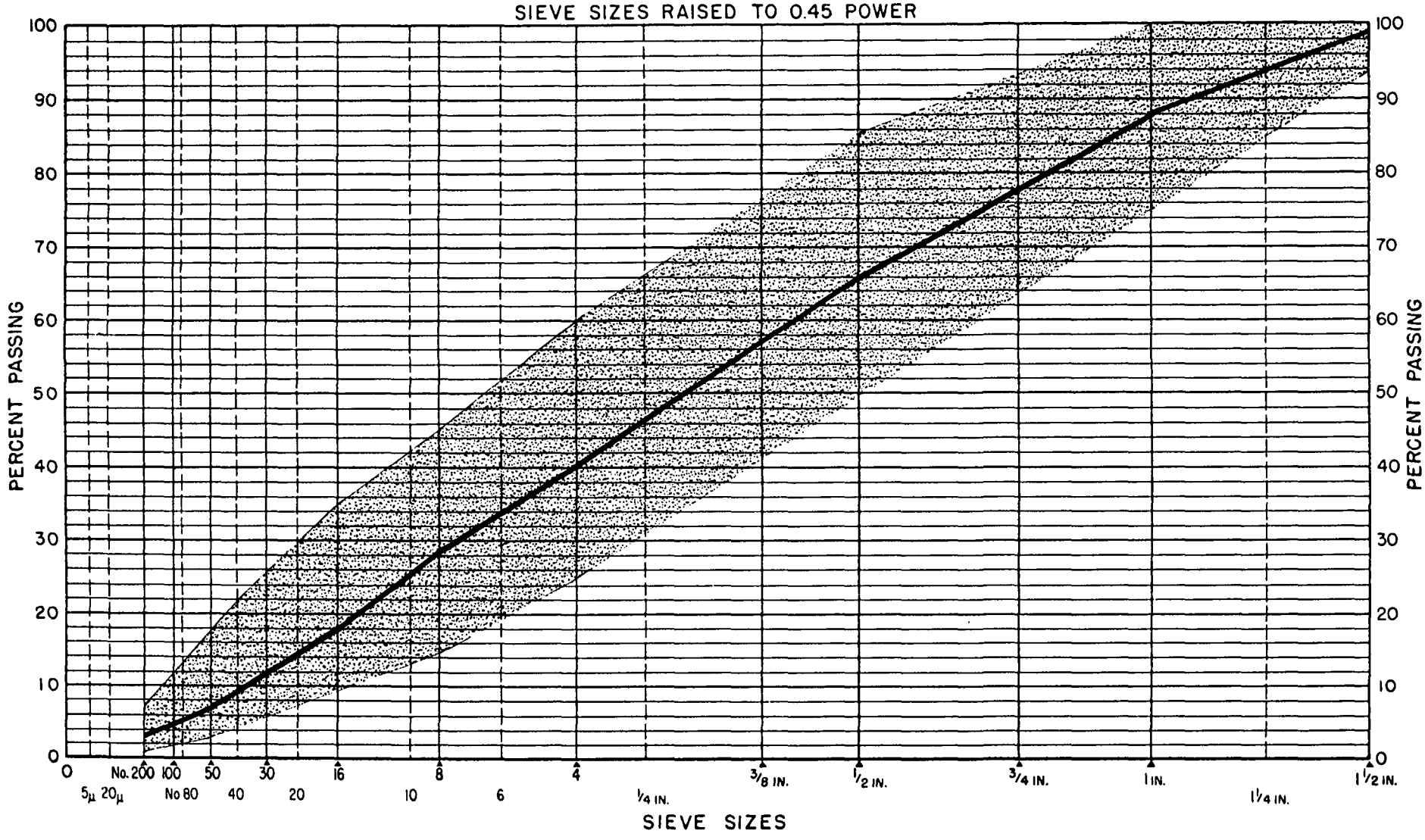


Figure 4

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES

Idenification of gradations:

ITEM 301 40% GLASS 60% LIMESTONE

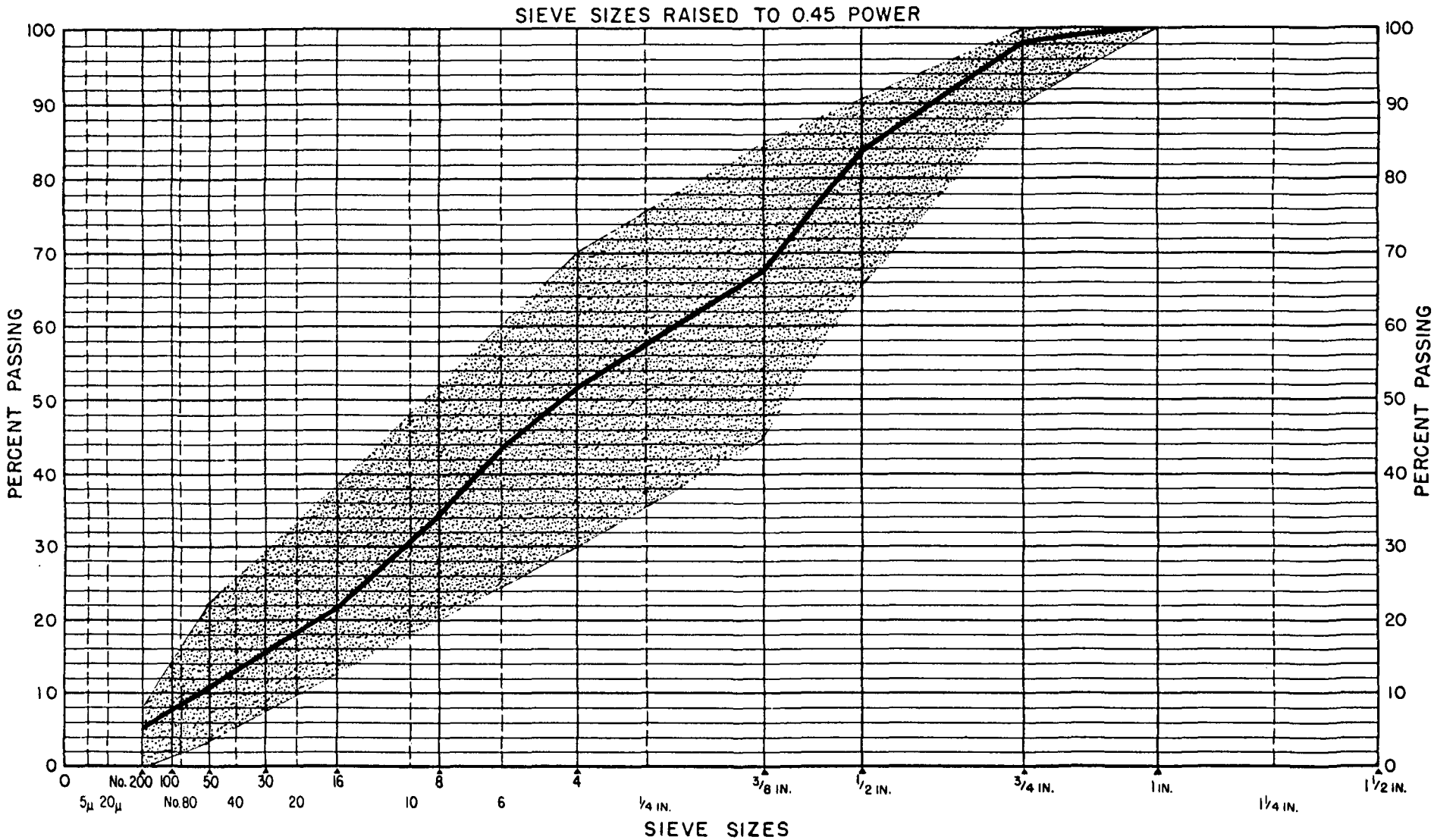
Sheet No.

Date

Form No. GC-3

Figure 5

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES

Idenification of gradations:

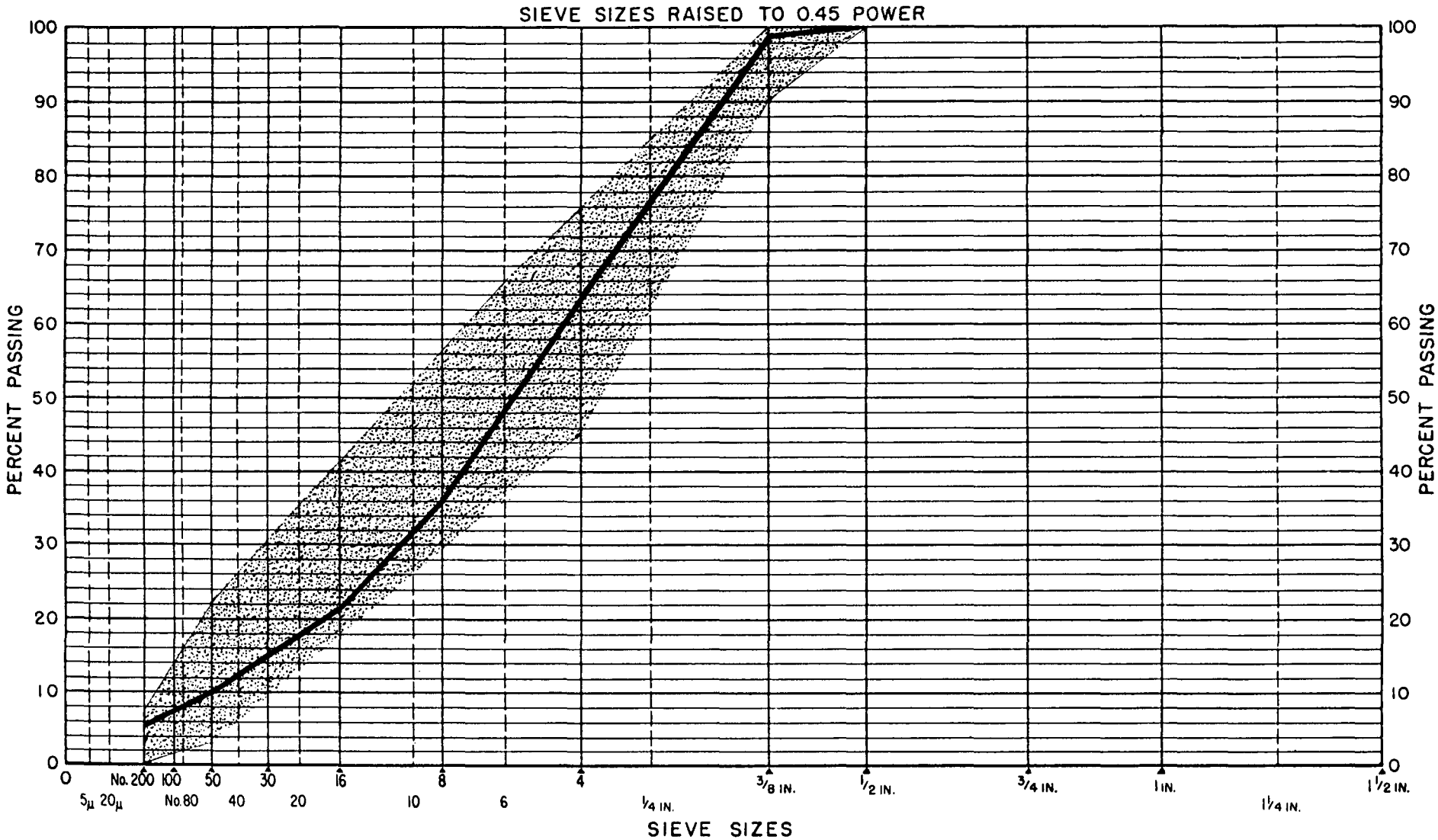
ITEM 402 36% GLASS 64% LIMESTONE

Sheet No.

Date

Figure 6

UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART



▲ THIS SYMBOL IDENTIFIES SIMPLIFIED PRACTICE AND COMPATIBLE SIEVE SIZES

Identification of gradations:

ITEM 404 50% GLASS 50% LIMESTONE

Sheet No.

Date

Form No. GC-3

required for each layer of pavement. This suggestion was based upon a preliminary sieve analysis of the glass aggregate which had been crushed. The glass replacement for aggregate which was incorporated into each course of the road was sized as suggested in the original road design. Some difficulty was encountered in blending crushed glass with limestone. Mixing using a front end loader as opposed to bin mixing was not efficient. This was especially true with the non-asphalt course materials. This could easily be overcome by using bins and conveyors for mixing a more uniform blend.

Because of the basic research, which was accomplished initially at the University of Missouri at Rolla[6], hydrated lime was added to the asphaltic and glass mixtures in order to improve the adhesion. It had been suggested by the researchers[7] at Rolla that at least to improve adhesion, a 1% hydrated lime by weight of the aggregate should be added and blended with the various hot mixes in which one was utilizing glass as an aggregate. Since glass is essentially non-porous, the surface is extremely smooth. It was suggested that there would be very little mechanical bonding between the asphaltic cement and the glass aggregate, unless hydrated lime or an anti-stripping agent were added.

Stabilization during compaction of the subbase aggregate-glass material was somewhat difficult. It was noticed that the water which was sprinkled on the material to promote compaction quickly drained away. A possible reason for this is the fact that some of the crushed glass surface was very smooth and therefore mechanical locking between particles was minimized. However, this high degree of permeability suggests that a blend of crushed glass and stone would be advantageous for usage as an aggregate back-fill for under draining.

Instability was not noted when the 25% crushed glass was used in a mixture with stone in item No. 304. There was no suggestion of instability or other problems while compacting or rolling the other layers. Limestone was the stone aggregate in all five courses. The asphaltic cement contents of items 301, 402, and 404, which were incorporated with the glass substitute for stone, were 4.2, 5.0, and 5.5 percent respectively by actual analysis.

It was also noted that the glass aggregate seems to retain heat longer and as such it was suggested that the mixing temperature of the glassphaltic mixtures be reduced to between 250-275°F. The reduction in mixing temperatures will have a tendency to minimize the delays in compacting due to the tendency of a very hot glassphaltic mixture to crawl during breakdown rolling operations. However, there were not great differences found in the mixing and construction operations of a glass substituted for stone aggregate as compared with a standard asphaltic paving operation. The high heat was noticeable. However, after laying the first course, it was decided to minimize the temperature somewhat, and placing a second layer as well as the topping layer with reduced heat, caused no difficulties as far as rolling or finishing the surfaces.

The surface of a GLASPHALT® paving material road does have some particles of glass lying in such a way that they give some reflection. This serves to show where the pavement surface begins and ends, and it may be a benefit to traffic safety. However, because of the break up of the glass, it is not such that there is a highly reflective character which could cause blinding by head lamp reflection on this type of roadway.

Skid tests were conducted on the Westwood Avenue project on November 30, 1971 by the Office of Research and Development of the Ohio State Department of Highways. Test procedures were used which conformed with ASTM E-274

Figure 7

SKID RESISTANCE OF GLASS AGGREGATE PAVEMENT

Westwood Avenue, City of Toledo, November 30, 1971

	SKID NUMBER SN_{40}			
	Southbound Lane		Northbound Lane	
	1	2	3	4
Glass Aggregate Mix			42	43
			45	40
			40	40
			43	34
			43	39
			40	40
			40	51
			44	43
			42	43
			40	
No. of Tests			10	9
Range			40-45	34-51
Avg. SN_{40}			41.9	41.5
Regular 404 Mix	34	40	33	32
	32	49	36	30
	53	49	47	45
	51	47	50	47
	50	48	45	
	54	49	49	
	50	47		
	51			
No. of Tests	8	7	6	4
Range	32-54	40-49	33-50	30-47
Avg. SN_{40}	46.9	47.0	43.3	38.5

Standards. The results of those skid tests are shown in Figure 7. The skid tests show that there is not a significant difference between the regular topping (404 mix) and a GLASPHALT® material topping. If anything, the GLASPHALT® material may have a slight bit more skid resistance. Each individual test, the value spread and the average value for each lane of the conventional topped road can be compared.

SN 40 represents the standard skid number representing a standard speed of 40 miles per hour. The suggested minimum skid number, at SN 40, for main roadways is 33.[8] Larger skid numbers correspond to greater skid forces and better skid resistance.

The differences in the average values between the glass aggregate topping and the conventional pavement are indicated. It is noteworthy that the values found were all within an acceptable level, and the non-uniformity of the several runs would not be considered unusual in normal new bituminous pavement tests. Additional tests after further aging would give a better indication regarding the skid resistance of these materials. The State of Ohio intends to run another set of tests. These tests have not been accomplished to date due to scheduling problems and weather.

Dynaflect measurements were also taken on November 15, 1971. Data generated from these tests are shown in Figure 8. Values for maximum deflection, surface curvature index, and spreadability were determined for each pavement composition section. The surface curvature index is a measure of pavement stress, whereas the spreadability is a measure of the pavement stiffness. The average values are indicated and it can be seen that maximum deflection, surface curvature index, and spreadability for all of the test sections were relatively uniform. The engineer[9] who made the tests stated that he really couldn't see any significant difference in the conventional

Figure 8

AVERAGE DYNAFLECT MEASUREMENTS

LOCATION	SENSOR 1 DEFLECTIONS IN MILLI-INCHES	S C I SURFACE CURVATURE INDEX	S SPREADABILITY
GLASS AGGREGATE IN ITEM 404 LAYER	0.81	0.12	64.8%
GLASS AGGREGATE IN ITEM 404 AND ITEM 402 LAYERS	0.79	0.12	65.7%
GLASS AGGREGATE IN ITEM 404, 403 AND 301 LAYERS	0.84	0.14	64.2%
GLASS AGGREGATE IN ITEM 404, 402, 301 AND 304 LAYERS	0.84	0.12	65.5%
LIMESTONE AGGREGATE IN ALL LAYERS	0.70	0.07	66.9%

asphalt pavement and the glass replaced for aggregate pavement.

Core samples were removed from the street on October 11, 1972 beginning at 100 feet from the south end of the test section in both lanes. Cores were taken every 200 feet thereafter with a total of 20 cores removed. Figure 9 shows a typical core. The cores were carefully examined and checked for voids in the material. No apparent differences between the glass aggregate replaced for stone and normal stone pavement were found. The State of Ohio at the present time is studying ten of the cores. Another set of ten cores was taken to the University of Toledo where they were stressed on a Tinius Olsen machine. The main purpose of this testing was to find out what would happen when great stress was placed upon a core of this material. The separation of the glass from the asphaltic binder had been suggested. Figure 10 shows a core after it was stressed. Unfortunately the photograph does not clearly show the separation or breaks through the aggregate or glass. However the arrow points to one found after stress tests. In every case either the rock or glass broke before the asphaltic cement separated from the surface of either aggregate or glass.

The cores which were stressed in this apparatus all failed at approximately 100 pounds per square inch. After 14 months, the surface of Westwood Avenue where GLASPHALT® paving material was placed compares favorably with the pavement which was placed at the same time. There is some difference in roughness of the surface--the GLASPHALT® material being rougher than the rest of the road. No cracks, breaks, or pot holes have appeared in any section of this roadway to this time. This experiment does show that glass aggregate may be used not only in the top layer, as GLASPHALT® paving, but in all courses for road construction.

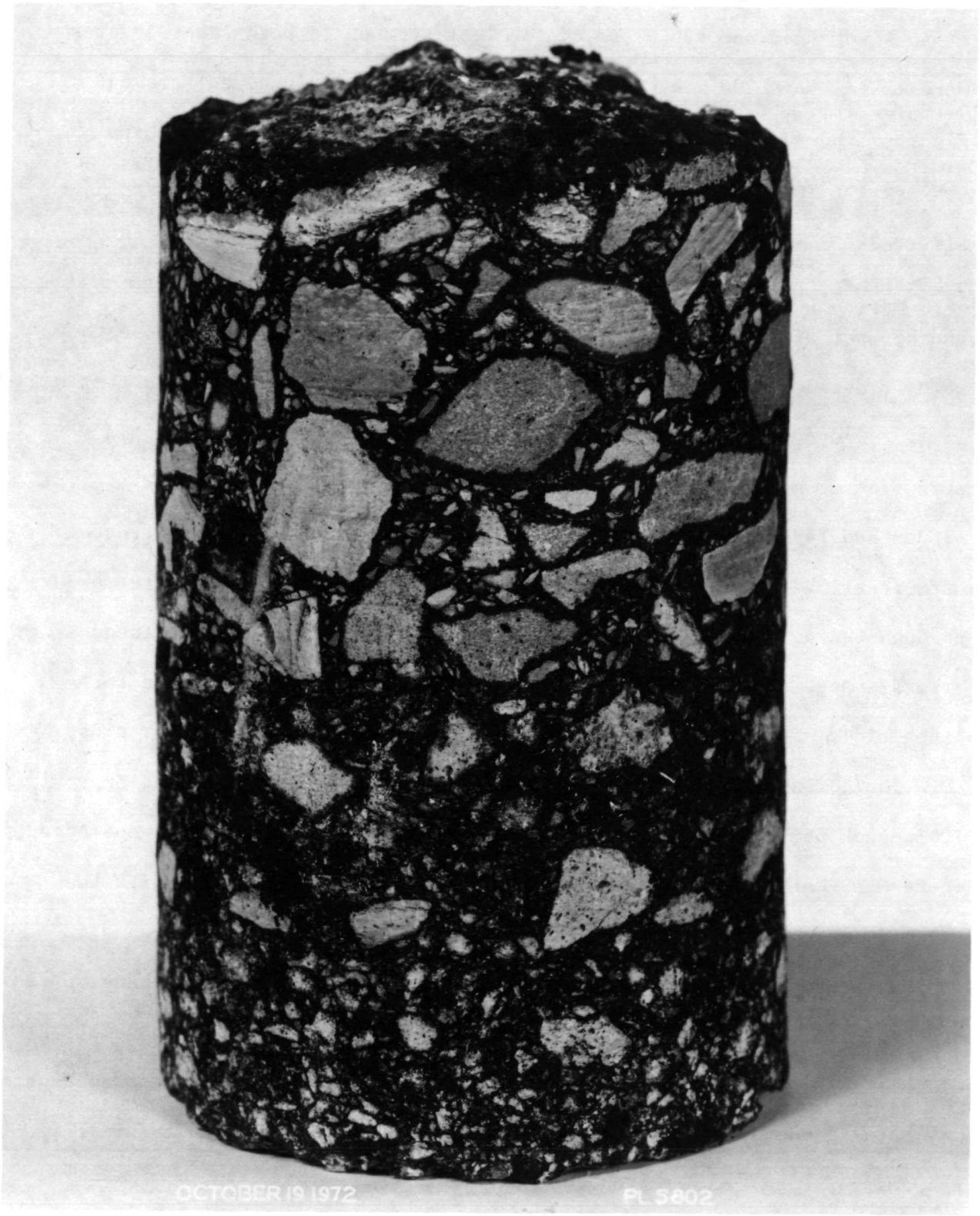


Figure 9

Figure 10

Compared with the total amount of material used in the United States, waste glass is insignificant. However in urban areas where there is a fair amount of glass recoverable which under some system will be recovered, the use of glass as an aggregate for replacement for stone is a viable and useful method for waste disposal. When disposal of waste glass in sanitary landfills is impractical for transportation or other reasons, an alternate disposal method would be to use recovered glass as a material for roadbed construction, backfill or paving with bituminous cement.

The author wishes to acknowledge the valuable help from C. Ray Hanes, Ohio Department of Highways; Eugene Kasper, Service Director City of Toledo; David D. Young, City of Toledo; and Burton R. MacRitchie, president of A. S. Langenderfer, Inc., contractor for the Westwood Project.

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COLD WEATHER PAVING WITH GLASPHALT

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INTRODUCTION

Field tests of glasphalt pavement have shown abnormally long periods of time required for cooling of the glasphalt mat compared to conventional asphalt mats. Under cold weather conditions, this extended cooling time for glasphalt would be extremely beneficial in allowing increased time for compaction of thin mats, where, with conventional asphalt pavement, paving operations would not be possible (1, 2).

To achieve adequate compaction of hot-mix asphalt pavement, the temperature of the mat must be sufficiently high for the period of time necessary to complete rolling. Because failure of asphalt pavement is usually related to insufficient compaction, it is highly desirable to extend the allowable time for compaction for cold weather paving.

The purpose of the present study was to determine the thermal conductivities of glasphalt and various percentages of glass and stone aggregates in asphalt mats and to determine the mechanism by which the thermal conductivity of glasphalt is lower than that for conventional asphalt pavements.

EXPERIMENTAL PROCEDURE

To investigate the mechanism for decreased glasphalt conductivity, experimental testing was carried out on a model rotary dryer as well as hot line source experiments for thermal conductivity.

TESTING ON MODEL ROTARY DRYER

Twenty-seven experimental runs were performed with the model rotary countercurrent dryer which was constructed for this work. Results of these tests are summarized in Table I.

The "effective" heat capacity as here defined is a measure of the relative ease of energy transfer to and within the aggregate material. "Effective" heat capacity is the heat capacity that would be required for the material to absorb the energy that it did (as found by calorimetry) and for the material to be at "bulk" temperature

TABLE I

Model Rotary Dryer Data

Run	Material	Aggregate Moisture Content: Dryer Inlet	Aggregate Moisture Content: Dryer Exit	"Effective" Heat Capacity: $\frac{Cal}{g\ ^oC}$ or $\frac{Btu}{lb\ ^oF}$	
1	Sand	--	--	0.1523	
2	Sand	--	--	0.2199	0.1827 Avg
3	Sand	--	--	0.1758	
4	Stone Aggregate	--	--	0.0965	
5	Stone Aggregate	--	--	0.1254	0.111 Avg
6	Stone Aggregate	--	--	0.1112	
7	Glass Aggregate	--	--	0.1565	
8	Glass Aggregate	--	--	0.1650	
9	Glass Aggregate	--	--	0.1745	0.164 Avg
10	Glass Aggregate	--	--	0.1617	
11	Glass Aggregate	--	--	0.1622	
12	Stone Aggregate	5.43	3.04	0.2002	
13	Stone Aggregate	3.59	1.38	0.1440	
14	Stone Aggregate	3.46	1.43	0.1543	
15	Stone Aggregate	0.83	0.11	0.1290	
16	Glass Aggregate	4.7	1.6	0.2770	
17	Glass Aggregate	5.72	3.5	0.2198	
18	Glass Aggregate	3.09	1.94	0.1897	
19	Glass Aggregate	5.00	2.06	0.2184	
20	Asphalt Coated Glass (2.42%)	--	--	0.2120	
21	Asphalt Coated Glass (2.42%)	--	--	0.1750	0.1935 Avg
22	Asphalt Coated Glass (3.91%)	--	--	0.2290	
23	Asphalt Coated Glass (3.91%)	--	--	0.2420	0.2355 Avg
24	Oyster Shell	--	--	0.1984	0.2125
25	Oyster Shell	--	--	0.2265	
26	-3 +4 Mesh Stone Aggregate	--	--	0.1913	
27	-3 +4 Mesh Stone Aggregate	--	--	0.1995	0.1954 Avg

throughout. A low value of the "effective" heat capacity indicates that the particle has not been heated through to the center and that the internal temperatures are lower than the outer or bulk values. A schematic of this is given in Figure 1.

The model, rotary, gas-fired dryer was fabricated from a 6-inch diameter steel pipe, 30 inches in length. Five evenly-spaced flights, 1.0 inch in height, extended 20 inches from the aggregate inlet end.

Bulk temperature of the aggregate was measured at both the inlet and exit of the dryer. After steady-state conditions were achieved, a sample of the aggregate was taken at the dryer exit and quenched in a water calorimeter. Measurement of the initial and final water temperature together with the temperature of the aggregate at the dryer exit and the masses of both the water and aggregate allowed the calculation of the "effective" heat capacity of the aggregate. This calculation is based on the assumption that the entire mass of the aggregate particles is at the measured bulk temperature. The accuracy of this assumption depends, of course, on the effectiveness of heat transfer to the aggregate particles and the ease of conduction within the particle. For our purposes here, i.e., evaluation of the relative effectiveness of heat transfer to different types and shapes of aggregate, this is what is needed. It should be noted that the purpose of testing in the dryer was not to dry various materials but to compare effectiveness of heat transfer to various types of materials. The net result of all this is that, on a relative basis, the higher the reported "effective" heat capacity the better is the heat transfer to and within the particle.

Examination, in Table I, of the "effective" heat capacity values for the first eleven runs shows average values:

Material	$Cp_{effective}$ (average)
Sand	0.1827
Glass Aggregate	0.164
Stone Aggregate	0.111

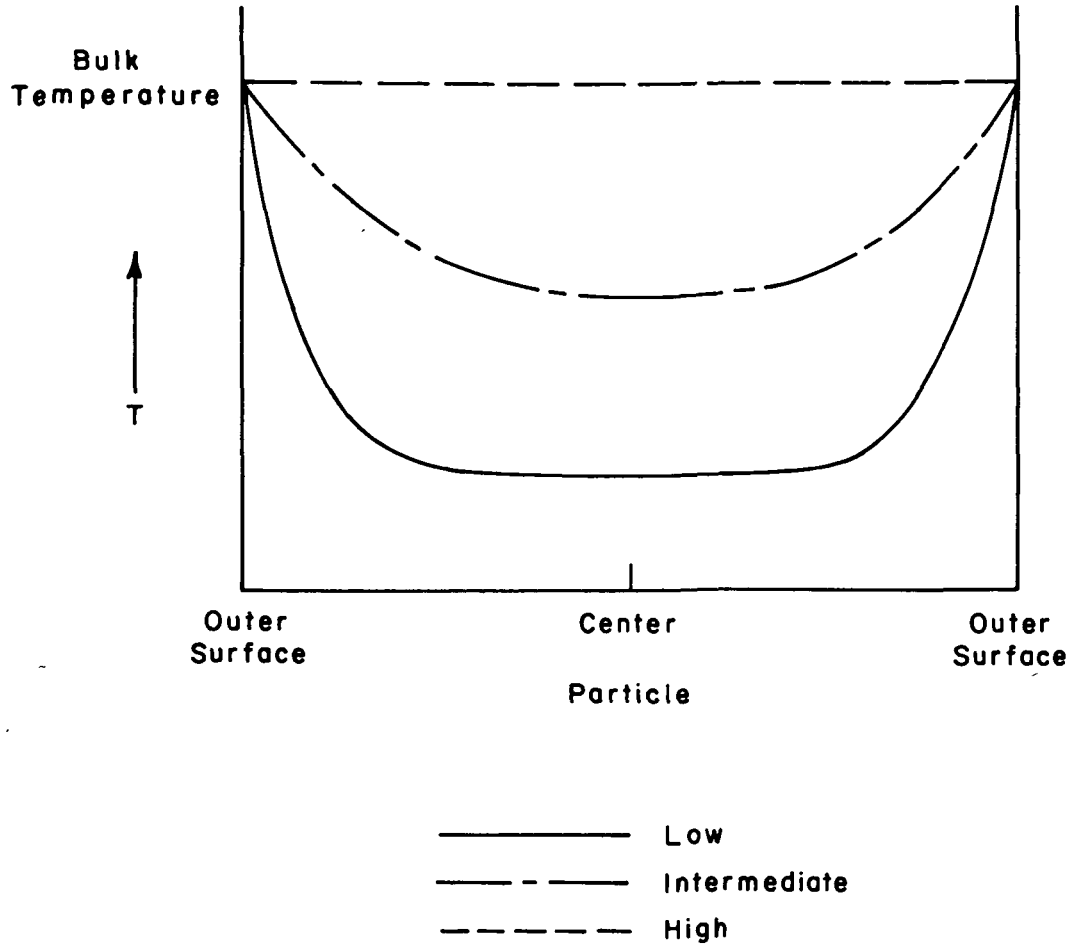


FIGURE 1

"Effective" Heat Capacity

From the prior discussion, we can see that the sand particles have the more uniform temperature distribution throughout and the stone aggregate the least uniform (i.e., the center of the stone aggregate particles is much lower than the outer surface).

The sand particles are of the same general shape as the stone aggregate. Because of their small size, the sand particles have a very short conduction path within the particle as well as a large surface area per mass. The result is a much more rapid heating for sand than stone aggregate. In this regard, a comparison between the experimental results and the true heat capacity for sand is of considerable interest. At the temperatures involved here, sand (quartz) has a heat capacity of about 0.185, to be compared with the experimental average of 0.1827. Not only does this close agreement indicate that the temperature throughout each particle is nearly uniform at the measured discharge temperature, but also that the experimental procedure and measurements were valid.

The glass aggregate is relatively large in one dimension and relatively small in another. The net result, in comparison to stone aggregate, is a larger surface area for heat transfer and a short conduction path in one direction. Results of the foregoing can be seen in comparing the "effective" heat capacities of glass and stone aggregates.

Runs 12 through 19 were performed on stone and glass aggregates which initially contained significant amounts of moisture. The physical situation in these runs is a transfer of heat into the particle. This heat must not only heat the particle but must also supply the latent heat of vaporization for the water being evaporated. This evaporated water diffuses outward from the particle and the relative cool vapor in the void space between particles causes a much lower "bulk" temperature. This lower "bulk" temperature results in a higher "effective" heat capacity, as can be seen from examination of an energy balance equation for the calorimeter. It should be noted for the cases where significant moisture content remained in the exit aggregate that the appropriate corrections in the energy balance equation were made.

Qualitative comparison of the "effective" heat capacity for the moist stone and glass aggregate runs shows the same greater heating of the glass aggregate as was observed on the preceding "dry" tests.

The asphalt coated glass aggregate (Runs 20 through 23) was tested to determine if internal absorption of radiant energy in glass aggregate was the explanation for glasphalt's slower cooling rate. If this internal energy absorption were significant or controlling, addition of an asphalt coating layer before heating would not allow the radiation to penetrate into the glass for absorption and result in a lowered "effective" heat capacity. However, the "effective" heat capacities obtained are higher for the asphalt coated glass aggregate than for the uncoated glass aggregate. This eliminates internal heat absorption in the glass as the mechanism for the decreased cooling rate of glasphalt over conventional asphalt. What physically occurs is that the black asphalt surface of the coated glass aggregate is a very effective absorber of the radiant energy impinging on it. The result is that this surface temperature (and the bulk temperature) goes up and creates a greater driving force for conduction into the particle. The net effect is a more effective heat transfer in the coated case than the uncoated case for glass. From this we can conclude that internal radiant energy absorption for glass is not a significant effect here and not the explanation we are seeking.

Oyster shell was tested as representative of the shape of crushed glass. Physical observation of the oyster shell shows its length-to-thickness ratio to be somewhat larger than that for glass aggregate. For this situation of increased surface area per mass and shorter conduction path, one would expect more effective transfer of heat. This was observed with a larger effective heat capacity for oyster shell than for glass aggregate.

The -3 +4 mesh stone aggregate was run to compare the effectiveness of heat transfer to an aggregate with a rather short but relatively fixed conduction path.

Conclusions to be drawn from the model dryer testing are:

1. Ability of glass to internally absorb thermal radiation is not the mechanism which explains glasphalt's decreased cooling rate.

2. Low residual moisture content for glass is not the answer either, as can be seen by comparing stone and glass aggregates with essentially zero moisture contents.

3. The shorter conduction path and larger heat transfer surface area per mass for glass aggregate as compared to stone aggregate result in a more effective transfer of heat to the glass. For the same measured "bulk" temperature, the thermal energy contained in the glass aggregate is actually greater than in the stone aggregate.

THERMAL CONDUCTIVITY DETERMINATIONS

Theroetical Basis

The transient line source was used to determine the thermal conductivities of glasphalt. In the transient line source method, heat is supplied at a constant rate from a long thin heater wire (line source). As the heat front expands radially from this line source, a thermocouple placed near the midpoint of the heater wire measures the temperature rise of the specimen being tested as a function of time. The specimen's thermal conductivity can be calculated from a relationship between the power input to the heater wire, the temperature rise of the sample, and time (3).

The size, shape, and surface characteristics are relatively unimportant for the purposes of this method. The proper ratio must be maintanied between the length and diameter of the line source, however. A ratio of 100 to 1 is considered ideal and 30 to 1 minimal (3).

Experimental

The hot mix samples (both glass and conventional aggregate) were prepared by the Marshall method. The samples, of 4-inch diameter, are allowed to cool

after compaction before the hole is drilled for the probe assembly. Due to the restriction placed on the length-to-diameter ratio of the line source, it is desirable to drill as small a diameter hole as is practical. The heterogeneous nature of the samples being drilled places lower limits on the size hole drilled. The smallest carbide-tipped drill which can be used successfully has been found to be 1/8 inch diameter.

The length-to-diameter ratio for the prepared samples is 32, within the minimum value discussed previously. The only sample where this minimum value was violated was in the case of the road core sample* from Jack Abrahams (GCMI) where the diameter was less than 4 inches.

The probes inserted into the samples consisted of chromel-alumel thermocouples (of 24 gauge wire) with 32 guage nichrome wire wrapped in a sprial around PVC shrinkable tubing which has been placed around the thermocouple. When the sample was placed in the oven, the nichrome wire was connected to the power source and the thermocouple was connected to the strip chart recorder.

The remaining equipment consisted of an oven ($\pm 0.5^{o}F$), a digital voltmeter), (±0.01 volts), a digital ammeter (± 0.001 amperes), a DC power source (1.5 amperes capacity), a strip chart recorder (0.1 mv full scale), and a standard resistance. The standard resistance, with a resistance essentially equal that of the probe, is used in the system to adjust the voltage and current, before switching to the probe curcuit.

The temperature rise (approximately $1.5^{o}F$) was measured as a function of time on the strip chart recorder as soon as current was passed through the probe. These results are plotted as temperature versus ln time, as indicated in the theoretical development. For a short period of time this plot is nonlinear due to the energy required to heat the probe itself. Following this heatup period, the predicted linear plot results, from which thermal conductivity can be calculated.

*From Anchor-Hocking, Winchester, Indiana

DISCUSSION

The thermal conductivities, determined by the hot line source technique, are given in Table II. Samples with various percentage compositions of glass and conventional aggregate were tested, as well as fine sand and oyster shell. The reason for testing the fine sand and oyster shell was to provide additional checks on the mechanism responsible for the decreased thermal conductivity observed for glasphalt samples as compared to conventional aggregate.

In addition to the prepared samples tested, thermal conductivities were determined for road core samples obtained from Anchor-Hocking and the Glass Containers Corporation.

The majority of the testing was carried out at temperatures of approximately 200°F, since thermal conductivities of solids are known to be somewhat temperature insensitive. However, some testing was carried out at temperatures up to 250°F to obtain definition of the magnitude of the thermal conductivity variation with temperature in this temperature range.

In Table II the averages for the thermal conductivities determined at approximately 200°F are given for the various samples tested. A definite trend of increasing thermal conductivity with decreasing glass content can be discerned. A plot of these averages for the various compositions of glass is given in Figure 2.

The glass-aggregate mixture (glass + 50 mesh, stone aggregate - 50 mesh) was studied because of its potential practical application. Crushing of glass to sizes below 50 mesh presents a considerably more difficult problem than that of obtaining the larger sizes. For this reason, a glass-aggregate mix of this type with the larger sizes of glass with a conventional aggregate filler in the smaller size range, might be used. The 0.473 value for k average obtained is in the range expected for an 86% glass mixture, as seen in Figure 2.

Oyster shell was run at the suggestion of Charles R. Foster of the National Asphalt Pavement Association as a model of the shape of the glass aggregate. Visual

TABLE II

Thermal Conductivity Results

Sample	Temperature °F	Density lb/cu ft	Thermal Conductivity Btu/ft hr °F	
100% Glass	200	131.8	0.362(2)	0.340 Avg
	199	131.8	0.333	
	199	131.8	0.326	
	206	133.0	0.397	
			0.40	
	244	131.8		
75% Glass	198	138.1	0.394	0.384 Avg
	197	138.1	0.373	
	203	140.0	0.464	
	249	138.1	0.445	
66% Glass	208	145.5	0.579	0.579 Avg
50% Glass	196	146.7	0.607(2)	0.594 Avg
	196	144.5	0.600	
	197	144.5	0.575	
	208	147.0	0.718	
	246	144.5	0.515	
25% Glass	200.5	152.2	0.776	0.752 Avg
	198.5	152.2	0.710	
	198	152.2	0.770	
	206	154.0	0.782	
	248	152.2	0.761	
0% Glass (100% Stone Aggregate)	199	158.7	0.99	1.07 Avg
	197	158.7	1.09	
	200	158.7	0.985	
	197	158.7	1.23 (2)	
	200	160.0	1.03 (3)	
	200	145.0	0.87 (3)	
	248	158.7	0.885	
Glass Aggregate Mixture (1) (glass +50 mesh, stone aggregate -50 mesh)	197	133.7	0.433	0.473 Avg
	203.5	133.7	0.512	
Sand (-100 mesh)	196	106.1	0.327	0.341 Avg
	197	106.1	0.355	
	249	106.1	0.293	
Oyster Shell	204	127.7	0.308	0.307 Avg
	197.5	127.7	0.307	
-3 +4 mesh Stone Aggregate	205.5	155.0	0.443	
Road Core Sample (from J. Abrahams) (2.7 in. D sample)	201	134.5	0.393	0.384 Avg
	197.5	134.5	0.375	
California Road Core Sample 1 (from Glass Containers Corp.) (~6 in. D sample)	198	130.0	0.332	0.343 Avg
	206		0.320	
	206	130.0	0.378	
California Road Core Sample 2 (from Glass Containers Corp.) (~6 in. D sample)	201	137.0	0.534	0.518 Avg
	203	137.0	0.485	
	204	137.0	0.590	
	196	137.0	0.464	

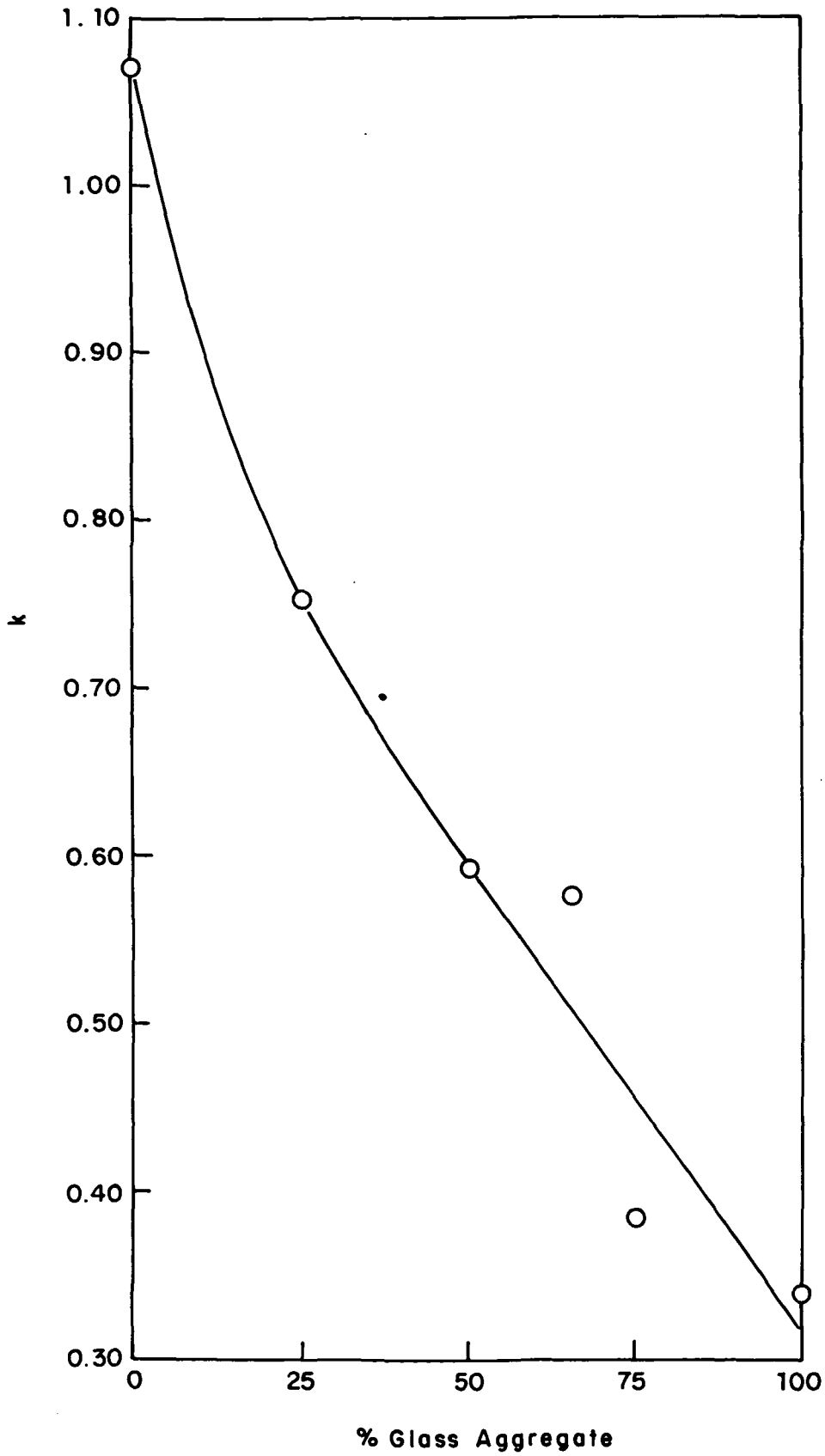
(1) Screen size distributions given in Table 3.

(2) Initial runs in which sample was placed in oven from 8 to 12 hr before testing. Some fluctuation was found in the experimental results. Subsequent tests were conducted with samples placed in oven 36 hr before testing. This eliminated the observed fluctuations.

(3) B. Gist's M.S. Thesis (CSM 1971).

FIGURE 2

k Average, 200°F vs Percent Glass Aggregate



examination of the oyster shell shows its thickness-to-length ratio to be less than that of the crushed glass. The -3 +4 mesh stone aggregate and sand were also run to test the postulated mechanism of decreased thermal conductivity for glass aggregate.

Thermal conductivity is not only a function of a glass content, but is also a function of the density of the compacted mat. It was observed in this testing that, for the same compaction conditions, an increase in glass content resulted in a decrease in sample density. However, examination of samples of similar density but different glass contents show the thermal conductivity to be a strong function of glass content. For example, from Table II we can extract the following data at 200°F for illustration:

Glass Content %	Density lb/cu ft	k Btu/ft hr°F
0	145.0	0.87
50	144.5	0.588 (average)
66	145.5	0.579

In the above tabulation, the density of these three samples is effectively constant at 145 pounds per cubic foot but the thermal conductivity decreases rapidly with increased glass aggregate content.

The thermal conductivity of the glasphalt road core sample from Anchor-Hocking is subject to a greater error than the other samples because its diameter was approximately 2.7 inches. For this sample then, the probe length to diameter was approximately 21.6, which violates the required value of 30 or greater to minimize error. The thermal conductivity determined for this road sample, 0.384 average, is certainly compatible with the values found for the prepared 100% glass samples, as seen in Table II.

The California Road Core Sample 1 contains approximately 63% glass, 36% rock dust, and 1% hydrated lime. The resulting average thermal conductivity, 0.343, is somewhat lower than one would expect for a 63% glass aggregate, ~0.5. The first

possible explanation is a greater orientation of the glass aggregate in the direction of compaction for the road sample than the laboratory sample. Visual inspection of these samples, which have been sliced in two with a diamond saw, shows no more pronounced orientation for the road sample than for the laboratory one. Both samples, however, show a distinct tendency of the glass particles to be oriented with their longer dimension parallel with the ground. The second, and more probable reason for the decreased k in the road sample, is that Figure 2 was prepared from data where the stone aggregate used contained large stone particles as well as small (see Table III. The 36% rock dust used in the California road sample would probably be as fine or finer than the sand used in this work. Noting from Table II that 100% glass aggregate has a k of 0.340 and that sand (fine stone aggregate) has a value of k = 0.341 it seems very consistent that the California Road Core Sample 1 has a k = 0.343, since it is in effect a mixture of these two.

The California Road Core Sample 2 is believed to be made of conventional stone aggregate. Although its measured thermal conductivity is lower than would be expected, its density is also somewhat lower than the stone aggregate samples tested. However, comparison of the two California samples shows the stone aggregate core to have a significantly higher thermal conductivity than the glass aggregate core.

Examination of the data determined on the various samples shows that the decreased thermal conductivity of glasphalt is due to a combination-of-resistances type effect. This can best be explained in conjunction with Figure 3. In Figure 3, three combinations of fixed amounts of relatively high and low conductivity materials are illustrated. Simple heat transfer calculations would show that the heat flow through System A will be much greater than B, which in turn is much greater than C. Analogy may be made to System B as a qualitative model of the stone aggregate mix where the relatively high conductivity material (stone) is in contact with the

TABLE III

Gradation Determinations

Stone Aggregate

Mesh		% Retained
-3/4 in.	+3/8 in.	30
-3/8 in.	+4M	20
-4	+8	15
-8	+30	17
-30	+100	10
-100		8
		100

Glass Aggregate

Mesh		% Retained
-3/8 in.	+4M	10
-4	+8	40
-8	+30	30
-30	+50	6
-50	+100	7
-100	+200	7
-200		
		100

Glass-Stone Aggregate

Mesh		% Retained
	Glass	
-3/8 in.	+4M	10
-4	+8	40
-8	+30	30
-30	+50	6
	Stone Aggregate	
-50	+100	7
-100	+200	7
		100

Oyster Shell

Mesh		% Retained
	+3/8 in.	0.0
-3/8 in.	+4M	68.3
-4	+8	29.6
-8	+30	0.2
-30	+50	0.9
-50	+100	0.2
-100	+200	0.3
-200		0.5
		100.0

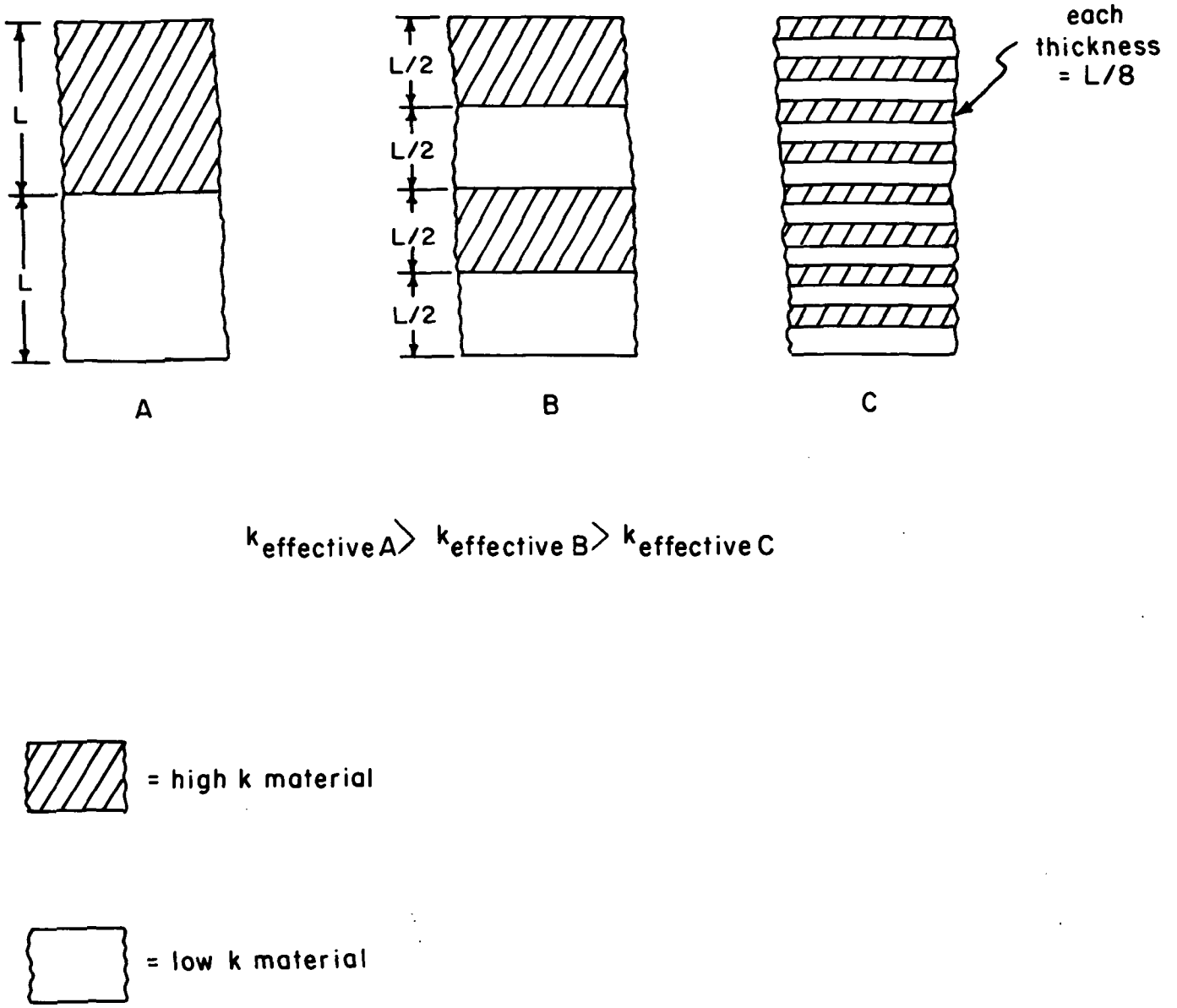


FIGURE 3

Effect of Combination of Resistances on Thermal Conductivity

relatively low conductivity asphalt. System C could be representative of glass aggregate systems. In making these analogies, it must be remembered that the glass aggregate tends to be oriented with its long dimension parallel to the ground and that the glass particles are thinner than the stone aggregate particles. Also to be remembered is that the actual thermal conductivities of glass and stone are of the same order of magnitude.

The combination-of-resistances model for the decreased thermal conductivity of glasphalt is consistent with the relative values of k determined for the various samples tested and with the visual observation of orientation in the glasphalt samples.

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QUESTION AND ANSWER PERIOD WEDNESDAY MORNING, JANUARY 24, 1973

QUESTION:

The technical aspects of glasphalt seem pretty well defined, and we can use relatively uncommon material such as glass for a purpose requiring just common rock. But what are the economic considerations relative to road life and extra road costs? Also what problems are involved in crushing glass with equipment made to crush rock? There are many waste materials which could be used instead of glass.

ANSWER: Dr. J. Cummings

At present, municipal separations systems are being readied to produce large volumes of waste glass. For example, the Black-Clawson system produces glass aggregate (glass-rich) material. There may be communities too far away from glass plants which could produce a sufficient amount of glass for use in products other than new bottles and jars. Disposal fees in many areas run as high as $4 to $5 a ton. Perhaps this glass material could be used in asphalted mix. Our responsibility was to determine if it could be used, where it could be used, and what the problem would be. Many systems produce a glass fraction up to 7/8" in size, such as Black-Clawson. Other systems produce a broken material up to 1/2" in size. In laboratory studies we had to crush our material to size, but I personally feel that the material coming out of the systems could be used directly without going through another crushing process.

ANSWER: Dr. P. Dickson

Concerning cold weather paving, you can handle this problem by several means. For example, you can place a 3" mat instead of a 1 1/2" mat which will work well in most of the cases we discussed. We are not conserving resources by doing this however. Other possible techniques that my group is looking at are to preheat the base before you put the mat down or add insulating material. In pre-heating, equipment will move along with a propane burner arrangement, for example, and pre-heat the base. But here again, we are using fuel, so this is not a conservation of natural resources.

The other way mentioned is to put an insulation layer down before putting down the mat. The advantage of using glasphalt is that it naturally has this type of advantage built in. We don't need to use more of our other materials. Further, rock aggregate is not cheap. It, in fact, is one of our largest costs in conventional asphalt. Generally from $1.50 to $5.00 a ton. In addition, the slow cooling of glasphalt is an advantage in cold weather paving.

ANSWER: Dr. Malisch

I want to cover another point. If a higher use of glass is available, the waste glass certainly should be used for that purpose. In other words, if color sorted cullet is available it should be used as a $15 a ton material to make new bottles instead of replacing a $2 a ton material. But in some cases

ANSWER: Dr. Malisch - continued

transportation costs will prohibit moving the glass to such points economically and in other areas this waste material may not be useful for other purposes. It could have too many non-glass components in it. It would be preferable to use the material as an aggregate having a value of perhaps $2 a ton rather than incurring a cost for disposal in a sanitary landfill.

The fact that there is not enough glass to replace all the aggregate is not a disadvantage of this concept. It simply means that there is a potential market for all of the waste glass that can be recovered. In fact, we have more of a problem finding where we can get this waste glass to use as an aggregate. We can't find these piles of waste that we hear about that were supposed to be created in the United States.

ANSWER: Mr. Bilbrey

The U.S. Bureau of Mines is developing a system which could be used by most large communities to separate the metals and glass and to sort glass into several color fractions for use in making new containers. Then the reject products of the mixed color glass could be disposed of in some of these secondary products to be discussed later in the day.

QUESTION:

I am Cyril Weeden of the United Kingdom and have followed glasphalt experiments closely. Many of my questions have already been answered today. In the United Kingdom, glasphalt is entirely a question of economics since rock aggregate is rather evenly distributed so there may be no great transportation costs involved for the aggregate. Speaking entirely from memory now, the position of the Road Research Laboratory is shown by this question. Why should we use glass at 3£ a ton processing when we can get an aggregate at 1£ a ton and the U.K. makes only 1.5 or 1.6 million tons (of glass) a year and we need something like 30 million tons a year as rock aggregate? So why not concentrate on special areas of research such as skid-proof junction areas where the costs are likely to be greater than that of normal road surfaces? To what extent has this particular aspect of road surface investigations been studied?

ANSWER: Mr. J. Bilbrey

The Bureau of Mines finds that waste glass available from municipal system may well be economic for glasphalt. First of all, the waste glass is collected by municipalities anyhow for disposal. Glass processed for recycling as cullet probably would be too high priced for use in glasphalt but the rejected glass would be available for a fraction of the cost that you mentioned.

ANSWER: Dr. Malisch

The results of field tests show that the skid resistance is adequate or better than normal in several cases. At Rolla, we conducted some studies using five different mixtures in small patches. These were glass-stone, glass-gravel, all-glass and two conventional mixes. A conclusion reached was that there originally was a lower skid resistance with the all-glass compared to other mixtures. As time progressed, we started getting a decrease in skid resistance in the glass-stone and gravel-glass mixes and only a slight decrease in the all-glass patch. But we found that the gravel mixtures were polishing and were losing skid resistance more rapidly than was the all-glass mixture. Statistically there was no difference after 23 months of study, between all-glass and gravel-glass mixtures.

Field studies indicate that some glass mixtures have a higher skid resistance that mixtures containing conventional aggregate. Additional research is needed, though, to determine whether combinations of glass and conventional aggregate will produce mixtures which are more skid resistant.

QUESTION:

I would like to question the economics of glasphalt. As brought up earlier, there is not enough glass to pave a normal city street in a town like Toledo. Is it the wisest use of glass to pave only a mile or two of the glasphalt streets? What does it cost to pave a mile with glass, and a mile with normal aggregate?

ANSWER: Dr. Malisch

We keep coming back to the point that there is not enough glass to replace normal aggregate. Our idea was to use this waste glass as a paving material rather than having to pay a disposal cost for putting it in a landfill. If we only have enough glass to supply 10 percent of the aggregate then we should merely blend that into the regular aggregate mix. This would be preferable to disposing of the glass in a landfill. In fact, our studies have shown that this 10 percent addition would have little influence on the properties of the asphatic concrete and it would not be necessary to change the design of the mix much at all. Glass would just be another component of the aggregate with enough added to use all of the waste glass.

If the glass is clean and color sorted, as would be the case at many recycling centers, it would have a higher value as cullet than as a paving aggregate. We used clean glass in our early studies to eliminate variables related to glass cleanliness. We wanted to find out first if clean glass would make an acceptable aggregate; the results were not negative so

we started looking at the possibility of using less clean glass as an aggregate. Since mechanical separation systems may produce a glass-rich fraction that is not pure enough to be used as cullet, we wanted to use this material as aggregate rather than disposing of it in a landfill. It would not be economical to remove only glass from refuse and use it as aggregate if all of the separation costs had to be borne by revenues from the glass-rich fraction. So this has to fit into a total recycling scheme where we recover several components from the refuse and market them.

ANSWER: Dr. J. Cummings

Obviously, in conducting these glasphalt experiments we do not have a normal paving operation in terms of cost and manpower. Taking the glass to a crushing point, getting it crushed, bringing it back, mixing it, having about a 1,000 people standing around watching you, gets very expensive. But if you are talking about a normal crew, laying out asphaltic materials and just adding glass at some point along the line into their regular mix or aggregate, then there will be no increase in cost for doing this. The end result of getting a glass-rich fraction from any system and mixing it into the asphaltic materials is that of no increase in cost. You will also be saving the landfill cost.

ANSWER: Dr. J. Cummings - continued

It is also obvious that if you can separate glass that is clean and a local glass company will accept the glass that they can use, then secondary products may be the way to go for the portion they cannot use. But it is certainly more expensive to put in a mile of glasphalt at this time than normal asphalt because of the special considerations. Today we need experts such as Drs. Malisch and Dickson on the scene to help lay the glasphalt. Later the normal asphalt crews and independent people can handle the problem, and thus there will be no increase in cost.

QUESTION:

So, if there is a higher use, that will be the way to go?

ANSWER: Dr. J. Cummings

That's true for anything.

QUESTION:

We must pay for glasphalt on a ton basis for a cubic yard. If we were committed to use waste glass on a contract in glasphalt, what are we talking about in finished weight, since glass is going to be heavier than limestone for a ton?

ANSWER: Dr. Malisch

The specific gravity of glass is around 2.5 which is not too much different from that of limestone. In our studies there has not been that much difference in unit weight between glasphalt and conventional aggregate asphaltic concrete. It may even be slightly less for glasphalt. It does not seem to me that it would make much difference in the total volume of glasphalt per ton.

QUESTION:

This question concerns cold weather paving. You spoke of an average temperature throughout the mat, but showed on graphs that the temperature changed a great deal. Does this apply to the surface as well? What other factors are important relative to temperature?

ANSWER: Dr. Dickson

It is true that the temperature I was showing had time to cool to 175 degrees F. This is the temperature averaged across the mat. The center temperature will be higher at that time than 175 degrees F. And the upper and lower surfaces will be lower. There is no one location where you can measure the temperature. Under normal ambient conditions--70 degrees F.--you will find that you will lose about the same amount of heat from the top surface of the mat that you lost into the base. But as you start dropping the base temperature, you lose more and more heat into the ground than to the atmosphere. So

ANSWER: Dr. Dickson - continued

under cold weather conditions it is the lower surface which is cooling much more rapidly than the upper. Further, the lower portion of the mat is where you will have more difficulty in getting proper compaction.

You will find that the void content of layers in the mat plot just like the temperature distribution. The highest voids are at the top and bottom, with the least voids at the center where the temperatures are higher. But every curve tends to change in relation to the environmental conditions. This is why we use the average figure.

QUESTION:

Have there been any economic studies concerning potential savings of a community to use glasphalt for cold weather paving, vs. the other alternates?

ANSWER: Dr. Dickson

Preliminary figures on base pre-heat show that the additional cost is somewhat between 5 percent and 10 percent. This is a conservative cost, and this is in addition to the depreciation of equipment, etc. Studies on both pre-heat and insulation are still in progress. For the cold weather paving situation, the costs are actually higher than replacing the $2 a ton aggregate.

ANSWER: Dr. Dickson - continued

The glass has the advantage that we do not also have to buy the additional fuel or buy the insulation and pay for the cost of laying it, or buying the extra thickness of asphalt to put down--the 3 inch as compared to 1 1/2 inch mat.

By insulation I mean a magnesia-type insulation or a polyurethane foam insulation. These types look good from the technical point, but we have not really looked at the economics.

QUESTION:

Have you taken into consideration what percentage of the pavement is laid in this country by contractors that have their own sources of aggregate which they own? If so, they would not want to pay for the glass. Also are you considering large metropolitan areas where the city itself has a paving business?

ANSWER: Dr. J. Cummings

We have not done an economic analysis, so we cannot make such a comparison at this time.

QUESTION:

There may have to be social cost attached to the use of waste material. If indeed glass is a waste material which must be utilized in paving, should there not be a government subsidy to use it?

ANSWER: Mr. J. Bilbrey

We already have a built-in subsidy in a way, in that the disposal costs are running $5.00 a ton or more in places where land fill costs are high or in places with long hauls to disposal areas. This price is already being paid which allows us essentially to get free transportation to a processing point.

QUESTION:

Again, is it economical to recycle glass? After the mat is laid is it practical as far as heat distribution is concerned? During the summer, the glass will absorb the heat. Will this make the mat plastic so that it is pliable? And what effect would the distribution of heat have in the winter time as far as snow removal? What about skid resistance on snow removal?

ANSWER: Dr. Dickson

The heating in summer is due to adsorption of solar radiation. Surfaces with either conventional or glass aggregate are black and the adsorption radiation should be about the same order of magnitude. There will be a somewhat different conduction rate into the glass, probably for glass at a slower rate than conventional. So you wouldn't notice the heat penetration into the glasphalt as you would in conventional aggregate.

ANSWER: Dr. Dickson - continued

This is both an advantage and a disadvantage. For glass, this could raise the surface temperature more. It is more difficult to conduct away from the heat in the glass; it has a lower effective conductivity. However, it should not make much difference between glass or stone aggregate from a practical point of view.

ANSWER: Dr. J. Cummings

In Toledo, there does not seem to be any difference due to last summer's heat.

ANSWER: Dr. Malisch

There is only one installation in Canada where they mentioned some softening at the surface. In general, there are no observations to my knowledge of any instability problems. There seems to be no rutting.

ANSWER: Mr. J. Abrahams

We did get a report from Vernon, British Columbia, that some softening was noticed in summer. I now understand that the contractor feels he used an excess of asphalt, since asphalt is not adsorbed by the glass fragments. He stated that excess asphalt with a high glass content (about 70%) apparently caused a flow of "bleeding" which could be corrected in future glasphalt installations.

END OF MORNING SESSION

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TERRAZZO AND OTHER GLASS PRODUCTS IN EXISTING BUILDINGS

by

Pickett Scott

Glass Containers Corporation

Fullerton, California

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TERRAZZO AND OTHER GLASS PRODUCTS IN EXISTING BUILDINGS

by

Mr. Pickett Scott
Glass Containers Corporation
Fullerton, California

At our new Industrial Park in Fullerton, California, we have incorporated several products made from waste glass into a practical construction demonstration. So that you can better visualize the utilization of these various secondary products made from waste glass, I will show a 13 minute film made by Glass Containers Corporation entitled "The All American Trash Barrel." It depicts the manufacturing and installation methods using waste glass in four different products.

As you may know, the initial impetus behind the development of new secondary products that would utilize waste container glass arose from the adverse transportation economics that are incurred in transporting waste glass over any appreciable distance. What some of you may not be aware of is that there appears to be a trend in the development of new solid waste handling and recovery systems that indicates an increased necessity to develop additional secondary uses even where glass container plants lie within an economically viable transportation distance. Without

going into the details of the various types of solid waste systems being developed, I believe the following discussion will illustrate potential solutions to these problems.

With current technology, it is not economically feasible to color-sort glass particles that are less than 1/4" in size. Unless there are practical economical uses developed for this glass, it would obviously have to be handled via a land fill type operation along with a resultant loss in recovery revenue.

The film just shown presented a brief over-view of the manufacturing and installation of glasphalt, insulation, masonry block, and two different types of terrazzo floors. The first terrazzo floor was laid in the conventional manner - that is, approximately 5/8" thick. The second utilized American Cement Company's thin set or Poly-Mod system, which means that the floor was laid approximately 1/4" thick. By incorporating small amounts of a polymer substance, terrazzo floors can be laid thinner, which results in significant weight savings - a major factor in high rise buildings. It also has 2 to 3 times the flexural strength of conventional terrazzo.

The hardness of marble chips range from 3 to 4 on the Moh's scale, while glass registers 4 to 5 on the Moh's scale. It should be noted that the Moh's scale is exponential; therefore, the difference between 4 to 5 on the scale is more than one arbitrary unit. Thus, all other factors being equal, terrazzo

flooring utilizing glass as an aggregate will have superior abrasion resistance over marble aggregate terrazzo, if the general correlation between hardness and abrasion resistance is valid. I should add that these two floors have been in use for approximately two years and no adverse data has resulted.

The last item, and perhaps the most significant one, is that waste container glass should have no problem in competing from an economic point of view with marble chips that range in price from $30 to $120 per ton, depending upon the aesthetic value desired. A few months ago, Glass Containers Corporation collaborated with Hartford/Emhart in putting down a terrazzo floor of approximately 1500 square feet in their new plant in Windsor, Connecticut. It should be noted that the floor utilized 60 percent amber combined with 40 percent flint, which provided an aesthetic effect that no one so far has found displeasing. The technical data involved in the manufacture and installation of terrazzo floors using glass has been compiled in a brochure which is available from GCMI.

In addition to these items mentioned, we are in process of completing an 82,000 square foot building in the same Industrial Land Development which will incorporate 6 new end uses for waste glass. Outside of the main entrance, we are installing approximately 4,000 brick in planters and the like, which were manufactured by Port Costa Brick in California, and contain 50 percent waste glass. We have also joined forces with this

same company in the manufacture of approximately 800 pavers to be used as the outside floor and walks, which were made utilizing approximately 10 percent waste glass. I should add that both Port Costa and Glass Containers Corporation believe that in addition to making a superior product, it will also result in cost savings in the manufacturing process.

Inside the lobby, the floor will be covered with ceramic tile manufactured from 50 percent sewage sludge and 50 percent glass utilizing a process developed by Dr. Mackenzie of UCLA. A portion of the lobby walls will be covered with glazed foam glass panels. Also, a portion of the office partition walls will be installed utilizing sandwich walls with an inner core of foam glass. The acoustical ceiling panels in the office will also be manufactured from foamed glass. I won't go into any further further details on these items, since the subject of foamed glass will be discussed in depth by Dr. Doug Mackenzie.

In conclusion, I believe it is worth emphasizing that, with the exception of Dr. Mackenzie's items, all of the products have been manufactured by companies currently in the business of supplying these building products to the industry without having to modify their equipment or methods in any way, other than substituting waste glass for the material they normally utilize.

REFUSE GLASS AGGREGATE

IN PORTLAND CEMENT CONCRETE

by

J. Craig Phillips

Technical Services Engineer, Riverside Cement Company

Riverside, California

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Introduction

Last year in the United States, over 3.75 billion masonry units were manufactured. In the same time period, close to 10 million tons of refuse glass were generated. Assuming that approximately 70 percent of the block use normal weight aggregate and that it would be possible to substitute glass in 10 percent of these, then 16 percent of the refuse glass could feasibly be reused at a 35 percent replacement of natural aggregate.

The main problem with using glass in conjunction with a portland cement system is the general attitude that glass is "not compatible" with the highly alkaline environment of the cement. This is substantiated by the fact that aggregates containing naturally occurring silicious materials, such as chert and opal are plagued with excessive expansion and pop outs. However, pozzolan, a processed silicious material, is often considered an ideal additive to concrete for replacement of cement.

Little work except a study by Klimmek (2) has been performed on feasibility of utilizing refuse glass as an aggregate filler in portland cement concrete. Previous studies (1,3) on the expansive reactions between natural aggregates containing amorphous silica and portland cement containing alkalies (Sodium and Potassium ions), and the Klimmek study, indicated that the direct substitution of

glass for natural aggregate could have deleterious effects on concrete properties.

The present study was performed to determine whether a direct substitution of refuse glass for natural aggregate would deleteriously affect the engineering properties of concrete masonry block. Concrete masonry units were selected because of the potential use as a structural as well as a decorative system. In addition to the decorative and structural properties, masonry units generally have a low cement content and a low water-cement ratio, which decreases the possibility of a cement-glass reaction. Masonry blocks also gain most of their strength at early ages, because of curing techniques so that any deleterious reaction should occur within a relatively short period of time.

A three phase program was initiated to fully characterize the engineering properties of masonry block using refuse glass as a substitution for natural aggregates. The purpose of the first phase was to determine the optimum glass replacement percentage for natural aggregate which would exhibit satisfactory compressive strength properties. The second phase was the casting of masonry units using the percentage replacement found in the first phase, and the measurement of the "short term" engineering properties to be compared with ASTM and industry standards. The purpose of the third phase was to measure the "long term" engineering properties and to ascertain the effects of a glass-cement reaction, if any.

Materials

Throughout the tests a partially crushed amber cullet, obtained from waste piles of a glass container manufacturer, was used. Additional crushing was necessary so that the glass could be graded into proportions and sizes similar to natural rock and sand.

The cement used was a specialty block cement which is a high-alkali Type I portland cement ground to a higher surface area than regular portland cement. Natural aggregates were pea gravel and sand, mostly rounded, and conforming to ASTM Standards.

Procedure

Preliminary Concrete Tests

As the crushed glass had many shards handling was foreseen to be a safety problem. Initial tests were made with glass tumbled in a large drum for periods of up to an hour to remove all sharp edges and give a round shape to the glass. However, the one hour tumbling caused a 70 percent reduction in strength from non-tumbled glass. Glass tumbled for 1/2 hour was used for the first phase of the program, but in the second phase it was concluded that the glass did not have to be tumbled for safe handling.

A mix design for masonry block similar to that being used by a local block manufacturer was used. The glass was proportioned to duplicate the grading of the natural sand and pea gravel. Five batches of concrete were mixed using 0, 12, 24, 35 and 47 percent by weight glass substitution

for sand and pea gravel (corresponding to 0, 10, 20, 30 and 40 percent volume). Fifteen 3 inch x 6 inch cylinders were cast from each batch using external vibration for compaction. The concrete was cured using low pressure steam at 140° F for 24 hours and then stored at 72° F, 50 percent relative humidity until tested for compressive strength at 1, 3, 7, 28 and 56 days.

Short Term Masonry Block Tests

The non-tumbled glass used in making the masonry units was screened to pass 1/2 inch and was used without further grading. It was determined that approximately 30 percent of the glass was finer than a No. 4 screen and the natural sand and pea gravel were reduced accordingly for a final 35 percent by weight replacement of glass (as determined in Phase I). Over 700 standard hollow core masonry blocks were made by a leading block manufacturer in Southern California using a Besser Mixer and Vibra-Pac unit. The blocks were cured using a Johnson gas burner, 6 hours preset time, heated to 200° F over 3 to 4 hours, then cooled slowly and stripped at 18-22 hours. Tests for compressive strength, net cross-sectional area, unit weight, absorption and moisture content (ASTM C-140) and drying shrinkage (ASTM C-426) were performed on the masonry block. Cut sections from the block were used in the drying shrinkage.

Long Term Masonry Block Tests

Masonry units manufactured in Phase II were used in this series of tests. The tests were initiated after four months of yard curing and at 1, 2, 3, 6, 12 and 18 months thereafter. The masonry units were moist cured (95% relative humidity) for the first 6 months and then cured under water. The block were completely dried at 220° F prior to testing.

A modified Alkali Reactivity Test (Mortar Bar Method - ASTM C-227) was used to determine the degree of reaction. Eight sections of the block were cut (see Figure 1) and subjected to the same test procedure outlined in this standard, i.e., 24 hour moisture at 72° F, then 100° F, 100% relative humidity for remainder. Four sections of block containing no glass were tested in a similar manner.

Compression tests were performed according to ASTM Standard C-140 (Sampling and Testing Concrete Masonry Units) using a sulfur capping compound.

Results and Discussion

Preliminary Concrete Tests

Compressive strengths of the concrete mixtures decreased almost linearly with an increase in percent glass replacement at all ages, as can be seen in Figure 2. This linear decrease is probably due to the smooth surface of the glass which does not afford as a good bonding site for the cement as natural aggregate; a fine dust left on the surface of the glass from crushing and tumbling would also

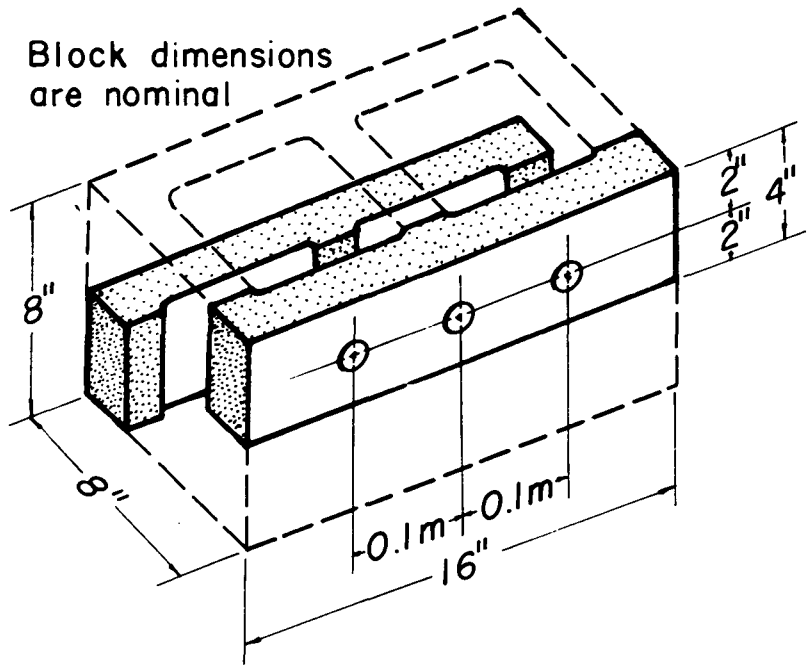

Figure 1—Cut portions of blocks and gage plug positions for Linear Stability (Short Term Block Tests) and Alkali Reactivity (Long Term Block Tests)

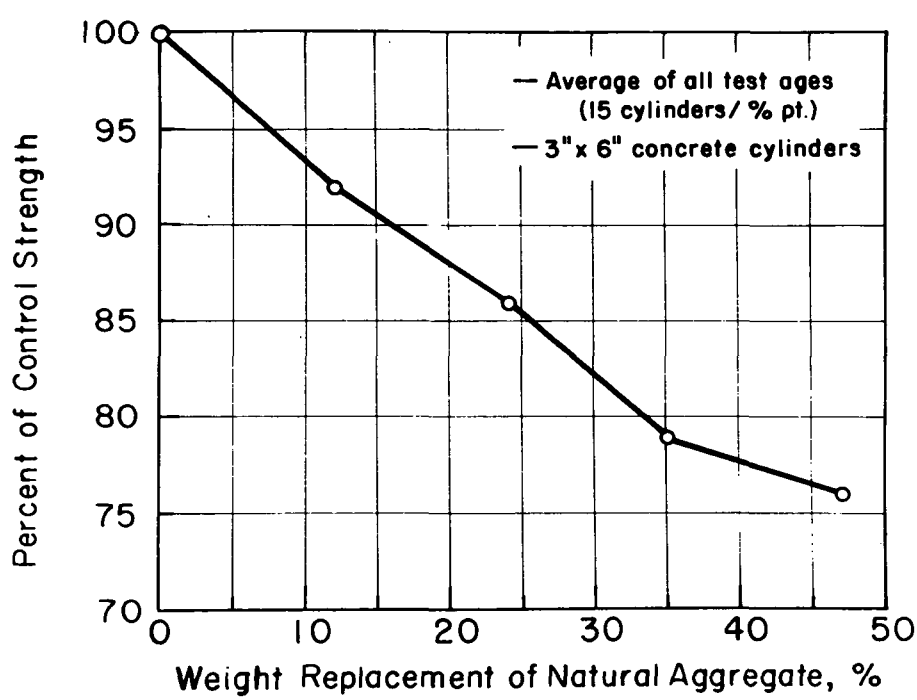

Figure 2—Concrete cylinder tests results—effect of percent glass replacement of strength

decrease the bond.

There is little evidence of a deleterious chemical reaction between the cement and glass up to 56 days. The slope of the strength vs. percent replacement line becomes more steep with increase in age, but this is probably due to the rate of bond development. That is, assuming that the glass does not afford a good bond with the cement matrix, the greater percentage replacement batches would be affected more by lack of bonding and the strength due to bonding would be more dependent on the percentage of natural aggregates.

From these results, it was decided that a 35 percent by weight replacement would be used for the blocks to be manufactured. This weight was selected because the 47 percent replacement could have decreased the compressive strength of the block to such an extent that strength requirements could not be met. This would also provide a margin of safety if there were to be a deleterious chemical reaction at later ages. The 35 percent replacement was considered to satisfy the three requirements of the masonry blocks, provide decorative effects due to exposed glass, satisfy structural standards, and utilize a significant amount of waste glass.

Short Term Masonry Block Tests

Physical properties of the masonry block are shown in Table 1. These results are compared to ASTM Standard C-90

Table 1: Physical test results of masonry block containing 35 percent by weight glass

	Observed	ASTM Standards N	ASTM Standards S
Average 28 day Compressive Strength			
Gross Area (117.8 in^2)	1047 psi	1000(min)	700(min)
Net Area (51.5% gross)	2032 psi		-
Minimum Individual Compressive Strength			
Gross Area	993 psi	800	600
Net Area	1928 psi	1600	-
Unit Weight	128.7 lb/ft^3	-	-
Linear Shrinkage	0.034 %	0.06(max)*	
Water Absorption	10.6 lb/ft^3	10(max)	13(max)
Moisture Content (percent of total absorption-below 50 percent relative humidity)	9.4 %	30(max)	30(max)

*California "Q-block" industry standard

(Specifications for Hollow Load-Bearing Concrete Units). The block gradings as defined in this standard are: N-grading - unprotected from moisture and frost action, for use above and below grade; S-grading - must be protected from moisture; interior and above grade use only.

The gross area of a unit is the total area of a section perpendicular to the direction of the load, including areas within cells. The average net area is only the solid area perpendicular to the direction of the load. Compressive strengths at 28 days are above those required for both gradings. The average glass-aggregate block strength of 1047 gross psi is below the 1350 gross psi usually observed for similar block made without glass; this difference may be caused by the lack of bond between the glass and cement, as discussed previously.

As the glass-aggregate block strength is approximately 30 percent lower than control block (no glass replacement), compared to 22 percent decrease from control for the concrete cylinders with the same glass replacement, the more severe curing regimen employed by the block company may not be as beneficial to the development of the cement-glass bond as the lower temperature saturated steam curing used in the concrete studies.

Even though the unit weight of the block is quite high compared to control block (122-124 lb/ft^3), the water absorption is slightly above N-grading requirements. This may be

indicative of poor glass aggregate grading rather than poor compaction, i.e., there are insufficient fines to fill the smaller voids in the concrete, even though the larger voids are removed by compaction, thus increasing the unit weight. Absorption should not be a problem in areas where basements or other subgrade construction are not generally used, such as Southern California.

The linear shrinkage of 0.034 percent meets industry standards of 0.06 percent and is below the 0.04 percent usually observed for similar block made without glass. Either the glass in the block actually reduces drying shrinkage or there was some expansion resulting from a silica-alkali reaction.

Long Term Masonry Block Tests

To date, the six-month test results have been completed. For these tests, it was decided to place the block in an environment which would enhance the possibility of the occurence of any destructive reaction during the two year test period (to 28 months after casting). The greatest potential for such a reaction should be under conditions of high temperature and relative humidity. Because of limited storage area at a high temperature, the blocks were cured at 100 percent relative humidity, but only 72° F; except for the alkali reactivity tests (see Procedure - Long Term Tests).

The results of the compression tests are shown in Figure 3. The blocks continued to gain strength to 12 months with no indication of a strength loss which would be expected if there were a deleterious reaction taking place. However, at 18 months a slight decrease in strength was detected. This is coupled with an accelerated linear expansion and at this time it appears that some reaction is taking place. There are no physical indications of reaction, such as cracking. At 18 months the blocks are still higher in strength than normal yard-cured block (1500-2000 gross pai). The strength difference between the normal and glass-aggregate block under moist curing is probably due to the bonding problem, as discussed above. Generally, yard-cured block do not gain much strength after the initial steam cure because of lack of water for cement hydration reactions.

The linear expansion specimens are slightly below the limits established by ASTM C-227 (.05 percent at 3 months; .10 percent at six months) and can be considered to be non-reactive at this point (see Figure 4). However, the accelerated upward trend indicates that a reaction may be taking place. At this time it is hard to make any positive conclusions. The early peak in the readings (at approximately one month) is hard to explain. Readings on volume expansion (not presented because of the large scatter of

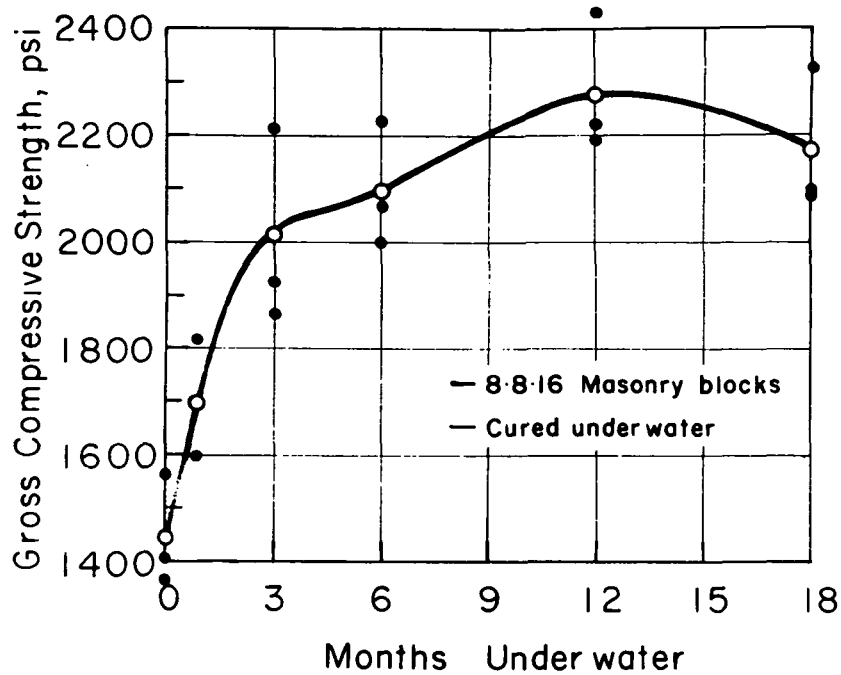

Figure 3—Masonry block compressive strength (Long Term Tests)—zero point is 4 months after the block were cast

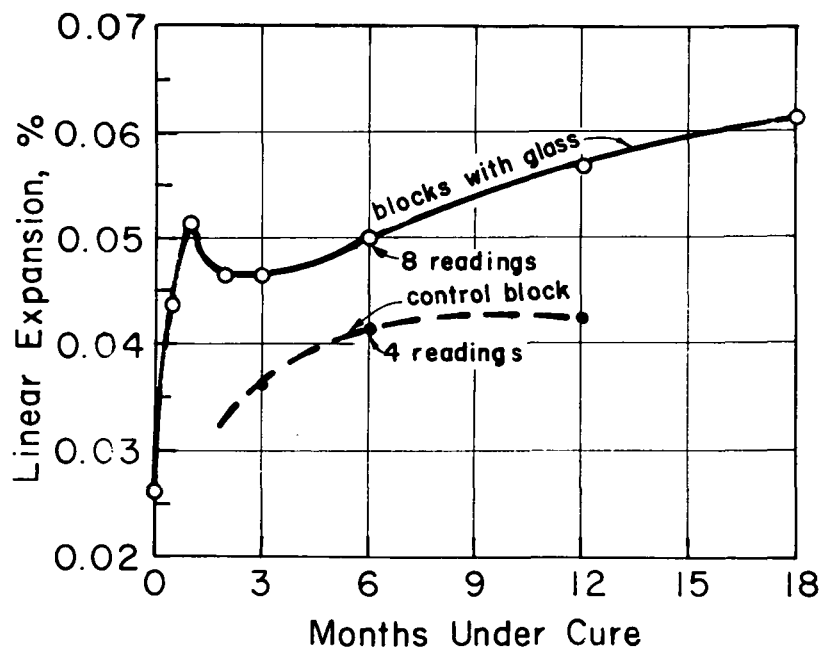

Figure 4—Linear expansion for alkali reactivity (Long Term Tests)—zero point is 4 months after the block were cast

individual results) indicated a peaking at this point. It could be possible that the system stabilizes after this point and normal contraction of the cementitious system influences the results.

Conclusions

There are many problems associated with the reclamation of refuse glass so that it can be recycled for use in the manufacture of new glass or other products. The particular problems involved in the use of reclaimed glass in portland cement products are: it must be washed to remove sugars which will retard the hydration of the cement; it must be crushed and graded to provide similar engineering properties as natural sand and rock; it should be color sorted if the glass is to be exposed for architectural purposes; and, of course, the cost must compatible with the present market.

Assuming that these problems can be overcome, the use of glass in concrete, specifically in masonry block, seems quite feasible. There may be some indication of a minor reaction between glass and cement. Any problems resulting from water absorption can probably be removed by proper mix design. Even with the slight decrease in strength at 18 months the blocks continue to show a good strength trend, which is, of course, one of the main considerations.

At the Fullerton Air Industrial Park in Fullerton, California (owned by Glass Containers Corporation), refuse glass has been put to innovative uses, including a road paved with "Glasphalt", floors surfaced with "Polymod" terrazzo using glass instead of marble chips, and walls insulated with fiberglass insulation made from refuse glass. The portal to the park is lined by a wall constructed with the masonry block containing crushed amber glass. The wall has been wire brushed to expose the glass, producing a pleasing facade. At the end of the test period, these glass-aggregate masonry units will approach characterization. If test results continue to corroborate the conclusions made at this time, there is every indication that the glass-aggregate masonry unit can offer a satisfactory means of disposing excess refuse glass.

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USE OF GROUND GLASS AS A POZZOLAN

by

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INTRODUCTION

Pozzolans are in common use in the United States, and their inclusion in concrete produces a much more stable and less expensive product. In addition, pozzolans in most applications produce stronger concretes.

Fly ash, blast-furnace slag, and volcanic glasses are the most frequently used pozzolans. Although they have wide acceptance, they all have one fault: their chemical composition is not consistent from batch to batch.

Because glass has a more consistent chemical composition and fulfills the chemical requirements of a pozzolan (see Background), a study has been made to determine whether or not glass behaves like a true pozzolan. A minor review of the economic feasibility of glass as a pozzolan has also been made.

BACKGROUND

The definition of a pozzolan as stated in ASTM C219 is, "A siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties."

Pozzolans have been used largely in massive structures such as dams, but recently have found use in smaller structures -- such as highways. The major purpose of a pozzolanic additive to concrete has been as a means of controlling or eliminating deleterious reactions between the cement and certain reactive aggregate types.

The material used most as a pozzolan in the United States is fly ash, but other materials including shale, volcanic glass, and blast-furnace slags are also used. All pozzolans are principally siliceous, but they also contain alumina, iron oxide, and alkali.

Since the major reason for adding pozzolans to concrete is to prevent deleterious reactions between cement and aggregate, the most common reactions are described below.

1. Alkali-Silica Reactions

Alkali (Na_2O and K_2O) in the cement will react with certain siliceous constituents that may be present in the aggregate. Aggregates high in unbound silica are the main problem aggregates. Essentially, silica migrates from the aggregate and reacts with alkali in the cement and causes reaction rims

around the aggregate. These rims cause swelling and produce internal pressures as high as 2,000 psi which in turn leads to cracking in the concrete.

2. Alkali-Carbonate Reaction

These reactions are referred to as "dedolomitization" reactions and can be simply expressed in the following equation:

$$\underset{\text{dolomite}}{CaMg(CO_3)_2} + \underset{\text{alkali}}{2MOH} \rightarrow M_2CO_3 + \underset{\text{brucite}}{Mg(OH)_2} + \underset{\text{calcite}}{CaCO_3}$$

$$M = K, \ Na, \ \text{or} \ Li$$

The effect of these reactions is to produce reaction rims around the aggregate which in turn lead to pressure buildup in the concrete with subsequent cracking.

3. Cement-Aggregate Reactions

Although reactions occur leading ultimately to cracking of the concrete, the mechanism is not fully understood. These reactions are common in sand-gravel aggregates found in certain rivers in Kansas and Nebraska.

EXPERIMENTAL

When determining the feasibility of using ground glass as a pozzolan, ASTM C618-71, was followed exactly.

Four raw materials were used:

Glass -- Waste soda-lime container glass was crushed and milled to pass 325 mesh.

Cement -- Monarch Type 1 portland cement conforming to ASTM C150.

Silica -- Ottawa sand conforming to ASTM C190.

Pyrex Glass -- Acquired by crushing Pyrex laboratory glassware.

All test equipment and procedures were in accordance with the various ASTM Test Procedures.

RESULTS

CHEMICAL REQUIREMENTS

The chemical specifications for a Type S pozzolan and the chemical results for soda-lime glass are both shown in Table 1. The only criterion that is not met is the available alkali, which is 1.87% higher than stipulated. However, this parameter is somewhat flexible and dependent upon the specific purpose for which the pozzolan is to be used. Highway Research Board Special Report 119 states that some pozzolans contain up to 10% available alkali and still appear to be beneficial.

PHYSICAL REQUIREMENTS

The physical specifications for a Type S pozzolan and the results of these physical tests using glass are shown in Table 2. As may be noted, seven of the nine tests met or exceeded specification. The only major variation from specification was in the test, "Pozzolanic activity index with lime at 7 days." This degree of variation is significant but may be acceptable in certain use situations.

COSTS

Scientific ideas have little value if they cannot be implemented economically into the society. With this application of ground glass as a pozzolan, the cost of grinding was determined because it was felt that crushing costs could prevent the use of glass as a pozzolan.

The Colorado School of Mines Research Institute determined the "Bond Grindability Index" for converting glass bottles to -100 mesh powder. The

TABLE 1

Chemical Requirements for Type S Pozzolan (ASTM C618)

	Soda-Lime Glass	Type S Pozzolan
$SiO_2 + Al_2O_3 + Fe_2O_3$	69.03%	70.0%
MgO	0.83%	5.0% max
SO_3	0.065%	4.0% max
Moisture Content	0.093%	3.0% max
Loss on Ignition	0.264%	10.0% max
Available alkali (as Na_2O)	3.37%	1.5% max*

*Applicable only when specifically required by purchaser.

TABLE 2

Physical Requirements for Type S Pozzolan (ASTM C618)

	Soda-Lime Glass	Type S
Surface area, min cm^2/cm^3	18,217	6,500
Compressive strength of mortar cubes		
Percent of control at 7 days, min	111.4	100
Percent of control at 28 days, min	121.7	100
Pozzolanic activity index		
With portland cement at 28 days, min percent	80.3	85
With lime at 7 days, min. psi	451	800
Water requirement, max percent of control	92.9	105
Increase of drying shrinkage of mortar bars at 28 days, max percent	0.016	0.03
Autoclave expansion or contraction, max percent	0.069	0.5
Mortar expansion at 14 days, max. percent	0.0024	0.02

obtained value of 14.70 shows that glass has grinding properties similar to granite (14.39), taconite (14.87), and syenite (14.80). It is easier to grind than basalt (20.41) and glass sand (16.38), but not as easy as clay (7.10) or magnetite (10.21).

The cost for grinding can now be accurately estimated by using known data from existing plants grinding materials with a similar Bond Index. For a plant producing 100 tons per day, the cost for grinding glass to minus 100 mesh is $1.95 per ton; these costs are detailed in Table 3.

To evaluate the potential of glass as a pozzolan, a cost comparison with existing pozzolans is needed. Today, pozzolans cost $15-20 per ton, delivered to the site. If it is assumed that an average delivery cost to the building site is $8 per ton and grinding costs are $2 per ton, then it leaves, at best, $10 per ton for buying and cleaning waste glass prior to grinding. If glass can be obtained without charge then glass pozzolans could be profit making. If purchase and cleaning of waste glass costs more than $5 the economics are questionable. At the present price being paid for waste glass (approximately $20 per ton) glass pozzolans are not economically viable.

TABLE 3

Cost of Grinding Glass to Minus 100 Mesh
(100 ton per day Plant)

Running Costs:	Power	$0.13/ton	
	Water	0.07	
	Grinding steel	0.13	
	Mill liners	0.04	$0.37/ton
Labor Costs:	Labor	$0.48/ton	
	Supervision	0.07	$0.55/ton
Overhead:	Plant overhead	$0.20/ton	
	Depreciation	0.39	
	General and administration	0.44	$1.03/ton
		Total	$1.95

CONCLUSIONS

Based upon 15 different tests (all specified in ASTM C618-71) the ground glass appears to have great potential as a Type S pozzolan additive in portland cement concrete.

Of these 15 tests, 11 met or exceeded specifications, three yielded borderline results, and only one definitely did not meet requirements. The failure was with the "Pozzolanic activity index with lime at 7 days." This degree of variation may or may not be significant, based upon specific use situations. This question can only be answered by contacting potential users of the pozzolan.

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GLASS AGGREGATE IN CONCRETE

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UTILIZATION OF WASTE GLASS
IN SECONDARY PRODUCTS

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ABSTRACT

The technical and economic feasibility of reusing the glass portion of municipal solid waste as a fine aggregate substitute for sand in Portland cement concrete is discussed. The potential of using crushed waste glass in concrete depends upon such physical properties as strength and expansion -- a measure of durability, and on available quantities of clean glass and processing costs as compared to natural sand.

Preliminary pilot experiments investigating the physical and chemical reactions between crushed glass and cement indicate that compressive strength is equal or greater than standard concrete, and that elongation of test bars is less than the 0.10% allowed by the A.S.T.M. Tests show that elongation is appreciably reduced when low alkali cement is used.

The possibility of chemical counter-measures, based on the hypothesis of calcium silicate protective rings around glass particles, was investigated by studying the reaction products with microscope, spectrophotometer, X-ray diffractometer, and microprobe. Although the hypothesized calcium-silicate protective ring was not detected in crystal form, there were indications of a lime-alkali-silica complex in gel form.

The rising costs and difficulty of solid waste disposal, and the decrease in the supply of sand aggregate in some metropolitan areas, increase the economic potential of glasscrete. There are other possible uses for large quantities of clean waste glass such as base material for highways and airports, and as fill material.

INTRODUCTION

Much has been said and written in the last few years about the problem of solid waste disposal in the United States. In fact, it is of interest that on December 2, 1905 under New York City dateline, the Boston Transcript presented this caption, "Waste Made Valuable" followed by "Notable Record of Utilization in New York; Rubbish Burned Gives Light and Power" and "83 Acres Fill In". This utilization of solid waste 70 years ago is still the solution in many cities, for example, Chicago. However, more and more emphasis and effort are being applied to development of secondary products, the subject of this Symposium, and procedures for reclaiming and reusing the constituent parts of the country's solid waste have been devised and are under test in many places. For a small sampling of recent reports see references cited[1/3,5,6,8,12,13] and especially their bibliographies. Major emphasis is now placed on the environmental consequences of solid waste disposal, and on the economic aspects of both the disposal process and the loss of natural resources.

These considerations have focused the attention of not only public and government officials but also industrial managers on the need for new and innovative practices in both disposal and reuse of solid waste. The increasing amount of this "unwanted" material, urban and rural, has stimulated a search for solutions by both public and private managers. On December 2, 1972 the Federal Highway Administration, U.S. Department of Transportation, announced the award of a research contract to the Franklin Institute of Philadelphia, Pa. "to explore the feasibility of converting municipal wastes into road construction materials". One of the several

research studies undertaken recently at Dartmouth College has been an investigation of using waste glass in Portland cement concrete [4,7,11]. It is the purpose of this paper to summarize briefly the results of these experiments and report some conclusions and suggestions.

The possibility of using waste glass as a substitute for sand aggregate in Portland cement concrete must be evaluated, eventually, as will all new disposal and recycling procedures, on both technical and economic feasibility. The results to date, though informative and encouraging, give only preliminary indications of technical feasibility. The economics is another matter, for estimates of both costs of solid waste disposal and values in recycling are not agreed upon from town to town, or region to region. Among experts there appears to be more pessimism than optimism about recycling solid wastes.[3] The Portland Cement Association has apparently discontinued their experiments on using ground glass in concrete.

GLASCRETE EXPERIMENTS AT DARTMOUTH COLLEGE

Background

There have been many reports, over the years, of the deleterious effect on concrete of a chemical reaction between silicate aggregate and the alkali constituent in the cement. The resulting expansion causes concrete cracking and aggregate pop-out which are known to be particularly bad with chert and similar silica stones. T.E. Stanton published a paper in 1940 on the "Influence of Cement and Aggregate on Concrete Expansion"[9], and since then various studies have been published on this subject. However, the complete chemistry and physics of the reaction have not been fully explained, to our knowledge.

It is suspected that this adverse silica - alkali reaction is concentrated on the surface of the coarse aggregate, or stone, and may be less serious with fine aggregate of sand size which presents a much larger surface to volume ratio. Phillips, et al[6] have recently reported linear expansions in concrete block using 35% crushed waste glass to be below ASTM limits, and that the reaction between the glass and the cement is minor for the short period of the tests.

The strength and linear expansion of glascrete, using Portland cement, sand, and crushed glass as a substitute for a portion of the sand (and in a few cases, finely crushed glass as an additive), were investigated in 1970 by Klimmek[4] at the Thayer School of Engineering, Dartmouth College. The results of these tests were favorable -- generally high compressive strength (ASTM-2" cube) and low linear expansion (ASTM-C157) -- so additional expansion tests using different glass gradations for a portion of the sand were completed with similar results.[7] It is of interest to compare the size gradation of the crushed glass used in these lab tests to that of two samples from glass bottles crushed by the Eidal International Universal Grinder in Albuquerque, N.M. These data are presented in Table 1.

During 1971-72 Vrahimis[11] completed pilot physical and chemical tests in an attempt to locate and identify the hypothesized alkali-silicates in solid or gel form on the surface of the glass particles. He also attempted to verify the hypothesis[10] that available calcium will generate a protective ring of calcium-silicate around the glass particles and thus reduce the alkali-silicate reaction and expansion. A summary of results follows.

Sieve Size		Percentage by Weight			
Passing	Retained On	Concrete 1	Concrete 2	EIDEL 1	EIDEL 2
	No. 4			0.5	1.0
No. 4	No. 8	10.		12.5	4.5
No. 8	No. 16	25.		39.0	11.5
No. 16	No. 30	25.	10.	32.0	20.0
No. 30	No. 60	30.	50.	12.0	38.0
No. 60	No. 100	10.	40.	2.0	12.0
No. 100		-	-	2.0	13.0

Table 1

GRADATION OF CRUSHED GLASS AGGREGATE

Concrete 1 -- Owens-Illinois glass
Concrete 2 -- Bureau Mines incinerator glass
EIDEL 1 -- Ground white bottles
EIDEL 2 -- Ground brown bottles

Strength Test Results

Standard compressive tests on 2-inch mortar cubes at age greater than 28 days gave the average values shown in Table 2. These data indicate acceptable compressive strengths for the small number of cubes tested. Variation in the % of alkali in the cement appears not to affect the compressive strength. Additional tests with full 6-inch by 12-inch cylinders are recommended, since 2-inch cube tests normally give higher value than the standard cylinders.

Klimmek also experimented with the use of pulverized glass (-200 sieve or <74 microns) as an additive replacing an equal weight of cement. The objective was to reduce the expansion of glascrete, mixed with hi-alkali (regular) cements, by providing more surface area of the silicates. Also, there is a possibility of the fine glass acting as a cement. The glass was not ground fine enough to act as a pozzolan, however, and the compressive strength decreased as larger percentages of the glass additive were used. This decrease may also have resulted from a higher water/cement ratio since the same amount of water was used, and the cement reduced. Nevertheless, the compressive strength for concrete cubes containing a fine glass additive of 7% to 12% averaged 5000 psi.

Linear Expansion

Test bars of glascrete were made in 1970 using the same mixes as those in the compression cubes: four cements with high to low alkali, standard Ottawa sand, with Owens-Illinois crushed cullet, and with 50% Ottawa sand - 50% O-I glass aggregate. A second series

Cement % Alkali	Standard Ottawa Sand	Crushed Glass (Owens-Ill.)	50% O. Sand 50% Glass
1.10	6000.	5700.	6900.
0.88	6000.	6000.	7100.
0.47	6500.	6500.	6800.
0.11	7600.	8500.	6300.

Table 2

AVERAGE COMPRESSIVE STRENGTH -- 2-INCH CUBES: psi

Age was more than 28 days.

of bars using the four cements, O-I glass, and fine glass additive were made.

In 1971, Piecuch and Vrahimis made a second series of expansion bars using regular cement (Type I - 1.10% alkali), and three sizes of glass aggregate (coarse to fine), as well as varied percentages of crushed glass (20%, 40%, 60%, 80%).

All bars have been cured under water, and the lengths of these bars have been measured at various times, since forming. The latest measurements were made in January, 1973, with the results shown in Table 3, grouped for simplicity.

It can be seen that all glascrete elongation bars, 21 and 33 months old, have expanded less than the ASTM C-227 allowable of 0.10% at age six months, and the mean values are far below this limit. Also, no cracking was observed, externally or internally, with a microscope. Therefore, a preliminary conclusion can be indicated that glass in sizes between 0.185 inch (No. 4 mesh) and 0.0058 inch (No. 100 mesh) does not cause a deleterious expansion of the glascrete.

Silica-Alkali Reaction

Vrahimis[11] completed pilot experiments to investigate the extent and location of the deleterious silica-alkali chemical reaction reported by others. He also investigated the use of calcium hydroxide to reduce the expansion of glass particles mixed with alkali cement by making gels of different ratios of sodium hydroxide, calcium hydroxide, water and glass. These gels were examined using an atomic absorption spectrophotometer, and an X-ray diffractometer to evaluate the formation of alkali-silicate products.

Cement % Alkali	Age Months	Elongation, % Mean	Max.	Stand.Dev.	Note
1.10	33	.021	.058	.014	Glass: O-I & Bu.Mines
0.88	33	.023	.070	.016	" " "
0.47	33	.009	.016	.004	" " "
0.11	33	.011	.071	[.027]	" " "
1.10	21	.035	.056	.010	Diff. gradations - O-I glass

Table #3

ELONGATION OF STANDARD EXPANSION BARS

Cross sections of glascrete bars were searched with a microprobe for the hypothesized calcium silicate "protective" ring around the glass particles. Also a microscope was used to check for sufrace and interior cracking of the glascrete. Finally, powder from glascrete bars was studied using an X-ray diffractometer to search for calcium silicate in crystal form.

The study's data are not ideal nor complete for proving or disproving the existence of a neutralizing protective ring of calcium silicate around the small glass particles. There is some tentative veidence of a ring's existence, not in crystal form but as a gel, from the microprobe analysis. This gel appears to be a lime-alkali-silica complex.

Conclusions From Tests

It is concluded that crushed glass, either clean cullet or incinerator glass (Bureau of Mines type), in sizes between No. 4 and No. 100 mesh, can be used with sand and Portland cement to form glascrete of acceptable compressive strength and with linear expansion less than that allowed by the ASTM. It is clear that low alkali cement produces smaller expansion in the glascrete, but expansion with regular cement appears acceptable also. Added calcium may reduce expansion but results of this experiment are not conclusive. Finer sizes of glass, within the range noted, do not appear to reduce expansion appreciably. Good size distribution appears to add to concrete strength. It is suggested, but not proved, that large glass particles may be inferior because of smaller surface/volume ratio. Glass as an additive smaller than

the 200 mesh, but not so fine as pozzolan, does not appear to act as a cement to increase the compressive strength of the glascrete nor does it appear to reduce the expansion.

POTENTIAL USE OF GLASCRETE

The best uses for glascrete today, in terms of existing codes, would be for non-structural concrete: sidewalks, parking areas, concrete block, ornamental concrete, etc. The U.S. Army, Corps of Engineers, reports, on the basis of a small field test in Georgia, that sidewalks are an excellent use. Pavements and structural concrete may well be acceptable uses if more extensive testing verifies present strength conclusions and establishes adequate durability.

Crushed glass can also be used for fills, embankments, pavement bases, drainage, and similar situations that call for earth or sand, with little or no processing.

Although indications are that glass can be used with all types of cement to make concrete, low alkali cement is preferable. Low alkali cement is a premium cement in some areas because of the natural ingredients, but the concrete industry reports that, nationwide, one-half to two-thirds of all cement is medium to low alkali. Some regions, like New York State, have good supplies of low alkali cement and there is no premium on price.

The amount of waste glass available might be considered a more serious problem, for far more sand is used than could be equaled in crushed glass. 1000 tons/day of solid waste would provide only 73 tons of glass (Los Angeles estimate), which is about 50 cu.yds. Therefore, one should think of waste glass as a product

to be recycled as available by adding to the general sand supply, not by replacing it. The equipment that contractors now use in making concrete could be used for glascrete. The cost of equipment ownership should not be increased, though the effect of glass on maintenance costs is not known. The Eidel grinding equipment can be used without modification in crushing glass for concrete fine aggregate as indicated in Table 1.

ECONOMICS OF USE

Accepting that it is technically feasible based on the above evidence to use waste glass as a substitute for sand in Portland cement concrete, these economic conditions must be taken into account:

1. The delivered price of crushed, clean glass must be no more than concrete sand -- $2.00/ton to $6.00/ton, national average = $3.00/ton. Sand in New York City costs $4.00/cu.yd ($2.50/ton) delivered - 1972 price. The price reflects available supply and transportation costs. Therefore, we can assume an average sale price of crushed, clean, but unsorted by color, glass of $3.00/ton.

Costs of disposal or processing solid waste have been estimated as:

a. Sanitary land fill --- $4.00 - $5.00/ton
   Exclusive of collection, transportation and land cost. Land presumably ends with a comparable value.

b. Separating, crushing, cleaning --- $6.00 - $10.00/ton
   This range may be much larger if voluntary separation is assumed at the low side, or a Black Clawson type grinding, cleaning and separation is used.

c. Usual incineration --- $12.00 - $16.00/ton
   Including land fill of 20% residue.

d. High temperature pyrolysis incineration -- $9.00 - $12.00/ton
Includes the value of by-products. For example, clean, inert frit sells for $4.00/ton

Clean glass separated by color sells for $20.00 per ton at the manufacturer's plant in Connecticut. Bargman[3] reports that 7.3% of Los Angeles solid waste is glass, and its market value, cleaned and color sorted, is $15.00/ton.

Note: Mr. Cyril Weeden, Glass Manufacturers Federation, England, reported that dirty waste glass sells at $7.00/ton, and clean, separated waste glass sells at $19.00/ton in England.

2. Rough estimates of the total value of the waste glass are:

Price as sand substitute	$3.00/ton
Cost of alternative land fill	5.00/ton
	$8.00/ton

The cost of processing, from above, is $6.00 - $10.00/ton. Therefore, there appears to be a marginal economic feasibility. This assumes that the collection and transportation costs balance out, which will not be the case for long hauls with no backhaul revenue. For example, truck transport of waste glass is about 8¢/ton mile in 1972.

Use of a Black Clawson type separation, crushing and cleaning process would appear to improve the economics because of the value of other by-products. Finally, voluntary separation of waste glass would improve the economics appreciably.

3. The alternative of separating the waste glass by color and selling for $20.00/ton appears to succeed or fail on the cost of color separating. The margin from above would be about $10.00/ton for color separation.

4. Finally, an economic comparison with incineration appears to favor use of the glass in construction materials or even as clean, color separated glass cullet, for the cost of usual incineration is approximately $15.00/ton plus residue land fill problems. High temperature incineration at $10.00/ton competes favorably as a disposal alternative if we neglect the value of destroyed natural resources.

The economic conclusion is then, that the cost of alternative disposal must be included in the balance sheet, as well as emphasis placed on recycling valuable natural resources, if the gap between sand prices and cost of delivering clean, crushed waste glass to the concrete manufacturer is to be bridged.

Other conclusions noted are that sand must be in short supply, which will normally be local, and costs of disposal and land fill sites are high.

CONCLUSIONS AND RESEARCH NEEDS

It is concluded that, technically, waste glass can be separated from solid waste, cleaned, crushed, and used as a substitute for sand in glascrete. However, the cost of this process compared to the cost of sand in many localities precludes this use of waste glass at this time unless there is subsidy, most probably in the form of volunteer labor, and/or municipal funding based on the acceptance of an environmental value associated with recycling.

Also, there is not a sufficient quantity of waste glass (7 to 8% of average solid waste) to stimulate a change in the

sand and stone industry procedures. Nevertheless, a small percent of the huge demand for sand could be provided by waste glass. This means that all the waste glass presently generated could be readily absorbed. The residue incinerator glass, especially high temperature frit, could be used in road building materials. This sand-like by-product might possibly be used as a construction material, such as concrete fine aggregate.

Research is now needed to determine the properties, especially durability, and costs associated with glascrete. Large-scale strength and durability testing of in-place glascrete structural elements is necessary to extend the pilot results obtained from 2-inch cubes and 1-inch square elongation bars of glascrete used in the tests reported here.

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A NOVEL THERMOPLASTIC PAVING MATERIAL

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Abstract

Stanford Research Institute's Technology Applications Team, under contract to NASA, is concerned with transferring aerospace technology to the public sector. In the area of transportation, the Team became aware of several universal needs related to improved road patching materials, better corrosion protection of bridge structural members, and less expensive oil- and gasoline-resistant paving materials for special purposes. A potential answer to these needs was found in NASA Tech Brief B66-10453, "A Thermoplastic Rubberlike Material." Additional work was performed at SRI to evaluate the basic properties of the thermoplastic material, the effects of various fillers such as glass on these properties, the methods of applications, and the potential commercial uses for the material.

Introduction

Stanford Research Institute has a Technology Applications Team under contract to the Technology Utilization Office of the National Aeronautics and Space Administration. This Team is concerned with the transfer of aerospace technology to the public sector area of transportation. In the course of its activities, the Team became aware of several universal needs related to improved road patching material, better corrosion protection of bridge structural members, and less expensive oil- and gasoline-resistant paving materials for special purposes.

A search of the aerospace data base uncovered a potential answer to these needs in NASA Tech Brief B66-10453, "A Thermoplastic Rubberlike Material," (subsequently U. S. Patent No. 3,527,724). The work was originally performed for NASA to develop new binder systems for rocket propellants.

This paper discusses additional work performed at SRI to evaluate the basic properties of the thermoplastic material, the effects of various fillers on these properties, the methods of applications, and the potential commercial uses for the material.

Experimental

The basic formulation is prepared by blending a copolymer of ethylene and vinyl acetate with asphalt and a petroleum distillate. For testing purposes, Examples 1 and 3 of the patent were reproduced. The asphalt used was Chevron 200/300; the petroleum distillates were kerosine and an SAE-50 motor oil. The ethylene-vinyl acetate resins were produced by DuPont under the name Elvax.

Modifications of the NASA-developed thermoplastic material can yield a product with a wide range of physical properties suitable for various applications.

Various blended combinations of asphalt and plastic were evaluated by the SRI Polymer Technology Group in order to determine composition limits that would yield mixtures having good physical properties and reasonably low processing temperatures. In one series of asphalt-plastic mixtures, the molecular weight of the plastic was varied; in another, different plastics in varying concentrations were used. Portions of these mixtures were then blended with oil and kerosine and the effects of this dilution noted. Various fillers were added to certain of the mixtures to determine effects on the properties. Mechanical properties were obtained on dog bone specimens prepared from these mixes. Tensile strength, elongation at break, and elastic modulus were calculated. No conventional methods of determining the softening point and penetration were used other than visual observations as to the ease of processing and pourability at mixing temperatures. Fillers and fluxing oils evaluated were generally waste products whose incorporation would be advantageous.

Incorporation of Elvax Ethylene-Vinyl Acetate Plastic in Asphalt

A rather wide range of Elvax ethylene-vinyl acetate resins was evaluated in asphalt. The major differences in these resins are the molecular weight and the ratio of ethylene to vinyl acetate in the copolymer. The resins evaluated are described in Table I.

Incorporation of Fluxing Oils in Asphalt/ Plastic Mixtures

Kerosine, SAE-50 motor oil, and used crankcase oil were evaluated as fluxing oils or diluents for the thermoplastic asphalt formulations.

Table I

PROPERTIES OF ELVAX ETHYLENE-ACETATE RESINS

	Vinyl Acetate, %	Melt Index g/10 min ASTM-D1238	Soft. Pt, °F Ring & Bell ASTM-E28	Tensile Strength, psi ASTM-0882	Elongation at Break %	Elastic Modulus, ps ASTM-D882
Elvax 210	28	400	180	500	800	750
Elvax 310	24-26	400	190	400	800	1500
Elvax 350	24-26	19	280	1700	1000	2200
Elvax 360	24-26	2	370	2700	1000	2800
Elvax 410	18	500	190	420	370	2000
Elvax 420	18	150	210	850	550	2750

Generally speaking, the low molecular weight copolymers melt at reasonably low temperatures but are lacking in strength and, conversely, the higher molecular weight copolymers are quite tough but have high melting points making processing with asphalt at reasonable temperatures difficult. It should be mentioned here that all mixing was done in a sigma type mixer at 250-300°F. These temperatures can be tolerated in commercial asphalt operations.

Polymer content in asphalt was varied between 12.5 and 50%. Obviously, higher polymer contents give a tougher product. Thus, the higher melt index polymers give higher tensile strength and modulus values for the corresponding thermoplastic asphalt mixtures. However, the processing difficulty increases with the higher melt index polymers. Without a particular application in mind, it is difficult to determine a definite amount of plastic to incorporate into asphalt for optimal properties. However, it can be safely stated that all of the Elvax resins

evaluated here are compatible with asphalt in amounts up to 50%. A cheaper, less viscous, more easily processed product is obtained with lesser amounts of plastic at a sacrifice in physical strength.

Kerosine was added in amounts of 10, 20, and 30%. In all cases, complete compatibility was achieved, but at great sacrifice in strength (proportional to the amount of kerosine that was added). Motor oil and used crankcase oil can be used interchangeably with no observed differences in physical properties or processing characteristics; however, motor oil is not as compatible with the asphalt-plastic mixture as is kerosine.

Incorporation of Fillers into the Mixtures

In addition to the standard tests performed on the various Elvax-asphalt-oil formulations, a program was initiated to determine the effects of some fillers. Filler materials selected for the feasibility tests represent sources of pollution or waste products from manufacturing processes. Using these waste materials on a large scale would, of course, be ecologically desirable. Given below are the filler materials incorporated into the thermoplastic asphalt, with general description of the results achieved (see also Table II).

Ground Rubber Tires

Several types of ground rubber tires were readily incorporated into the thermoplastic asphalt during mixing. Viscosity of the mixture is determined by the texture of the ground rubber and the amount used. Finely ground rubber can be added in amounts up to 50% of the mix and not suffer serious loss of strength or required elongation. Coarse mixes, containing

long pieces of rubber cord, can be processed but require considerably lower loadings to maintain a practical viscosity.

Buffing Dust from a Recapping Plant

One sample of buffing dust was incorporated into the thermoplastic asphalt in the amount of 35%. The sample mixed well but was quite viscous and had to be spooned from the mixer. This particular sample of buffing dust resembled lathe shavings more than dust. As a result, processing was more difficult. Pressed sheets looked quite good, however, and there is every reason to believe that buffing can be used advantageously.

Sulfur

Because of the great surplus of sulfur obtained as a byproduct in industrial processes, it would be ecologically advantageous to find a large-scale use for this material. Several batches of thermoplastic asphalt were mixed with 10 to 50% amounts of sulfur added. The sulfur is easily incorporated and actually aids in the processing. The mixing temperatures are in excess of the melting point of sulfur; therefore, the material is quite pourable. At mixing temperature, the sulfur appears to dissolve into the asphalt. Mechanical properties of the thermoplastic asphalt with 10% sulfur are comparable to batches containing no sulfur. The amounts over 10%, some loss of strength is observed, but mechanical properties are still satisfactory, even with loadings as high as 50%. Upon cooling to room temperature, the sulfur crystallizes to a very fine size. Thus, the final product may be defined as a homogeneous sulfur-filled thermoplastic asphalt. An ultra-thin layer of very fine sulfur crystals blooms to the surface on standing. For certain applications, sulfur could be a very useful filler material.

Glass

Samples of cullet and glass frit were obtained and incorporated in the thermoplastic material. For ease of incorporation, particle size of glass used was limited to minus 20 mesh. The samples mixed well, as the glass appeared to act as a processing aid. Viscosity of the mix was not adversely effected and the handling properties of the finished materials were considerably improved over the non glass filled version. Pressed sheets looked quite good and the material's utility in glasphalt applications seems feasible.

Used Crankcase Oil

Substituting used crankcase oil for fluxing oil appears to make no significant difference in the properties of thermoplastic asphalt. No valid objections have been found in the data collected thus far. Incorporating used oil in a particular formulation calling for a fluxing oil, in place of new oil, would have obvious ecological advantages.

Paper Lignins

Paper lignins from several sources were incorporated into thermoplastic asphalt at a loading of 10% by weight. At this loading, mixing and pouring characteristics were quite good, and mechanical properties were similar to those of an unfilled control material. The mixing and pressing temperatures ranged from 250-300°F. It should be noted that, in one case where the press temperature was excessively hot, decomposition of one of the lignins occurred liberating large quantities of gas which created a foamed structure in the thermoplastic asphalt. This decomposition could be useful, perhaps leading to the development of a foamed thermoplastic asphalt

Table II

EVALUATION OF FILLERS IN THERMOPLASTIC ASPHALT

General Formulation	%
Asphalt 85/100	72
Used Crankcase Oil	5
Elvax 350	24

Filler Variables	% Filler	Tensile Strength psi	% Elongation	Elastic Modulus, psi
Trastan 5PM	10	73	581	196
Trex DTA	10	51	382	182
Sulfur, Flowers of	10	48	432	196
Orzan	10	84	788	190
HRI 3219 Ground Rubber Tires	10	72	488	178
HRI 3219 Ground Rubber Tires	35	91	280	278
E9784 Ground Tire Fiber	10	78	116	322
E7329 Ground Rubber Tires	10	68	552	175
Glass Frit (-20 mesh)	10	38	200	nc*
Glass Frit (-20 mesh)	20	42	143	nc*
Lignosite	10	61	691	180
Raylig-261	10	81	822	185
Control-No Filler	0	72	645	200

* not calculated

General Formulation	%
Asphalt MC 250	60
Elvax 310	40

Filler Variables	% Filler	Tensile Strength psi	% Elongation
Glass Frit (-20 mesh)	10	21	57
Glass Frit (-20 mesh)	20	18	49
Control-No Filler	0	22	121

Table II (Continued)

EVALUATION OF FILLERS IN THERMOPLASTIC ASPHALT

General Formulation	%
Asphalt 200/300	62.5
Elvax 350	37.5

Filler Variables	% Filler	Tensile Strength psi	% Elongation	Elastic Modulus, psi
Control-No Filler	0	325	860	315
Sulfur, Flowers of	10	350	975	500
Sulfur, Flowers of	20	240	780	480

for applications such as insulation. A means must be found, however, to cool the material rapidly to prevent foam collapse.

Impact of the Proposed Application

The feasibility study, conducted under the NASA Technology Applications program, was designed to investigate general properties of the improved thermoplastic material. The resulting information should provide interested parties with a basis for determining their continued interest. Some potential applications of this material include special-purpose paving, waterproof membranes for bridge deck protection, sealants, roofing, resilient backing for synthetic turf, coatings, and membranes for land fill operations. The proposed applications are currently in the conceptual stages only, and each use will require individual study by the interested industrial or public sector organization.

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THE EIDAL VERTICAL SHAFT GRINDER

by

Vernon A. Osell

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THE EIDAL VERTICAL SHAFT GRINDER

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In a recent issue of EPA Citizens Bulletins published by the U. S. Environmental Protection Agency in Washington, D. C., the following story appeared. "Citizens Actions get Results" - Rhode Island citizens zapped away more than 10,000 tons of debris in an extensive one-day clean up campaign along the Blackstone and Sukonk Rivers. An estimated 5,000 volunteers, aided by over 200 pieces of donated equipment, pulled and lifted rubbish from the area. The 'zap' idea was conceived by the Providence Journal which publicized and guided the day's efforts.

These and other stories are a daily occurrence, and we who are deeply involved and much more well informed know that in spite of the "Johnny come lately" experts, industry has invested millions in an effort to find the answers. Technology is at hand and the hardware exists to do the complete job. As Samuel Hale, head of EPA's office of solid waste management said recently, "What we throw away, doesn't really go away at all."

Many of you attending this Symposium are educators and know that a theory is the meaning we give a certain observed sequence of reality. The closer the theory meets this reality, the more valid the theory. A valid theory is one that enables us to make predictions because it fits the nature of what is being observed. Now you must admit these remarks have little or nothing to do with recycling glass, but, when I was asked to present the story of the EIDAL Grinder, and the different principles involved, it would, for at least a few minutes, raise the question - "What is he going to say next?"

It is not my purpose today to cuss or discuss the relative merits of diverse types of equipment. Being marketing and sales oriented, I have always believed that the best way to kill a sale is to knock your competitor. With this brief preface and guidelines defined, I will get on with my subject - "The EIDAL Vertical Shaft Grinder."

First and most importantly, we establish the fact that our grinder achieves material reduction by progressive grinding, in which the feed material joins in acting as a force against itself. The grinding rings which we utilize, float freely, and the materials are impinged against specially shaped liners. The rings turn in relation to the materials introduced into the machine as well as in relation to the rotor direction. This enhances grinding action. This imparts the electro/mechanical energy of the system to the material being worked, with the least shock loading on the grinding mechanism, all forces are centrifugal,

resulting in a relatively low vibration and sound level while the materials are squeezed and torn by the revolving rotor. These ring grinders and liners are made of a high impact resistant knife quality steel to prolong their useful life. Low maintenance and wear factors are a most important factor in the design. The machine can be called lazy, as the rings bounce against the object again and again, much like a skilled boxer wearing out his opponent to deliver the knockout punch.

Any object delivered to the mouth of the barrel is initially struck by a rotating striker bar. This bar on our Model 1000 (1000 H.P.) is rotating at close to 400 RPM shaft speed, approximating a tip speed of 13,000 FPM. The striker surfaces of the bar are protected with a special hard face alloy and have replaceable surfaces to improve life and maintenance. This is the only step in which energy is imparted directly to the material by forceful impact. As it is so imparted the feed material is broken into smaller particles; they travel directly into the grinding area, where they are worked by the free floating grinding rings and the fixed conical shell liners. Further reduction in individual size is achieved, as the material flows to the next stage. Final reduction by the last series of grinder rings is to a chosen particle size range, these particles then drop into the collection area to be discharged by rotating sweeper blades. I refer again to the Model 1000, to add that these sweeper blades not only physically push the material but generate positive air pressure flow in the discharge duct area, aiding in expelling products.

An additional control of the desired particle size may be achieved by a restrictor ring device, located at the bottom of the shell between the last grinding area and the discharge area. With this device, no material can pass into the final discharge unless a predetermined reduction in size is accomplished. The thru-put capacity and flow of materials being reduced are facilitated by the vertical pressure of the incoming materials, gravity, air flow and the force components created by the tapered barrel. Here we have followed the sequence of our progressive grinding, summarized as follows:

Initial impact of the striker bar; grinding forces applied with loose, free-floating grinders enhanced by the particles actually grinding against themselves - thus resulting in reduced wear and longer life of the moving parts utilized in the machine.

With materials being ground over a 360° area of the conical shell, and no screens or uncontrolled particle limiting barriers to restrict a large percent of the grinding chamber, the processing time is minimized and thru-put capacity is maximised. Our grinder's capacity depends upon the amount and type of material feed and the coarseness of the grind desired.

A recent study and test, for example, using our Model 1000 handled 120 tons of compactor refuse per hour. Our advertising defines solid waste refuse as including white goods, large bulky cardboard cartons, tree trunks, rubber tires, with or without wheels, which can be processed at a conservative 45-50 tons per

hour. It is understood that for incineration procedures the non-combustibles would be removed prior to incineration. This indicates that combustibles can be processed at the higher rate indicated earlier.

Our present standard models are often specifically tailored for the types of material to be processed; the only limiting factor being size of the infeed objects. For example, our small Model 100, which we appropriately call the Mini-Mill, can handle a 30 gallon steel drum. Our next larger model will handle normal city compactor refuse, less tires, wheels, domestic appliances, stoves, refrigerators, sofas and bed springs. One such installation utilizing this model, the 400, operating at Edmonton, Alberta, was installed in November 1970. Similar models are used for industrial plant refuse of all types from wood pallets, steel turnings and rejected products, plus recycling applications which are of a proprietary nature. We are proud that among our list of satisfied users, better than 60% are listed in Fortune Magazine's directory of the top 500 industries. One of the big three automobile manufacturers uses a Model 100 for the destruction of papers, correspondence and drawings, while a large paper mill reduces raw stock directly to soft, sanitary, disposable diapers.

From a Midwest Research Institute report of February 12, 1971, we quote the following: "The development of new concepts for the disposal of solid wastes has been part of the response of industry and government to the now recognized need to protect the quality of the environment. Many of the new concepts of waste disposal

require a continuous supply of shredded solid wastes for efficient operation. Until 1967, Hammermill type shredders were the only type of solid waste shredding equipment available. The EIDAL solid waste grinder operates on a patented concept of progressive grinding where massive and multiple ring-grinders reduce bulky materials to a desired size in seconds.

"The EIDAL solid waste grinder promises to play an important role in the effort to dispose of, or to recycle solid wastes. The grinder is capable of processing a variety of solid wastes for reuse and is capable of being applied to an even greater variety of materials."

A further statement from the same report states: "We have been impressed with the design concept. It is simple and the machine is effective in its operation."

In a recent publication written for the Federal Solid Waste Management Program, entitled "Air Classification of Solid Wastes" by R. A. Boettcher, the statement was made, "The overshredded material from a conventional hammermill tended to agglomerate forming a floc of paper and cardboard that picked up and carried with it other light material."

In a further statement from the same publication, we quote: "Film plastic is a difficult contaminant to remove from recovered paper. Shredder output of this material is, therefore, important. It would be desirable to reduce this material to small fragments and at the same time to produce large size particles of paper. There was a great deal of film plastic material larger than 1/2 inch

in the output of all shredders except EIDAL. Although this machine also produced relatively small size particles of paper, these paper particles were twisted and crumpled, and this condition increased the bulk density and permitted better separation from the small particles of film plastic."

I would like to note that thirteen different firms with their equipment are compared in this study.

We are enjoying an ever growing list of satisfied customers, we have 53 machines installed and operating in the United States, Canada, Japan, Norway and France. Manufacturing and distribution contracts have been finalized for the Far East and Europe. All this is a growing testimonial of the capability and capacity of our Vertical Shaft Grinder.

Thank you for asking EIDAL to participate, and to give you this brief description of the machine. Since our plant is located only 10 minutes from this hotel, we will recess to our plant and watch a series of demonstrations using waste glass. One objective will be to note the ease with which the machine handles the glass and the size range of the crushed glass. With the present ring setting, the glass size is about 4 mesh and less. Larger sizes can be obtained with a larger ring clearance. You will note too that by adding a small amount of water, all grinding dust can be eliminated.

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QUESTION:

Are there any advantages of glass in the cement block?

ANSWER: Mr. J. C. Phillips

Basically, the two advantages are: (1) a means of disposal of waste glass; and (2) a decorative effect. There do not seem to be any other advantages.

ANSWER: Mr. P. Scott

An economic benefit of glass in cement block is the substitution for decorative rock aggregate which is white dolomite and costs at least $30 a ton. Thus for decorative purposes it is possible to have one color or several colors without color sorting of the glass. It is not competitive in the $1.50 range for ordinary rock aggregate but it is highly competitive for decorative rock aggregate.

QUESTION:

How do you crush the bottles to obtain the proper size ranges for use of glass fragments in concrete blocks?

ANSWER: Mr. J. C. Phillips

The glass used in the block tests went through a hammer mill. The glass fragments would have to go through the same procedure for proper gradation as would normal aggregate. Block manufacturers generally are not set up to do this gradation. It

ANSWER: Mr. J. C. Phillips - continued

would have to be done by an aggregate company. Then there is the problem of transporting the glass to the plant for crushing and grading.

QUESTION:

One crusher company I know is wary of crushing glass because it gets mixed in with his own products. However, this company saw no reason why it wouldn't crush and separate the same way the aggregate does. He was also concerned because of wear on his equipment. Due to the hardness of the glass could you comment on this?

ANSWER: Mr. P. Scott

The Kaiser Sand and Gravel Company located north of San Francisco is in business to produce aggregate for the asphalt people. They did not notice any wear and tear on their equipment when they crushed glass for us. Their only problem was in getting the proper setting on equipment such as draw and roll crushers. In setting the crushers, the company noticed that the glass aggregate did not appear to vary in hardness from the rock aggregate in the higher range they customarily crush. The same was true in the Hartford, Connecticut glasphalt installation where the glass was crushed and sized in a commercial rock aggregate plant.

QUESTION:

It seems there are some interesting properties involved between glass and cement depending upon the particle size. If ground very fine the glass could be used as a pozzolan. Is that correct?

ANSWER: Mr. J. C. Phillips

The effect of the pozzolanic reaction is, in fact, to choke the system with silica in a controlled dispersion. Any "explosion" or cracking that is heard about is because of the large volume of reaction products around the large pieces of aggregate. It really is a macro-stress in the system, while with pozzolans you are talking about a micro-stress. When concrete is still plastic enough, it can withstand the micro-stresses. With the larger aggregate there is a relatively large volume but small surface for a macro-stress, such as the 2,000 lbs. per square inch mentioned earlier. I have seen some aggregate pop out for distances of some three feet, which is actually an explosive failure.

But with the combination of the two size ranges, the small size will tend to draw the alkalies to these portions and it will remove the possibility of explosions occurring with the larger pieces. This is why we studied a wide range of sizes, and it is part of the reason for the success of the glass block.

ANSWER: Mr. R. Stearns

Another test conducted by one of my students was an attempt to find answers to this alkali-silica reaction. He investigated the chemical and physical reaction microscopically with x-ray and micro-probe. He was not able to find actual crystalline forms of the sodium silicate, which is the bad actor. He formed some gels in various proportions of the sodium, calcium, silica, and water, and investigated these first in the gel form, then dried them out to study the solid form. With a photometer he was

ANSWER: Mr. R. Stearns - continued

able to detect that if he added more calcium to the mix he could neutralize some of the sodium-silicate formation which he found in a gel form. This shows that there are osmotic pressures involved and there is a migration that starts at the surface of the particle.

QUESTION:

With the physical, aesthetic, and economic advantages of glass in terrazzo, what are the prospects of developing markets for this product?

ANSWER: Mr. P. Scott

General contractors and architects are not prone to try anything new. Even minor innovations are hard to get started. It took two years to introduce the tilt-up type panel variation we are using in Fullerton, California. Now it is acceptable in Southern California.

ANSWER: Mr. J. C. Phillips

The polymer used in this terrazzo system, developed at the American Cement Technical Center at the time we started to work with glass, turned out to be a superior method, but it was a major problem to interest a very traditional terrazzo industry. The next real problem is to interest the architect. They fall in love with something and will stick with it for the rest of their lives. If they like marble chips, they will stick with marble chips.

ANSWER: Mr. P. Scott

As an example, there is a 65-story bank building in Los Angeles where we tried to interest people in using architectural facing panels that would have about 6,000 tons of flint glass. We thought it was aesthetically pleasing but they turned thumbs down and spent an extra $600,000 in order to use polished marble sheathing.

QUESTION:

In the mortar studies Mr. Stearns, did you measure flow or make consistency measurements?

ANSWER: Mr. R. Stearns

The only measurement we had was slump. We noticed that the addition of fine glass additive affected the workability very seriously by adding all that additional surface area. As a result, we had to add water to get the desired consistency. The fine glass affected the mix appreciably. However, we didn't add any cement to get the water to cement ratio for the sand and glass. Maybe this was why the strength dropped.

QUESTION:

You said the Army was happy with the sidewalk they placed in Georgia using glass aggregate. What were their reasons?

ANSWER: Mr. R. Stearns

I called them last week concerning the sidewalk placed a year ago and they said it was easy to put in, good for finishing, and is still in excellent condition.

QUESTION:

With respect to terrazzo and the Polymod System, is there any interaction or alkali problem, or any deleterious effect because of the glass?

ANSWER: Mr. J. C. Phillips

The reason that the latex increased in strength is that it stabilized the whole system. The cement after a certain point acts only as a filter. Further, the particles become coated with latex so these alkalies and the silica cannot move throughout the system.

The only way that the alkali-silica reaction can take place is due to the free moving ions resulting from saturated systems. Thus, as long as the concrete is relatively dry, properly dried, and above grade, you should not have this problem. It will start to occur in sub-grade construction and where water is a constant problem. Our tests were under the most severe conditions. Professor Stearns, for example, has carried the mortar bars under water. We cured our blocks under water and we have not seen any indications of a reaction taking place. If there were to be a reaction, it would probably be less under dry conditions.

QUESTION:

Have you found any economic advantage for using glass in thermoplastic road surfaces or would this be only a waste disposal method?

ANSWER: Dr. T. Anyos

It probably is some of both. Thermo-plastic asphalt is expensive, perhaps four or five times more expensive than conventional asphalt. So, if we can use a filler of negative or minimal value and not affect its properties, then there would be a definite economic advantage. We have been fighting now for some five years to get these products accepted by the highway department, and feel that we have achieved this goal. We have the same problem with the highway people as those in construction have with the architects. Highway people have been using asphalt for a long time and they want to stay with it. The change occurred because of the high cost of labor. If we can save a highway maintenance crew one trip a year to fill a pothole or seal a section of the road, the highway people would be willing to listen to us. I feel we are at that point now.

QUESTION:

Aren't a lot of these cementitious materials in terrazzo non-portland cement, such as magnesium-oxychloride and so forth?

ANSWER: Mr. J. C. Phillips

All we are using in the Polymod System is white cement, which is low alkali. In the U.S., white cement is used almost exclusively as the base material.

QUESTION:

You indicated that the thermo-plastic material is less expensive than the epoxy asphalt. Yet thermo-plastic is 4 to 5 times more expensive than regular asphalt. What is the asphalt used for?

ANSWER: Dr. T. Anyos

The San Mateo Bridge is paved with epoxy asphalt. It is by far a tougher, better wearing material. It serves as a better bridge membrane for corrosion. Unfortunately, the company having it done had two of its trucks set up on the way to the site. This is hard on a $25,000 truck. Thus, we feel we have a market for our material.

QUESTION:

Has the Bureau of Mines conducted studies to use a high temperature incinerator frit as an ore in separating the metal portion from the non-metal portion?

ANSWER: Mr. J. Bilbrey

We have never really studied this aspect. The problem is that all of the materials, the metals, the glass, and the inorganic ash in the frit have combined. The metals are converted to oxides and silicates, for example, so it makes a poor ore. Because of this we do not favor that system unless we remove some of the valuable materials first. Our studies show there are about 12 million tons of iron and about one million tons of non-ferrous metals in the trash annually, and we would like to remove them.

END OF AFTERNOON SESSION

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VIBROCASTING GLASS-CONTAINING CONSTRUCTION PANELS

by

Howard Campbell*
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Presented at the Albuquerque Symposium on
Utilization of Waste Glass in Secondary Products,
January 24-25, 1973

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INTRODUCTION

Large, fired ceramic pieces, suitable for use as structural materials, or decorative facing, can be fabricated from inorganic waste material by using a vibratory casting technique. Waste siliceous material together with discarded glass products and a minor amount of clay, when ground to the proper size and combined in appropriate proportions, can be fired at relatively low temperatures to produce strong, low water-absorbing objects with a wide variety of esthetic finishes. This method of fabrication can be used to make large, complex shapes, presently available to architects and design engineers only at a high cost.

The manufacturing process is uncomplicated and requires only standard equipment to make products that are competitive with, and often superior to, present day materials. Building materials containing 13, 31, and 94% glass were investigated to determine their physical and commercial characteristics.

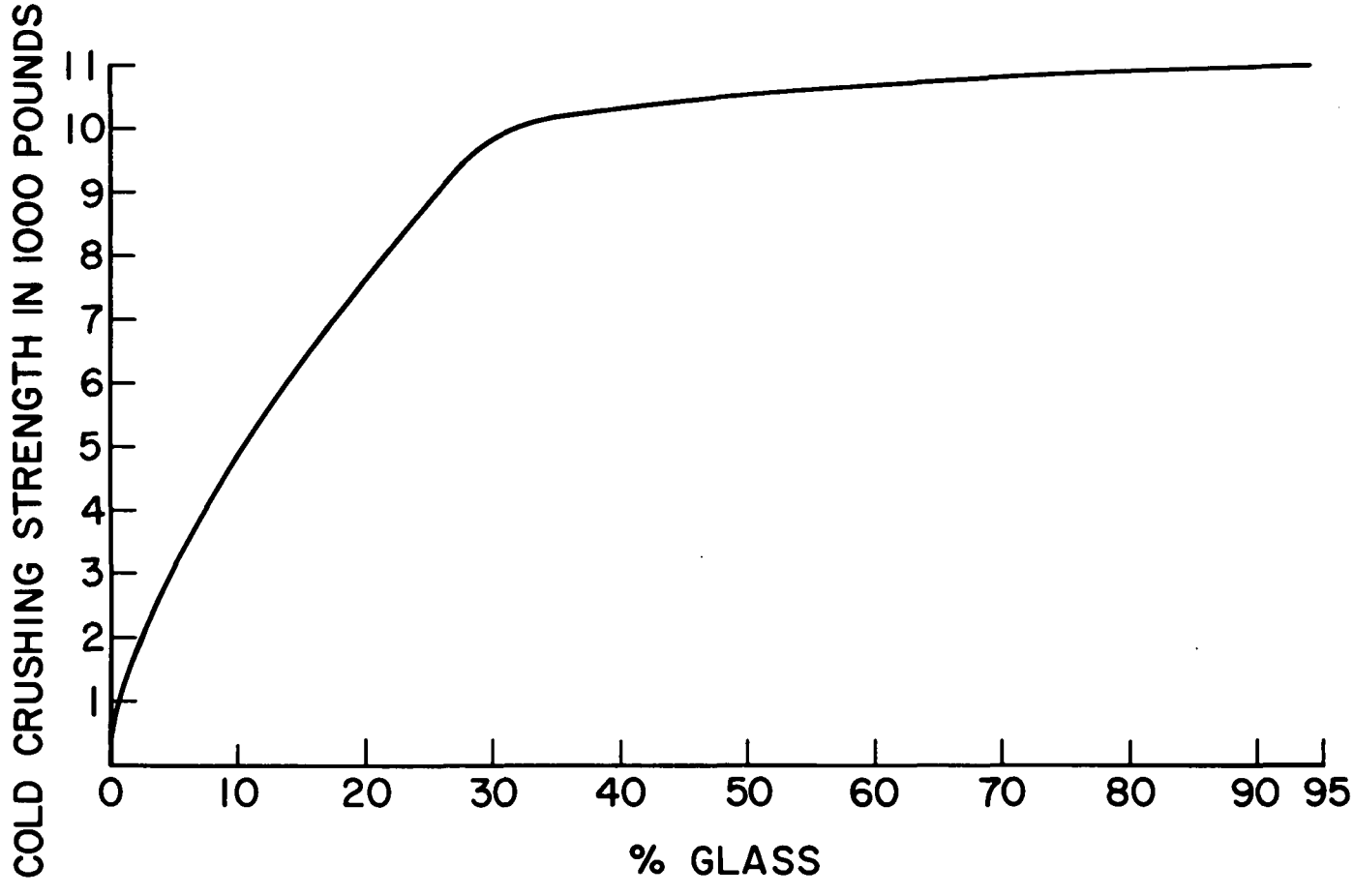
RAW MATERIALS

Three types of raw material are required, only one of which is virgin; these are clay, and grog or bulk filler.

The clay comprises 6% by weight of the mix and serves both as a thixotropic carrier and to fill the very small voids between the larger aggregates.

Glass is required as the binder in the fired product and may vary from 10% to 94% by weight, depending upon the desired physical properties and final appearance. Figure 1 shows an idealized curve illustrating the functional

FIGURE 1
COLD CRUSHING STRENGTH VS GLASS CONTENT
ASTM METHOD C133-55



relationship between glass content and compressive strength. Material containing less than 10% glass is probably too weak to be useful, but it is possible to vary the glass content between 10% and 94% to tailor the material to the desired compressive strength and esthetic appearance.

Three sources of glass have been investigated:

1. Glass redemption quality with only labels and aluminum safety rings as impurities along with minor amounts of the bottle contents,

2. incinerator residue from USBM Metallurgy Research Laboratory at College Park, Maryland, and

3. glass-rich residue from the Franklin, Ohio, solid waste disposal plant after the paper, aluminum, and iron fractions have been removed.

The glass redemption quality can be used easily, with no trouble from labels on aluminum safety rings.

The incinerated glass source assayed at 75% glass with the remainder being mostly the remnants of clay products. Some adjustments in the formula had to be made to have the glass at the desired level. However, this source is probably satisfactory provided the glass percentage does not fluctuate too widely.

The glass fraction received from Franklin, Ohio, contained considerable organic material such as rubber and dense plastics. The fired articles using this material were very weak. If the glass fractions are first put through a heavy-media or similar type of separation, then satisfactory fired objects are obtained.

Unless large pieces of glass are used as grog for visual effect, no color sorting is required. Most of the glass is finely ground and is not visible

until the glass content is about 60%. The remainder of the mixture (grog) is made up of any materials that are stable at the firing temperatures, have small coefficients of expansion, are strong enough to match the final desired strength characteristics, and will adhere to glass. In general, most siliceous rubble, blast furnace slag, mine tailings, and discarded concrete will meet these properties; this includes huge amounts of building demolition.

MAKING PROCEDURE

Crushing

Both the siliceous grog and the glass must be crushed and sized into specific screen fractions. The glass used for bonding must be further ball-milled to the required fineness.

Conventional crushing and milling equipment are used; the type would depend upon the volume of material needed.

Mixing, Forming, and Firing

The screened materials are weighed and mixed in a suitable blender for about 5 min and then thixotropically cast in molds, using a mechanical vibrator. After a short drying period, the piece is stripped from the mold and then fired. Firing times and temperatures are shown in Table 1.

The making rate is dependent upon the thickness of the piece, regardless of the area.

RESULTS OF PHYSICAL TESTS

Three glass compositions were tested, 13%, 31%, and 94%. Brick size specimens were cast for measurement of compressive strength, modulus of rupture, and water absorption.

ASTM C67-66 compressive strength method specifies a half brick to be crushed. This is the usual testing method for structural clay products. The results are shown in Table 2. The Tinius Olsen press that was used for crushing had a 110,000 lb total compression limit and consequently only the 13% glass content brick could be crushed; the higher glass composition bricks successfully resisted the 110,000 lb total compression.

ASTM C133-55 compressive method was next used to determine compressive strength. This test is normally used on refractory and ceramic products. This test requires the whole brick be crushed on end. The test specimens had a depth of 7-1/2 in. and a surface area of 2-1/2 x 4-1/2 in. The results are shown in Table 2. For comparison, commercial concrete bricks of the same dimension were also crushed.

The 13% glass brick shows twice the compressive strength of the concrete block, while the 31% glass brick is 3-1/2 times stronger than concrete. The 94% glass brick is only marginally superior to the 31% glass brick.

The results of the modulus of rupture test, ASTM C133-55, are provided in Table 2 and show a clear superiorty of all glass compositions over the concrete block. The strength increases with increasing glass content.

The water absorption test results are shown in Table 3. Grade SW (severe weathering) facing brick is required to resist the disruptive action of freezing when it becomes saturated with water. ASTM standards require a SW brick to have a saturation coefficient of less than 0.78. The 13% glass brick is within the limit and the other glass bricks are well within it.

Table 1

Firing Times and Temperatures

Glass (% in mix)	13	31	94
Firing Temperature, °F	1650	1625	1425
Firing Time, hr	3	2	2

Table 2

Results of Physical Strength Tests

Percent Glass in Brick	Compressive Strength (psi) ASTM C67-66	ASTM C133-55	Modulus of Rupture (psi) ASTM C133-55
13	6,000	5,800	840
31	>7,700	10,000	1,500
94	>8,300	10,700	1,900
Concrete Block	--	2,800	400

Table 3

Saturation Coefficients

Percent Glass in Brick	Saturation Coefficient
13	0.76
31	0.45
94	0.56
SW Brick Standard	0.78

Table 4

Freeze Thaw Test on 31% Glass Content Bricks ASTM C-67 Method B

	Brick No.				
	1	2	3	4	5
Weight (start), g	1094.0	1088.5	1091.0	1120.0	1112.5
Weight (finish), g	1093.5	1087.0	1091.0	1119.5	1112.0
Weight Loss, g	0.5	1.5	0	0.5	0.5
Weight Loss, %	0.046	0.138	0	0.045	0.045
Average Weight Loss, %	0.055				

Freeze thaw tests (ASTM C67, Method B) were conducted by the NAHB Research Foundation, Inc., of Rockville, Maryland, on the 31% glass brick. One cycle of this test consists of exposing water-soaked bricks to a freezing temperature for 20 hr and thawing the bricks for 4 hr in water. After each five-cycle period, the bricks are air-dried for 40 hr. The test continues for 50 cycles of freezing and thawing or until the bricks have broken or have lost more than 3% of their original weight. If no evident disintegration occurs and the weight loss is 3% or less, the material is considered suitable for cold-weather construction. Table 4 shows the results for the five bricks tested. All specimens were well below the 3% loss maximum allowed.

All physical tests show that the glass-containing materials are sufficiently strong and water resistant to be of structural use.

COLORS AND FINISHES

It is not sufficient just to make strong articles. At the present time there are plenty of stout building materials from which to choose. The public also demands pleasing, esthetic, and colorful shapes and designs. These standards are all possible with this new material because of the flexibility of color and finish. If several different, large volumes of grog are available of consistent color, different mixtures of these may be incorporated. Inorganic dyes may be added while the material is being mixed. With no dyes, the material has a natural buff color, the shade varies with the clay sources. Iron, chromium, cobalt, and manganese oxides result in red, green, blue, and gray colors, respectively.

Four finishes have been investigated in addition to the clay finish that results from the thixotropic casting. In order of increasing expense they are:

1. Wet-Brush Finish. This involves brushing the unfired piece with a damp brush to remove the thin clay layer and expose the large grog sizes.

2. Sand-Blast Finish. This involves sand blasting the desired surface of a fired piece with the usual sand blasting equipment. A light or deep sand blast produces a different effect from the same basic composition.

3. Glaze Finish. Glazes can be applied to the surface before firing. The entire surface may be covered or designs may be used on part of the surface.

4. Polished Finish. The desired surface can be polished using stone polishing equipment. The higher the glass content, the smoother and more reflecting is the surface. The 94% glass material will take a finish as smooth as the finest marble or granite.

The versatility of the casting process means that products of many shapes can be made. Designs may be included in the mold and almost any shape can be cast. The possible variations are limited only by the imagination of the architects.

CONCLUSIONS

A new type of ceramic, having possible use as a structural product, can be easily and quickly fabricated using a thixotropic mix and vibrocasting. Advantage is taken of the high strength and low temperature softening point of ordinary glass to manufacture a low-temperature fired ceramic product with

a small clay content. The glass content, to achieve a usable strength unit, may vary from 13% to 94%. Six percent is the minimum requirement but the remainder may consist of almost any siliceous material, such as rubble from urban renewal projects. The compressive or flexural strength is highly dependent upon the glass content.

Several different finishes may be applied including wet brushed, sand blasted, glazed, or polished.

Large pieces with functional or ornamental shapes can be cast easily. By selection of a suitable level of reclaimed glass, the strength and water absorption characteristics of these products can be varied. The product has all of the beauty of bricks, but considerably larger and more complex shapes can now be cast and fired than are presently available from conventional methods for making brick and tile.

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GLASS-RUBBLE PICNIC PAVILION

by

J.J. Wuerthner, Jr.

Vice President - Public Affairs

Glass Container Manufacturers Institute, Inc.

Washington, D.C.

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GLASS-RUBBLE PICNIC PAVILION

by

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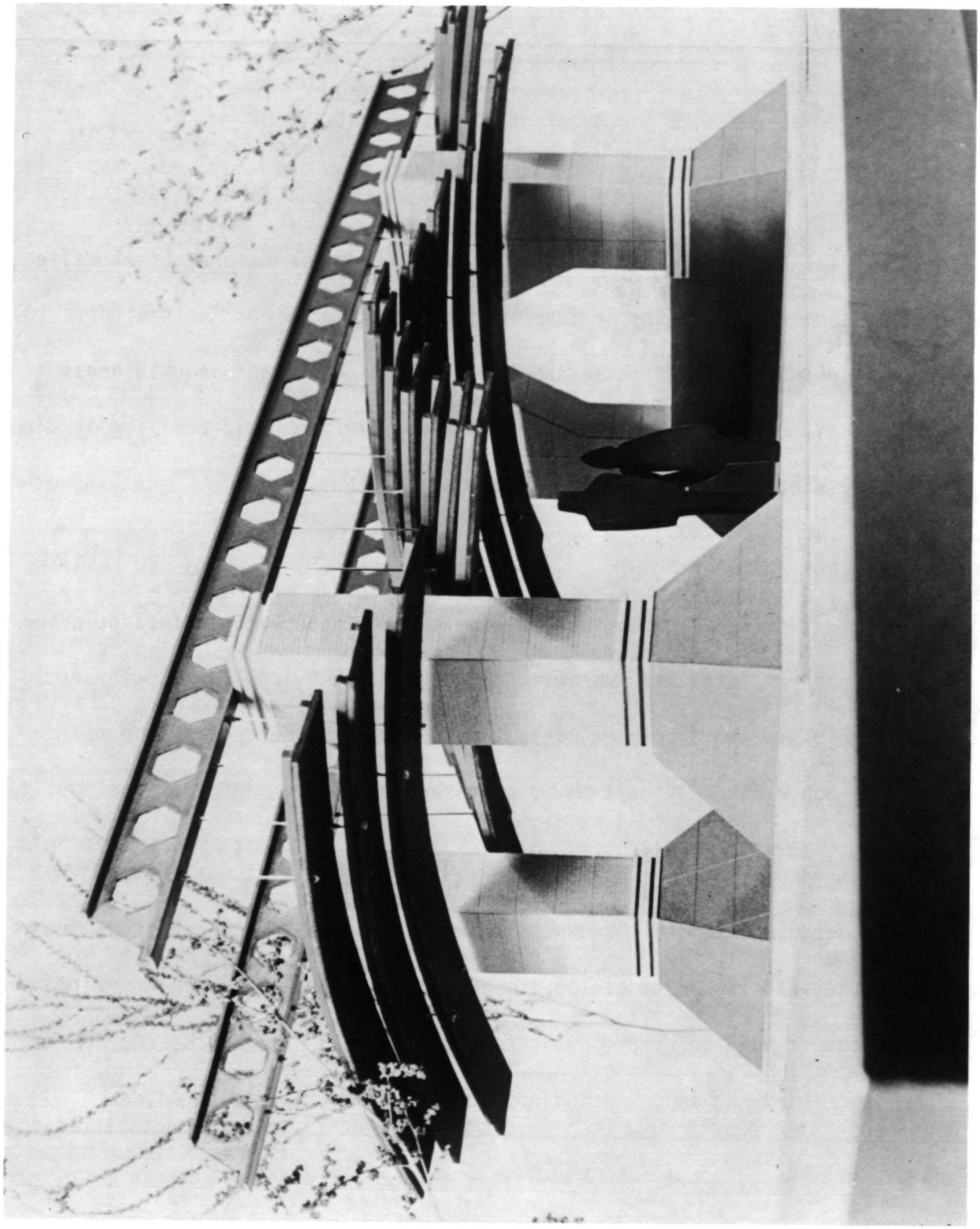
Today, I'd like to tell you about a development in Colorado that we in the glass container industry believe is a landmark in our nation's efforts to solve its solid waste and litter problems. We are about to put used glass bottles and demolition rubble to work to build a large picnic pavilion in Denver's Washington Park.

The shelter, when completed, will demonstrate the use of a new building material, in the form of construction panels developed by the Colorado School of Mines Research Institute from waste container glass, rubble and clay. Since waste glass and rubble will account for about 94 percent of the raw materials, you can safely call the picnic shelter we are planning "the pavilion that ecology built."

The building material, known as thixite, consists of construction panels of different sizes and was developed by CSMRI with financial support by the Glass Container Manufacturers Institute. The new material has been proved out in the laboratory and is now being produced in a pilot plant at Golden, Colorado.



GCMI has joined with CSMRI and the Colorado Soft Drink Association in the construction of the picnic pavilion to provide a practical demonstration of the thixite panels in actual use. The Ideal Cement Company will donate the concrete slab on which the pavilion will be built.

We joined with CSMRI in funding the development of the thixite panels as part of a long-range glass container industry program to find constructive uses for waste container glass recovered from solid waste and litter. The glass container industry is dedicated to the philosophy that the only logical, long-range solution to the solid waste and litter problems will be large-scale, mechanical recovery of resources from solid waste and litter for recycling or conversion into useful materials or energy.

This pavilion will stand as visual evidence of the extensive efforts now underway in Colorado and elsewhere throughout the United States to recycle the discards of modern civilization. It represents the many uses such as new products being developed from the resources recovered from municipal refuse.

The picnic pavilion is a rather striking building. It was designed by Denver architect, Maxwell L. Saul, who also will supervise its construction. We plan to have it ready for use by the people of Denver this coming spring, at which time it will be deeded over to the city.

The thixite panels will be in a combination of 14 colors and textures to blend with the environment. Nearly all of the colors will be earthen tones of browns and greys, with the exception of some all white areas and a cobalt blue

roof. The pavilion will be floodlighted at night. The panels will be used both as supporting and decorative members of the pavilion. The only non-Thixite material will be two steel girders and steel hang-downs supporting the roof and some cement blocks in the internal portion of a wall at one end of the building and in columns at the other end.

The pavilion will be 36 feet long, 27 feet wide and 13 feet high and will rest on a concrete slab. Its construction will require 1,534 Thixite panels, in six sizes up to 2 feet x 2 feet x 2 inches thick. This will require about 29,000 pounds of demolition rubble, about 15,000 pounds of reclaimed container glass, and some 2,800 pounds of clay. The entire structure will be sandblasted "in situ" when completed to provide the finished texture and to bring out the colors.

The CSMRI pilot plant will furnish additional information on the technical and economic aspects of Thixite production. Meanwhile, a recent study by Midwest Research Institute indicates that Thixite panels will be "an extremely attractive product for manufacture in carefully defined areas at a carefully determined scale of operation."

The Denver pavilion, we believe, symbolizes a big step toward that solution. The beginning of a new and profitable way of reusing salvaged waste materials. Hopefully, it will mark also the creation of a new industry based on resource recovery.

GLASS WOOL AND OTHER CERAMIC PRODUCTS FROM WASTE GLASS

by

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ABSTRACT

A process for making commercial quality glass wool from the glass fraction of municipal incinerator residues was developed by the Bureau of Mines. This research was a part of the Bureau's program to recover usable materials from reclaimed urban waste. Molten glass was fiberized into glass wool on a laboratory scale by impinging a jet of compressed air on a stream of the molten glass. Melt compositions were varied by adding dolomite and alumina to obtain molten glass with the handling characteristics required for producing final wool products of the desired composition and physical characteristics.

When no charge is made for the waste glass and a credit of $70 per ton is allowed for the wool product, a 10 percent rate of return on investment after taxes is possible. If a charge of $5 per ton is placed on the waste glass, a selling price of about $72 per ton would be necessary to obtain a 10 percent rate of return.

Introduction

Glass wool manufacturing is a growing industry. During 1970, about 1.2 billion pounds (1) of glass fiber insulation was produced. Assuming a value of $70 per ton of wool, industry revenues amounted to about $42 million.

Glass wool is used principally for thermal insulation; acoustic uses are probably the next most important. Both its thermal and acoustic values result primarily from a physical structure of high porosity and resiliency. Differences in chemical composition within fairly wide limits are relatively unimportant, and for most conventional applications all types are competitive in properties and value (5).

Better insulation in homes and apartments could reduce the nation's comsumption of coal, gas, and electricity for heating and air-conditioning by 8-16 percent over the next 10 years, according to the National Mineral Wool Insulation Association, Inc. (New York City). The association says that adequate insulation would conserve as much as 15,000 trillion Btu of energy, which would amount to a $30 billion savings to consumers over the next decade. The association calculates that the potential savings are equivalent to 15.3 trillion ft^3 of natural gas, 108 billion gal. of fuel oil, or 4.5 trillion kw of electricity (2).

The solid waste research program conducted at the Tuscaloosa Metallurgy Research Laboratory has been concerned with the utilization of the glass fraction from municipal incinerator residues in the production of glass wool and various other structural products. The glass residue used for this research was obtained from the Bureau's incinerator residue pilot plant at Edmonston, Md. (6). Glass wool is an ideal use for either clean or poorly

cleaned residue waste glass, because even the presence of non-glass particulates in the batch mixture does not significantly interfere with the fiberizing process.

Although this report mainly concerns the development of a process for making glass wool, other studies were made on such products as building brick, quarry tile, lightweight aggregate and glass spheres.

High-quality building bricks of good color were fabricated from a mixture of 30 percent common clay and 70 percent waste glass. Manufacturing costs per thousand bricks were estimated to be $42 for a shuttle kiln plant and $29 for a tunnel kiln plant (7). These manufacturing costs are comparable to those for brick made from 100 percent common clay. Substitution of waste glass for one-half the clay in red brick reduced the maturing temperature from 2150° to 1650° F, a reduction that could result in the conservation of 64,240 thousand cubic feet of 1000 Btu natural gas per annum and a 30 percent increase in production without additional kiln capacity.

Raw Materials

Incinerator residue glass, uncalcined dolomite, and alumina were the raw materials used to make glass wool in this investigation. Table 1 compares the chemical analyses of municipal incinerator residue glass and clean, unincinerated waste glass.

Experimental Conditions

Batch Composition

Raw materials were weighed and blended mechanically before being charged to the melting furnace. Table 2 gives the two batch compositions used.

Table 3 compares the chemical analyses of the two glass wool products with that of a commercial glass wool produced from slag. The principal difference between the slag wool and the fibers made from waste glass is in the distribution of fluxes. In the slag wool, calcia is the major flux; in the glass wool, part of the calcia is replaced by soda.

Orifice Size

Each batch was melted in a natural-gas-fired furnace at 2,600° F in a silicon carbide crucible with a 3/16-inch diameter bottom orifice for producing fine fibers and a 1/4-inch diameter orifice for making coarse fibers. The larger orifice size for coarse fibers was necessary to facilitate flow of the melt, because of its higher viscosity.

Fiber Formation

After approximately 3-1/2 hours at 2600° F, melts were sufficiently fluid for fiberizing. A plug in the orifice was then removed, permitting the molten glass to flow from the bottom of the crucible and out of the furnace. About 10 inches below the bottom of the furnace, the molten glass was fiberized by impingement of a jet of compressed air (100 psig) directed perpendicular to the downward flowing glass stream. An air flow of 50 cfm was required to fiberize a typical batch in 15 minutes, amounting to approximately 750 cu ft of air to produce 8.6 lbs of glass fiber. Figure 1 shows the equipment used for producing glass wool.

TABLE 1. - Chemical analyses of municipal incinerator residue glass and clean, unincinerated waste glass

Material	Analysis, percent							
	SiO_2	Al_2O_3	Na_2O	CaO	MgO	Fe_2O_3	K_2O	Cr_2O_3
Incinerator residue glass	64.80	2.50	14.20	7.60	2.00	5.70	0.50	0.05
Unincinerated glass	69.30	1.74	13.91	10.02	.43	.86	.55	.03

TABLE 2. - Batch Composition

Wool fiber type	Weight-percent			
	Residue glass	Dolomite	Alumina	Total
Fine	46	52	2	100.0
Coarse	78	20	2	100.0

TABLE 3. - Chemical analyses of test fibers and a commercial slag wool

Wool fiber type	Weight-percent						
	SiO_2	Al_2O_3	Na_2O	CaO	MgO	Fe_2O_3	K_2O
Fine	42.4	4.4	8.35	28.0	15.0	0.25	0.29
Coarse	60.3	4.2	12.50	14.3	3.9	.16	.29
Commercial	41.0	4.5	.17	35.3	14.1	1.60	.82

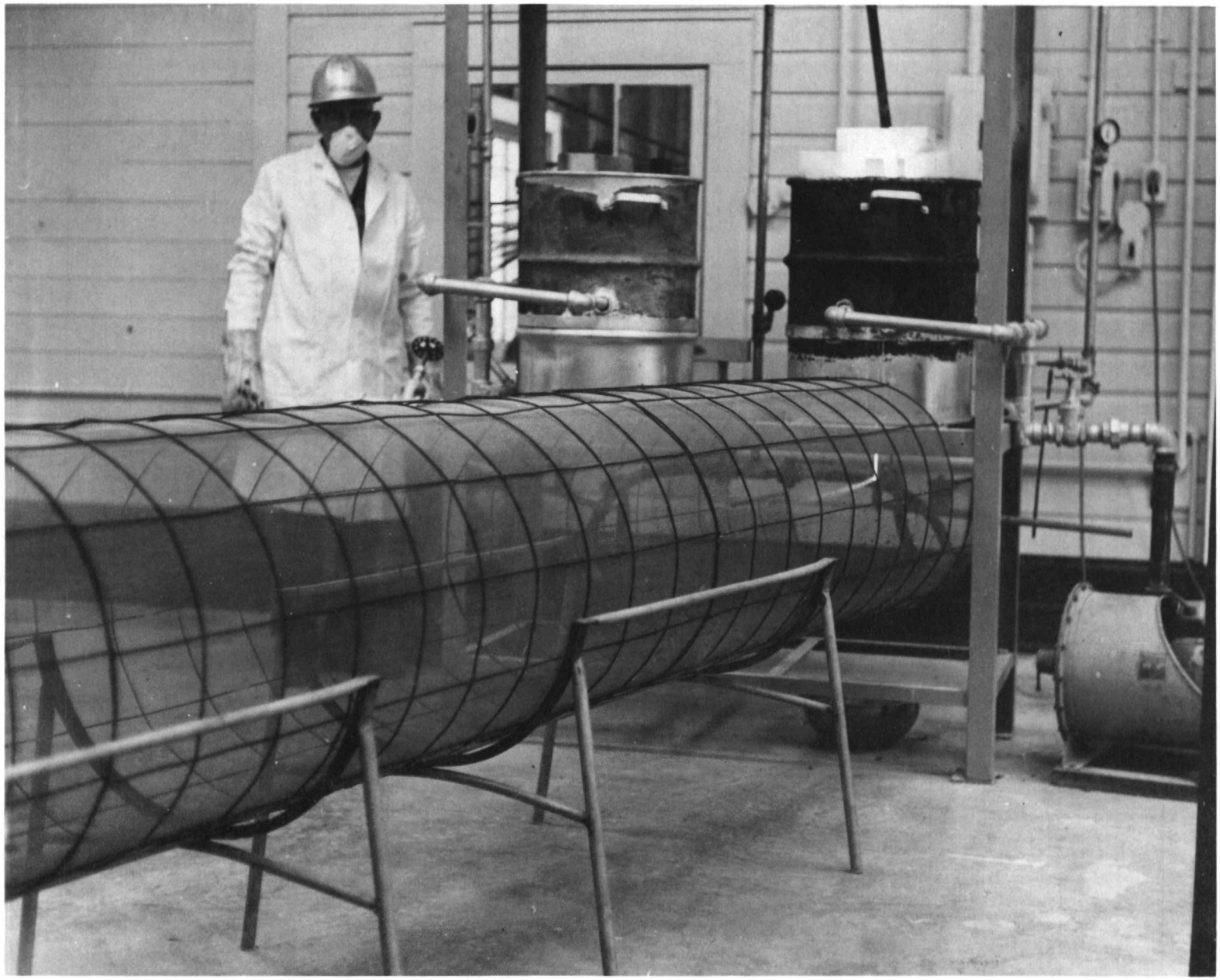

Figure 1—Melting Furnace and Collection Drum Used for Producing Glass Wool.

The compressed air shears the molten glass, causing it to form individual drops as it is blown into a collection area. As the drops of molten glass are propelled through the air, friction causes them to develop long "tails". These "tails" are the insulating fibers; the globular remnants of the original drops are called "shot" (3). The shot content, which was generally less than 25 percent, was not considered excessive for wool made in laboratory scale equipment. Figure 2 shows coarse fiber wool made in this manner.

Product Properties

Glass wool samples were tested according to methods described in Commercial Standards CS-131-46 issued by the U. S. Department of Commerce.

Microscopic examination of the glass fibers indicated an average fiber diameter of 4.3 microns for fine fiber and 21 microns for coarse fiber, while the commercial fiber was approximately 10 microns in diameter. The higher value for the coarse fiber wool was due to the greater amount of silica in the batch which made the melt more viscous.

Figure 3 compares the compressive characteristics of fine and coarse fiber wools with those of a commercial wool. This property is a measure of the resiliency of the wool, or its ability to be compressed for shipping and then to spring back to near original volume for installation. The coarse fiber wool showed greater resilience than the fine fiber wool.

Fiber colors ranged from light gray to white, and densities from 2.1 lb/ft^3 for the fine fiber wool and 1.0 lb/ft^3 for coarse fiber wool. The density of the commercial wool was approximately 2.0 lb/ft^3.

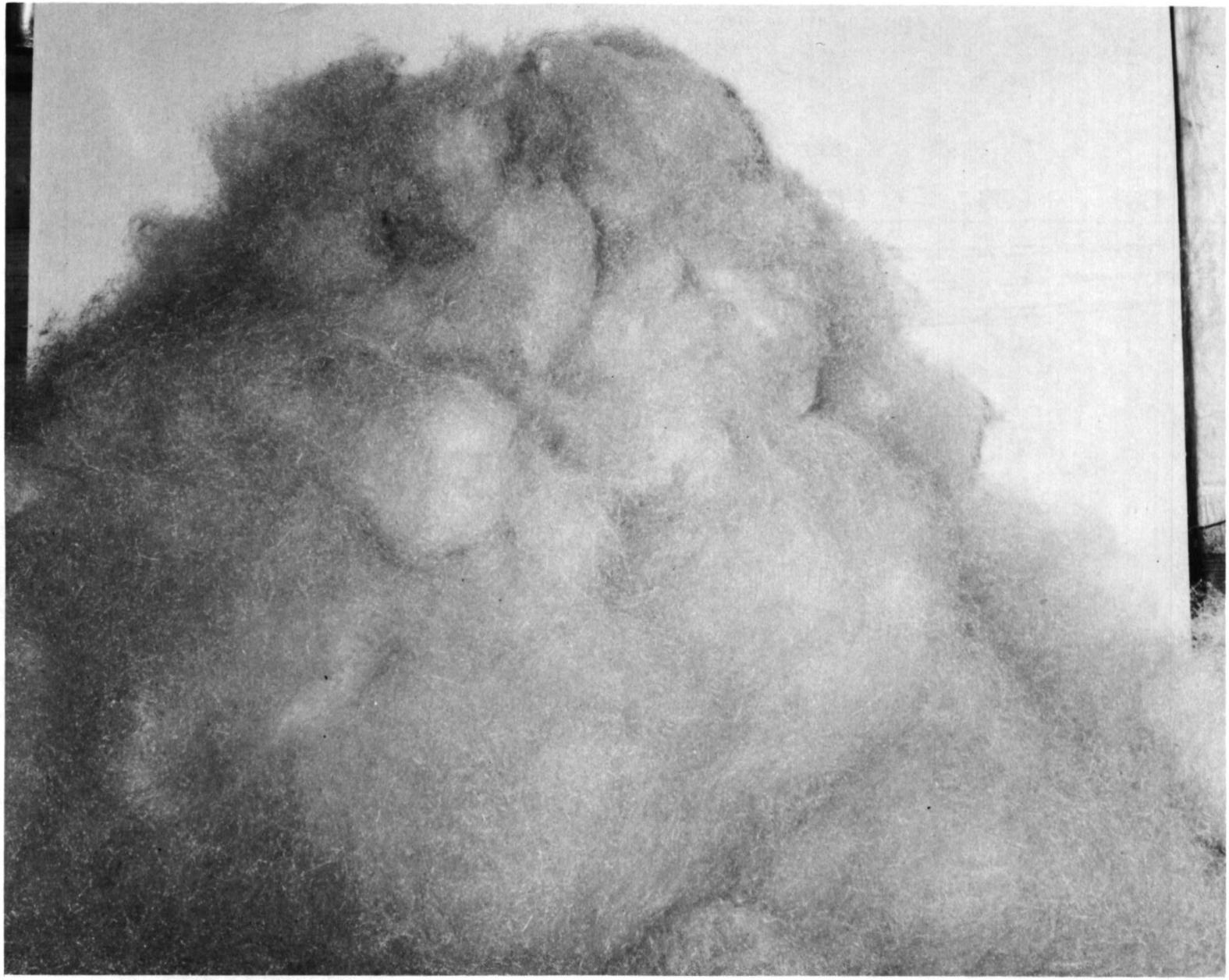

Figure 2—Glass Wool Coarse Fiber.

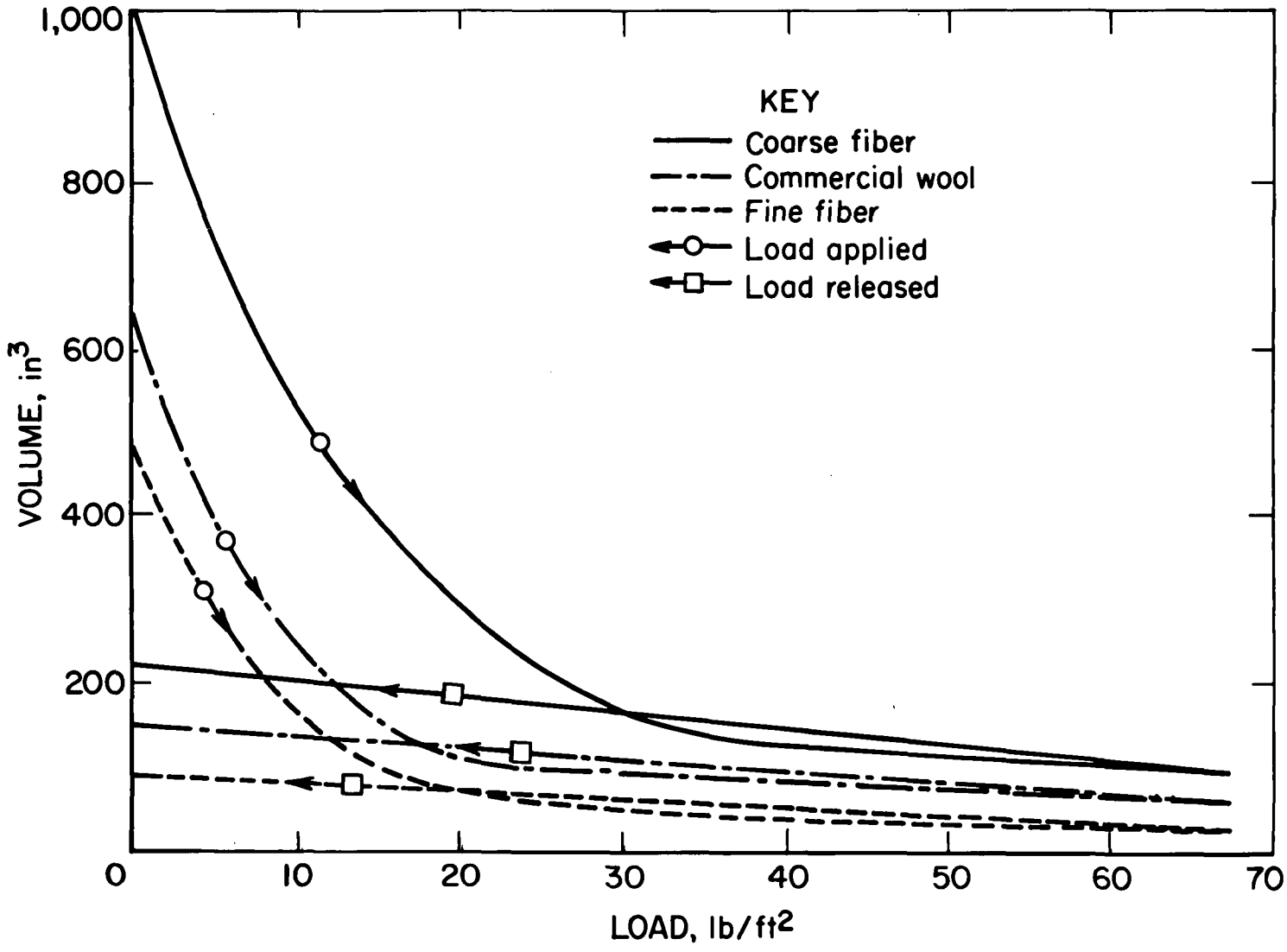

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Figure 3—Compressive Characteristics of Glass Wool.

The high resiliency of the coarse wool product makes it more suitable for use as blanket-type insulation, while the fine wool product would be more suitable as a loose fill insulation that is installed by air blowing.

Economic Evaluation of the Process (4)

The flow chart for the glass wool process is shown in figure 4. Waste glass is mixed with uncalcined dolomite and alumina and is melted in a furnace. The glass formed is fiberized with air and granulated to remove shot. Products are packaged and sold in 40-pound bags.

The estimated fixed capital cost for a plant producing about 77 tons of glass wool per day, equivalent to 3,835 forty-pound bags per day, is approximately $2.5 million, based on first quarter 1972 costs. The estimated annual operating cost based on one shift, 5 days per week, 250 days per year, is approximately $1 million when no costs are included for the waste glass. Assuming the product can be sold at $70 per ton of glass wool ($1.40 per 40-pound bag), a 10 percent rate of return on investment after taxes is obtained. If $5 per ton for waste glass is charged, approximately $72 per ton ($1.45 per 40-pound bag) is required to obtain a 10 percent rate of return on investment after taxes.

Thus, the process for making glass wool from waste glass appears to be economically feasible.

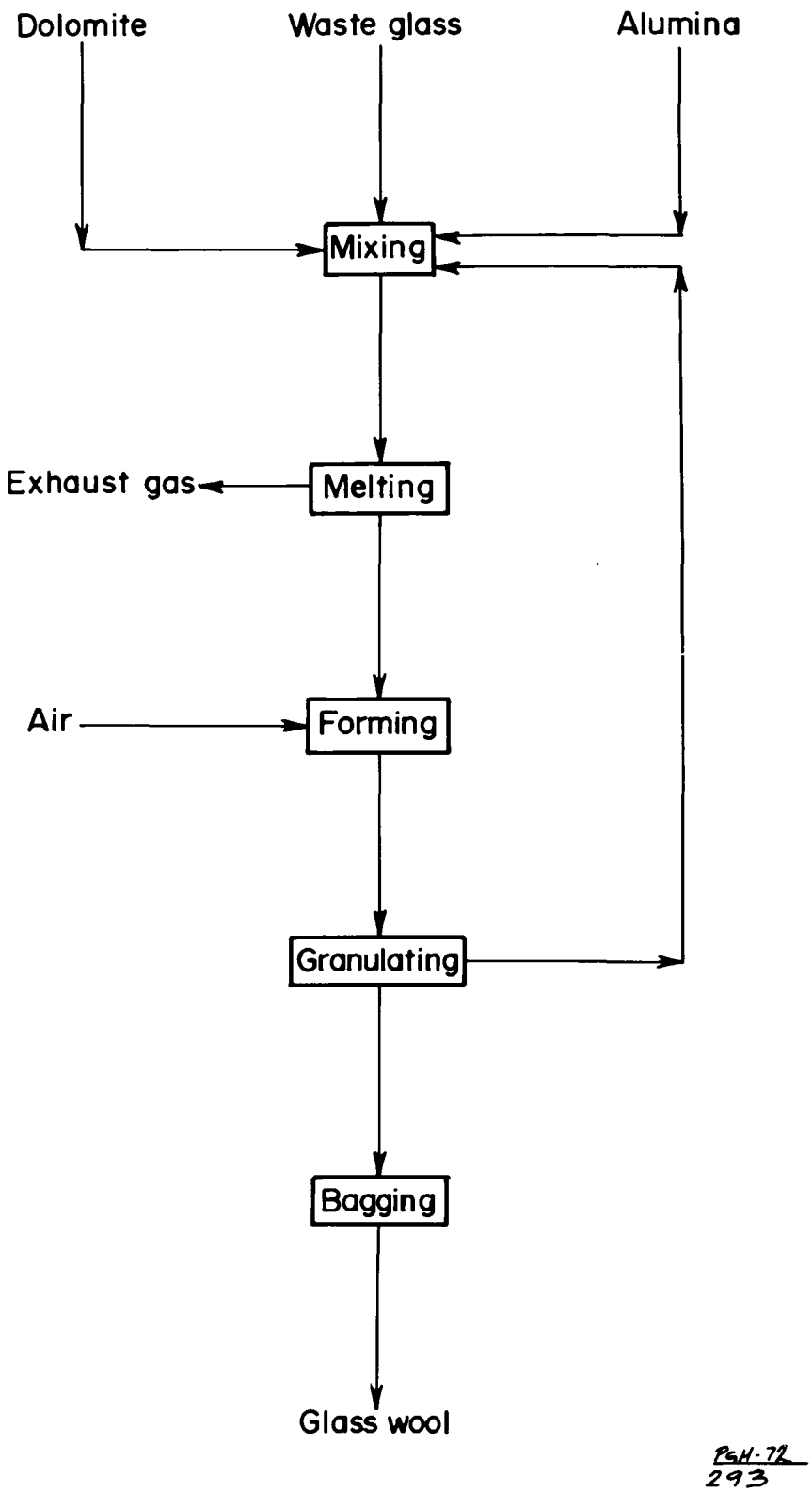

Figure 4—Process For Making Glass Wool From Waste Glass.

Conclusions

Research studies demonstrated that waste glass from incinerator residue can be used to make commercial quality glass wool suitable for thermal and acoustical insulation. Fine fiber wool appears to be suitable for loose fill insulation, while the coarse fiber wool is preferred for blanket-type insulation. The high economic value of glass wool makes this product particularly important in the area of solid waste resource recovery. An economic evaluation of the process indicated that a 10 percent rate of return on investment was possible for a plant producing 77 tons of glass wool per day.

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BROOKHAVEN NATIONAL LABORATORY
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DEPARTMENT OF APPLIED SCIENCE
Radiation Division

Informal Report

GLASS-POLYMER COMPOSITES

Morris Beller and Meyer Steinberg

January 1973

N O T I C E

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GLASS-POLYMER COMPOSITES

by

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Summary

The Concrete-Polymer Materials Development Program at Brookhaven National Laboratory has led to the use of urban solid waste components as aggregates in the development of structurally strong and durable composite materials. A glass-polymer composite (GPC) is produced by mixing crushed waste glass with monomer (either methyl methacrylate or polyester-styrene) and polymerizing by chemical initiation techniques. With ungraded crushed bottle glass, monomer concentrations are 13 to 16 percent by weight; graded sieved glass results in monomer loadings of 9 to 10 percent. The strength of GPC is 2 to 4 times higher than ordinary concrete. The durability, especially the resistance to chemical attack, far exceeds concrete. The application of GPC for sewer pipes is attractive because of the availability of waste glass in urban communities. Various casting techniques are being explored including centrifugal casting. Ten lengths of 8-in. dia, 3/4-in. wall, 42-in. long GPC pipe were produced and installed in a municipal sewer line on Long Island for a field test. For the same wall thickness, the three-edge bearing strength

of a polyester-styrene GPC pipe is more than two times higher than the ASTM C14-70 requirements for concrete pipe. Cost estimates indicate that GPC is potentially competitive with asbestos cement, vitreous clay, concrete and plastic pipe in the 8 to 24-in. dia pipe size range. The construction of large capacity solid waste separation plants within the next few years will make available an assured supply of waste glass for production of GPC products such as sewer pipe and building brick.

GLASS-POLYMER COMPOSITES

I. Introduction

The Brookhaven National Laboratory program for utilization of solid wastes is an outgrowth of previous work on concrete-polymer composite materials development.[1] For the past several years, the Atomic Energy Commission has sponsored work at Brookhaven and at the Bureau of Reclamation which has resulted in techniques for impregnation of concrete with monomer systems.[2,3,4,5] When a monomer is impregnated in concrete and polymerized *in-situ* using radiation or thermal-catalytic methods, the polymer formed in the pores of the concrete results in a polymer impregnated concrete (PIC) having compressive and tensile strengths four to six times greater than that of normal concrete. Most of the other strength properties are likewise improved. The impregnated material is also far superior to concrete in resistance to such phenomena as chemical attack by corrosive acids and salt solutions and freezing and thawing conditions of weathering. The durability properties are thus greatly improved. The polymer content of PIC is usually of the order of 6 percent by weight.

By eliminating the cement binder and substituting a polymer binder, a material which is called polymer-concrete (PC) was developed. Stone and sand can be used as aggregate similar to concrete. The strength and durability properties of PC exceed that of normal hydraulic cement concrete and approach that of PIC. The polymer content of PC can be as low as 7 percent by weight.

This development led to interest in the use of these techniques for application to the solid waste disposal problem.

Components from the solid waste stream such as glass, metal, paper and incinerator ash are a source of supply of solid aggregates from which concrete composites can be produced. The average composition of an urban waste is shown in Table I.

Table I[6]

Average Composition of U.S. Urban Waste

	Wt %
Paper and refuse	55
Garbage	15
Metal	9
Glass	9
Wood and garden waste	9
Rags, plastic and ash	3
	100

The supply of urban waste exceeds 200 million tons/yr so that the availability of recoverable aggregates from this source is large. For example, the potential supply of recoverable separated glass is estimated to be approximately 12 million tons/yr.[9]

Potentially useful structural composite materials are being developed from components of solid waste stream. Primary effort is presently being expended on a material designated as glass-polymer-composite (GPC). This consists of a crushed waste glass aggregate bound together by a liquid monomer which is

subsequently polymerized. Another material under study is paper, which can be impregnated in a manner somewhat analogous to concrete to form a paper polymer composite (PPC).[7]

GPC can be useful for the following applications:

1. Sewer pipe may be produced which is completely resistant to acidic corrosion. This is important since sewage flowing in underground pipes usually releases hydrogen sulfide which can mix with air to form sulfuric acid. The acid corrodes and shortens the life of concrete sewer pipe. Pipe made from GPC does not corrode under these conditions. In addition to its higher strength compared to conventional concrete pipe, GPC pipe has a lower density and is lighter. It may also be useful for cesspools, and tanks in waste and sewage treatment plants.

2. Glass bricks have been fabricated from waste glass and monomer. These are potentially more durable and decorative than conventional brick.

3. The material may also find application for such diverse uses as structural and architectural forms for buildings, or for acid-resistant tanks and reactors for the chemical industry to replace present high-cost vitreous enamel-lined steel tanks.

II. Formulation and Polymerization of GPC

There are three methods of initiating polymerization of monomers. Radiation initiation requires a radiation source such as Co-60 gamma source and can be initiated under any temperature condition. The thermal-catalytic initiation uses a chemical catalyst such as benzoyl peroxide (BzO_2) or methyl ethyl ketone peroxide (MEKP), and requires heating of the system to 60-80°C. The promoter-catalyst initiation uses a

promoter such as cobalt naphthenate to decompose a catalyst such as MEKP which initiates the polymerization usually at ambient conditions. Addition of heat accelerates the process. For low capital investment in production facilities, the promoter-catalyst system is the method of choice.

GPC formulations have been prepared with two liquid monomer systems. One is based on methyl methacrylate, and the other employs a polyester-stryene mixture. The compositions of the formulations are shown in Table II. The polyester-styrene system shown is only one of several compositions that have been investigated to date. Further work to optimize the system with respect to polyester/styrene ratio, viscosity, mixing and curing time, and additive composition is yet to be performed.

The silane is used to promote glass adhesion in the polymer matrix. The glass employed is obtained by crushing glass bottles in a hammer mill. The crusher employed at Brookhaven is a Shima-Sangyo Glassmill, Model GM-B having a rated capacity of 200 lb/hr. The particle-size distribution obtained from this machine is shown in Table III.

Three casting techniques have been used for producing composites. The first consists of adding glass to the monomer mixture already in the form. This results in some segregation of fine particles into a series of annular rings, since the fines float up during the addition of glass. The second method involves the preloading of the glass in a form and diffusing the monomer up through the glass packing. This sometimes results in air entrapment and causes a porous structure. The third method involves a premixing of glass and monomer and casting the mix in a form not unlike concrete casting. This appears to overcome the segregation and air

Table II

GPC Resin Formulations

A. Methyl Methacrylate (MMA) System

Component	Weight Composition
MMA	100
Benzoyl peroxide, initiator	1
Silane A-174	1

B. Polyester-Styrene (P-S) System

W.R. Grace GR-511 (65% polyester, 35% styrene)	16
Styrene	84
Co Naphthenate, promotor	1
Methyl ethyl ketone peroxide, initiator	1
Silane A-174	1

Table III

Particle Size Distribution - S.S. Glassmill

Basis: 1000 gms

U.S. sieve size	Approximate diameter, in.	Retained on screen, wt-gm
4	0.185	67 ± 12
8	0.093	308 ± 4
20	0.033	379 ± 2
30	0.021	71 ± 2
40	0.014	49 ± 2
60	0.010	52 ± 3
80	0.007	24 ± 2
100	0.006	7 ± 0
170	0.0035	29 ± 3
200	0.003	0
<200	<0.003	13 ± 1

entrapment. The work reported here to date has been mainly involved with fully loading the void volume of the glass by the first two methods.

During the glass crushing operation, no attempt is made to remove paper or foil labels, caps or rings from the non-returnable discarded bottle glass. The bottles are used as received - unwashed, undried, and not sorted by color. The composites which result from the addition of this ungraded glass to monomer in a form mold have final polymer loading ranging from 13-16 percent by weight. All composites are cured in the laboratory at 70°C for a period of 4 to 8 hrs to polymerize the monomer. Optimization of the polymerization cycle has yet to be investigated for production purposes. Shorter cycle times can be effected by adjusting the promoter-catalyst concentrations.

To minimize the void-volume and thus the monomer loadings of composites, separation of glass sizes by sieving operations may be necessary. No glass crushing device can produce the proper mixture of sized particles. An additional complication is caused by glass breaking into jagged, rectangular sections as opposed to spherical particles which are desirable for optimum packing arrays. Based on McGeary's[8] distributions for packing spherical particles, some experiments were performed with glass and sand mixtures. The results are presented in Table IV. The glass was preloaded in a form (~3-in. dia x 6-in. long container) and the monomer was diffused up through the aggregate for filling. The data shows that crushed glass can result in monomer loadings of 9 to 10 percent when size sorted. Replacement of some particulate fractions with sand, particularly intermediate sizes, can reduce loadings to about 7 percent. This is due to the greater sphericity of sand,

Table IV

Packing of Glass and Glass/Sand Mixtures

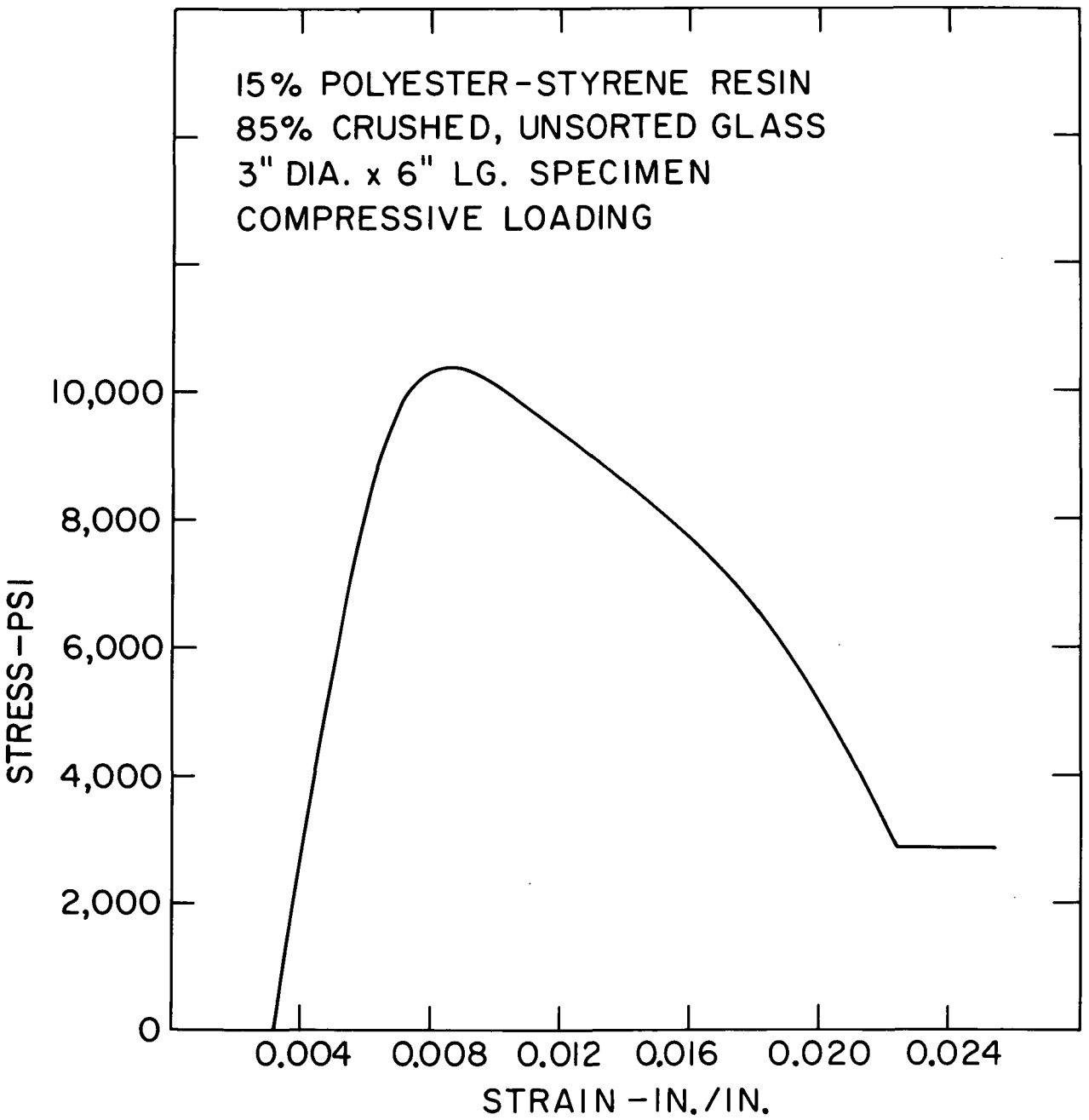
Glass preloaded in form and monomer diffused up through packing

Wt %	60.7	23.0	10.2	6.1	
Particle Size	1/8-1/4-in.	20-30 mesh	40-60 mesh	170-270 mesh	Monomer loading wt %
	crushed glass	crushed glass	crushed glass	crushed glass	9.2
	"	"	"	sand	10.3
	"	"	sand	sand	9.2
	"	sand	sand	sand	7.7
	"	sand	crushed glass	crushed glass	7.4
	glass beads	sand	crushed glass	crushed glass	6.6
	glass beads	sand	sand	sand	6.1
	glass beads	glass beads	glass beads	glass beads	6.3

which can fill the interstices of the matrix to a greater degree. The use of glass spherical beads permits achievement of loadings in the order of 6 percent. Work in this area is being continued. A major point requiring investigation is the economics of using unsorted glass with a higher monomer loading versus the additional expense of glass sorting, and reduced monomer usage and cost.

III. Properties of GPC

The physical properties of GPC samples made with crushed unsorted glass having the particle size distribution shown in Table III have been measured. Properties were determined using both methyl methacrylate and polyester-styrene formulations. The results are summarized in Table V. These are average values for multiple specimens. Individual samples have sometimes yielded compressive strengths exceeding 16,000 psi. These data indicate the GPC is 2-4 times stronger than ordinary concrete (≈4,000 psi in compression). The stress-strain curve measured for polyester-styrene GPC samples shows a gradual decline after reaching its ultimate strength, as shown in Fig. 1. This absence of abrupt failure is very desirable from a structural viewpoint, since it indicates that catastrophic failure will not occur with this material. This desirable characteristic is presumed to be due to the use of the particular short-chain polyester in the resin system. This polyester serves as an internal plasticizer for the resin matrix and imparts flexibility to the system.



STRESS-STRAIN DIAGRAM FOR GPC

Figure 1

Table V

Average Physical Properties of GPC Composites

Crushed, unsieved, unsorted glass added to monomer in form mold

	MMA[1]	P-S[2]
Wt % polymer	13.6	14.2
Compressive strength, psi	7,600	11,500
Tensile strength, psi	1,200	>1,500[3]
Mod. of elasticity, psi	1.76×10^6	1.70×10^6
Poisson's ratio	--	0.25
Water absorption	<0.5%	0.25%
Resistance to 5% H_2SO_4	No weight loss after 2 month immersion	

1) Average of 3 samples, (1¼-in. dia x 3-in. lg)

2) Average of 12 samples (1¼-in. dia x 3-in. lg - 6 samples; 3-in. dia x 6-in. lg - 6 samples)

3) Samples were stronger than bond to grips and broke away at bond interface.

IV. GPC Pipe Development

Initial work on a practical application for GPC was geared to sewer pipe. The economic potential for the sewer pipe market is attractive. Since extensive sewer systems are being installed on Long Island, an opportunity was presented for a practical field test of feasibility. Officials of the Town of Huntington in Suffolk County, were enthusiastic about the prospects for the material especially because of the possible reduction of solid waste handling in expensive land fill operations. They agreed to permit insertion of a section of GPC pipe into a new working sewer line being installed in the area.

Since a time period of only three months was available for production of the pipe (due to the sewer district schedule), plans were rapidly formulated to use a double shell fixed mold technique for pipe production. The pipe size required was 8-in. ID, 3/4-in. wall thickness, in sections about 42-in. long. The length was determined by the lengths of aluminum pipe quickly obtainable for molds. The ID of 8-in. corresponded to the sewer line section that was being installed which employed 8-in. ID Class 2400 asbestos-cement pipe.

Initial feasibility studies on pipe molding were carried out with small double shell molds, resulting in pipes 4½-in. ID, 6-in. OD. It was found that a mold release problem resulted and pipe removal from the mold was difficult. To overcome the problem, the mold was lined with 10 mil Mylar film. This permitted the pipe to slide out from the pipe within the Mylar, which was stripped off easily after pipe removal. This technique was subsequently used on the larger pipe sections and worked well. At present various release agents are under evaluation. These include silicone and Teflon coatings.

All pipes for the Huntington sewer lines were made with unsorted, crushed waste bottle glass. Initially, methyl methacrylate was used as the monomer but it was found that some pipes made with this material were porous. This was attributed to the high vapor pressure of MMA. During the thermal curing operation at 70°C, a peak exotherm develops which causes excessive heat buildup in the mold. The result is a porous matrix which causes leakage during hydrostatic tests at 10 psi. This could be overcome by using double promoters which cause the MMA to gel at room temperature, thus reducing the temperature developed by the exotherm during subsequent thermal polymerization.

During this time, the polyester-styrene system was also being tested. The advantage of higher strength, lower cost and reduced curing problems dictated a changeover to the polyester-styrene.

Ten pipe lengths, totalling about 35 ft were fabricated for the sewer line demonstration. Two of these were methyl methacrylate and eight polyester-styrene. The ends were easily machined with carbide tool bits to accommodate the standard 8-in. asbestos-cement couplings used in the existing sewer line. It should be noted that a joint configuration can be designed for integral molding with the main pipe body which would eliminate machining. The test pipes were installed on October 30, 1972. After the line is put in service, the pipe can be observed through a manhole at which the GPC section terminates. Fig. 2 shows a length of the pipe being installed in the system.

Other pipe sections have been made up for three-edge bearing tests. In addition to 3/4-in. wall, some pipes were

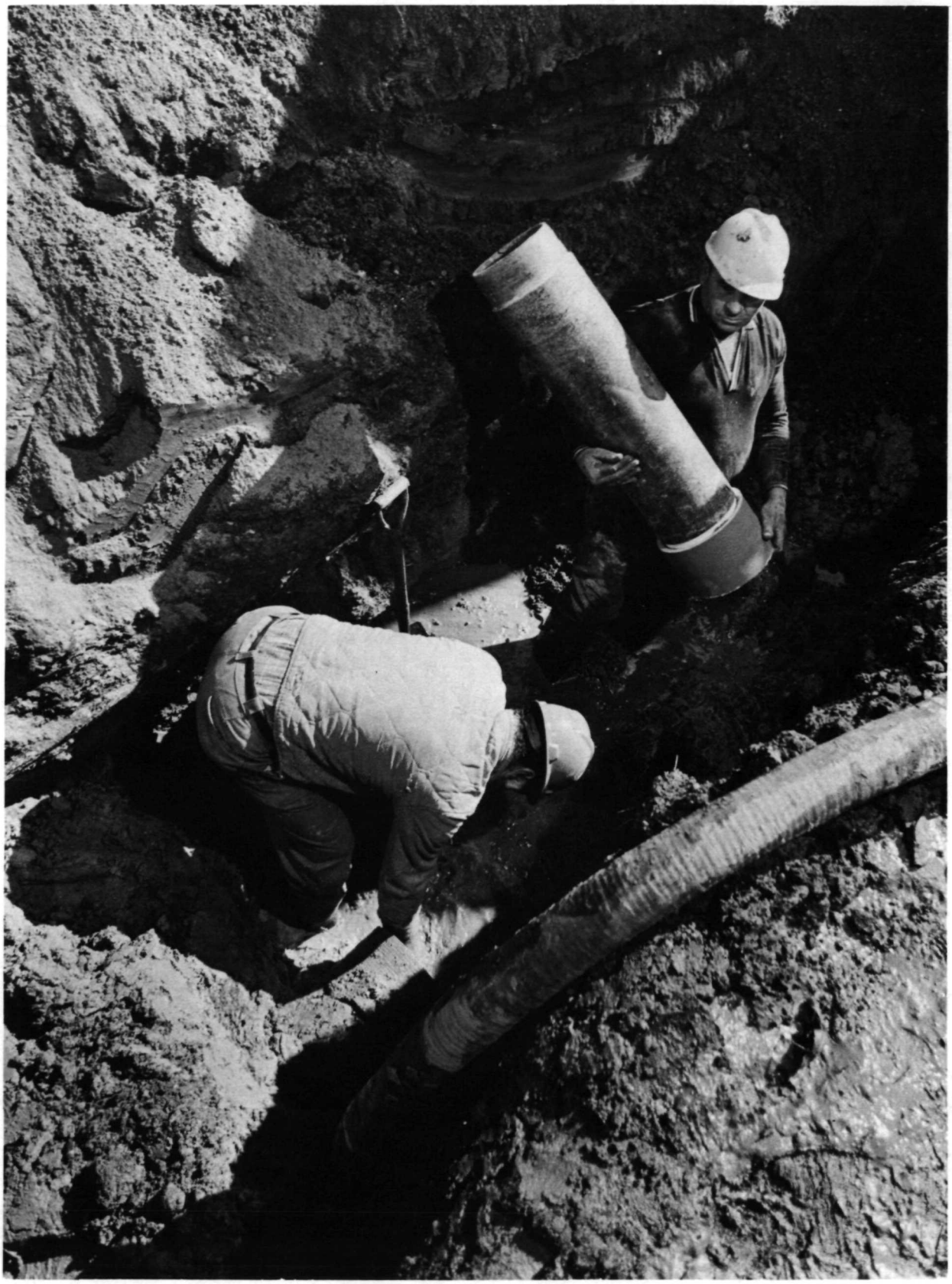


Figure 2—GPC Pipe Installation.

made with 1/2-in. wall to determine whether the higher strength of GPC over concrete permits reduced wall thickness. The physical properties of GPC pipe are shown in Table VI.

Table VI shows that with only 1/2-in. wall thickness, GPC pipe exceeds the ASTM C14-70 requirement of 1300 lb/ft for concrete pipe, which has a 3/4-wall, and also exceeds the tentative revised value (which has not yet been accepted) of 1500 lb/ft. For the polyester-styrene GPC pipe at 3/4-in. wall thickness, the three edge bearing strength is more than twice as high as the standard for concrete pipe.

The 3/4-in. value of 3,190 lb/ft for GPC also far exceeds the ASTM requirement for 8-in. extra strength concrete pipe of 2,000 lb/ft, for which a 7/8-in. wall is specified. These values are indicative that thinner walled GPC can replace concrete for pipe, with no sacrifice of strength. Lighter pipe is thus possible.

Simpler methods of producing pipe are being studied. A particularly interesting method is that of centrifugal casting, in which a mixture of plastic and glass is spun rapidly in a mold to form the pipe. Fig. 3 illustrates the method with a prototype mold and a water-glass mixture for the first test. Initial tests are proving satisfactory and work on this process is continuing.

VI. Economics

An economic evaluation[9] of the potential of GPC sewer pipe was performed by Arthur D. Little, Inc. GPC pipe was compared to competitors such as asbestos-cement, vitrified clay, concrete and plastic.

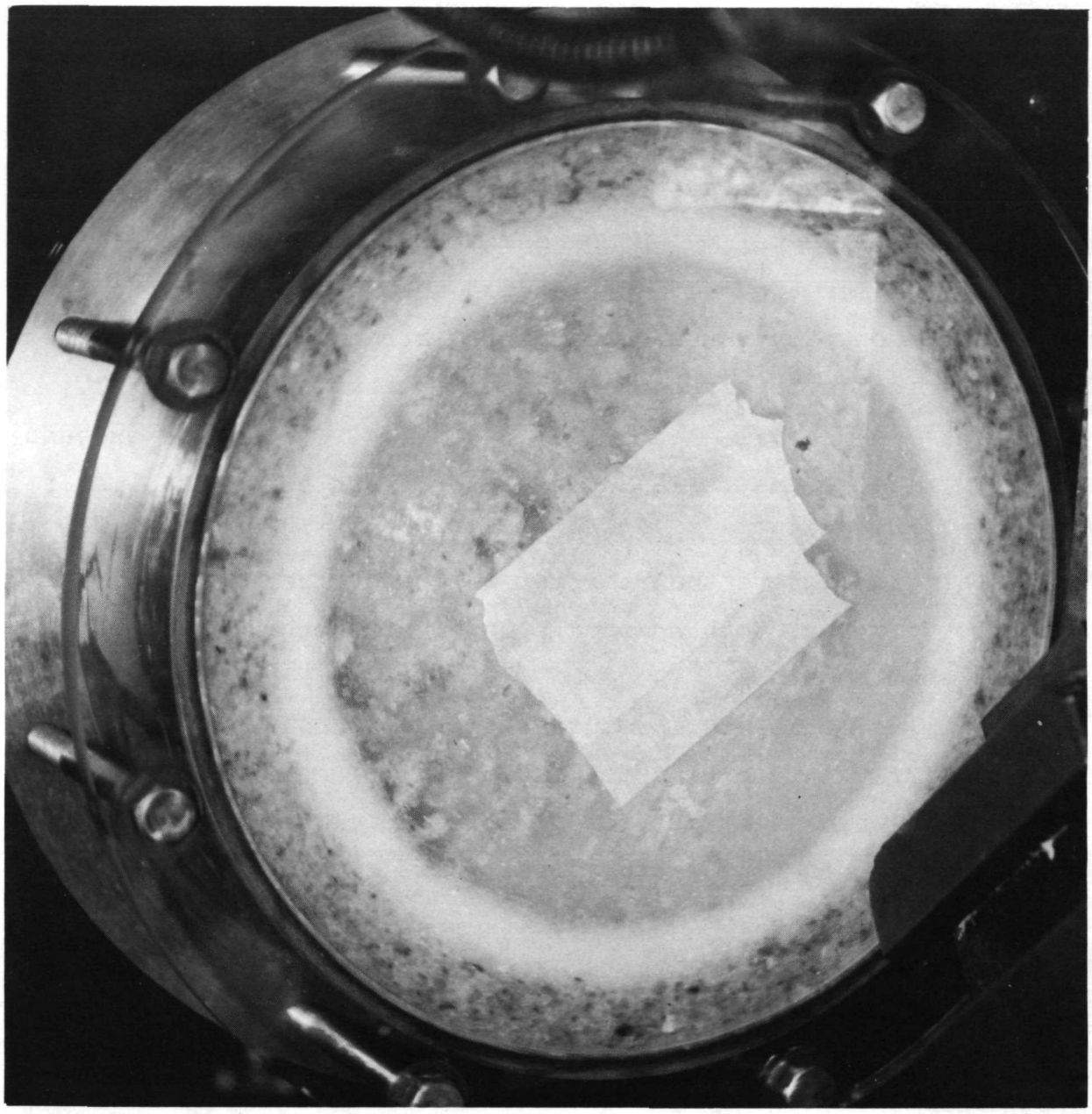


Figure 3—Centrifugal Casting of GPC

Table VI

Properties of GPC Pipe

(8-in. ID)

	Monomer			
	MMA	MMA	P-S	P-S
Monomer loading - avg., %	17.0	13.6	15.0	16.4
Wall thickness - in., (nom)*	3/4	1/2	3/4	1/2
Weight of pipe, lb/ft	18.0	11.4	18.7	12.7
Three-edge bearing strength, lb/ft	2,325	1,060	3,190	1,640
Hydro test, 10 psi, 10 min.	OK	OK	OK	OK

*Actual wall thickness ranged as follows:

3/4-in. MMA, 0.72-0.78 3/4-in. P-S, 0.67-0.72

1/2-in. MMA, 0.44-0.47 1/2-in. P-S, 0.50-0.51

Materials cost assumptions for monomer and waste glass are given in Table VII for two cases. The most favorable case is using styrene monomer and waste glass at $10/ton; the least favorable is with MMA and waste glass at $20/ton. In Table VIII, the costs of various types of pipe in terms of dollars/ft are given. For GPC the least and most favorable cases are given combined with a lighter wall (2/3 weight of concrete) because of the higher strength available and with the same wall thickness as concrete (full weight). The evaluation indicates that GPC is potentially competitive with asbestos cement, vitreous clay, concrete and plastic pipe, particularly in the 8 to 24-in. dia pipe size range. There also appears to be a good match between the waste glass generated in an urban community and the market typically available for sewer pipe in a municipality. Within the near future large capacity solid waste separation plants will be installed which will assure the supply of waste glass as a raw material for the production of GPC sewer pipe.

VI. Future Work

Work in progress and planned for the near future include the following areas:

A. GPC Material Studies

1. Void volume reduction studies, in which particle size distributions will be varied to ascertain effects on monomer loading and physical properties.

2. The effect of specific particle sizes on strength will be evaluated.

3. The effect of multiple passes through the glass crusher on monomer loading will be investigated and size fractions determined.

Table VII

Material Cost for GPC Sewer Pipe

	lbs	Cost (¢)
Most favorable case		
Styrene @6.5¢/lb	0.1	0.65
Waste glass @ $10/ton	0.9	0.45
	1.0	1.10 ¢/lb
Assumed weight of 8-in. pipe lb/ft (2/3 concrete)	21.0	
Least favorable case		
Methyl methacrylate @ 20¢/lb	0.1	2.0
Waste glass @ $20/ton	0.9	0.9
	1.0	2.9 ¢/lb
Assumed weight of 8-in. pipe (same as concrete)	31.0	

Manufacturing cost and margin for 8-in. pipe, $1.03/ft

Note: The 90% polyester - 10% styrene system falls between the styrene and methyl methacrylate case. Polyester monomer mixtures cost 20¢/lb.

TABLE VIII

COSTS OF VARIOUS TYPES OF PIPE (DOLLARS/FT.)

Type of Pipe	Diameter					
	6"	8"	10"	12"	18"	24"
Concrete Culvert*	-	-	-	1.80	3.20	5.05
Concrete Sewer*	-	-	-	3.50	4.40	9.25
Vitrified Clay Premium	.90	1.25	2.00	2.50	6.35	11.40
AC Class 2400	1.10	1.20	1.70	2.15	-	-
AC Class 4000	-	-	-	-	5.35	8.40
ABS Plastic	.85	1.15	1.65	2.20	-	-
GPC 2/3 Weight Least Favorable	1.36	1.64	1.99	2.78	5.00	7.83
GPC 2/3 Weight Most Favorable	1.12	1.26	1.49	1.98	3.20	5.03
GPC Full Weight Least Favorable	1.55	1.93	2.38	3.44	6.45	10.03
GPC Full Weight Most Favorable	1.19	1.37	1.64	2.23	3.75	5.85

* Reinforced pipe

4. The method of premixing the monomer with the crushed glass and subsequently casting will be developed. Viscosity, control, and effectiveness in reducing overall loadings for premixed glass/monomer systems will also be evaluated. The use of thermoplastic polystyrene to reduce shrinkage and eliminate voids will be studied.

5. Polyester-styrene ratios will be varied to study the effect on physical properties.

6. The use of fine fillers to reduce monomer loadings will be studied.

B. Pipe Design and Production Studies

Studies in this area will include extended work on the centrifugal casting technique, release agent evaluations for molds, pipe joint designs, optimized pipe design to determine minimum wall thickness and maximum length, and evaluations of curing techniques.

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FOAMED GLASS INSULATION FROM WASTE GLASS

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ABSTRACT

Waste glass, which has not been color sorted nor cleaned, is crushed and ground to micron size. Approximately one percent calcium carbonate, which acts as the foaming agent, and two to five percent bentonite clay are mixed with the glass powder. This mixture is pressed into bricks or pellets and heated to approximately 750°C to 800°C. At this temperature the calcium carbonate reacts with the softened glass, liberating carbon dioxide gas. This gas is trapped in closed pores of the sintered glass and expands it into a cellular foamed structure.

The foam density is as low as 10 lbs/ft^3 with compressive strengths in excess of 100 lb/in^2. Uniform cell structure with cell sizes ranging from 1 to 3 mm are common. The thermal conductivity is approximately 0.4 btu/hr ft^2 °F/in.

Over long periods of exposure to water, the foamed glass, having an extremely large surface area, may deteriorate and lower its quality and strength. The solubility of glass in water is significantly reduced with the addition of bentonite. The high Al_2O_3 content of the bentonite decreases the solubility and, therefore, extends the usefulness of the material.

Foamed glass can be used as an insulation for both cryogenic and moderately high temperature ranges. It is incombustible, waterproof, vaporproof, rigid, strong, and dimensionally stable. Foamed glass pellets can be used as a loose-fill insulation, light-weight aggregate, or a soil conditioner.

I. Introduction

In recent years, solid waste disposal in the large metropolitan areas of the United States has mushroomed into a major environmental problem. The average United States citizen generates 1800 pounds of solid waste each year. Of this amount, approximately six to seven percent is waste glass. Annually, as much as twelve million tons of glass are discarded. Unlike other solid wastes, glass presents no threat to America's natural resources since the major components of glass (silica, limestone, and soda ash) are very abundant in nature. Salvage and recycling of all materials, however, offer the only viable long-range solution to the waste disposal problem.

There are potential uses for all available waste glass in the country; however, most glass cannot be utilized until collection and separation systems are developed to provide a continuous source of glass. The most common use of recycled glass is the manufacture of new glass products. Alternate uses of waste glass include "glasphalt," reflective glass beads, tile, building blocks, and mineral wool insulation. Since the value of these products are low, there is little economic incentive to recycle glass, which is a relatively expensive process.[1,2] The purpose of this report is to describe a method of producing a foamed insulation material of high value.

The process of foaming waste glass was originally developed by eight University of Utah students during a twelve-week summer project funded by the National Science Foundation's Student Originated Studies Program (Summer 1971).[3] Figure 1 shows the major steps in producing foamed waste glass. Initially the glass is ground to an average particle size of one to twenty microns. The glass does not require color sorting, sizing, or cleaning, all of which would increase the cost of the recycled glass. Calcium carbonate ($CaCO_3$) and bentonite are next mixed with the ground glass. The bentonite is added to improve the

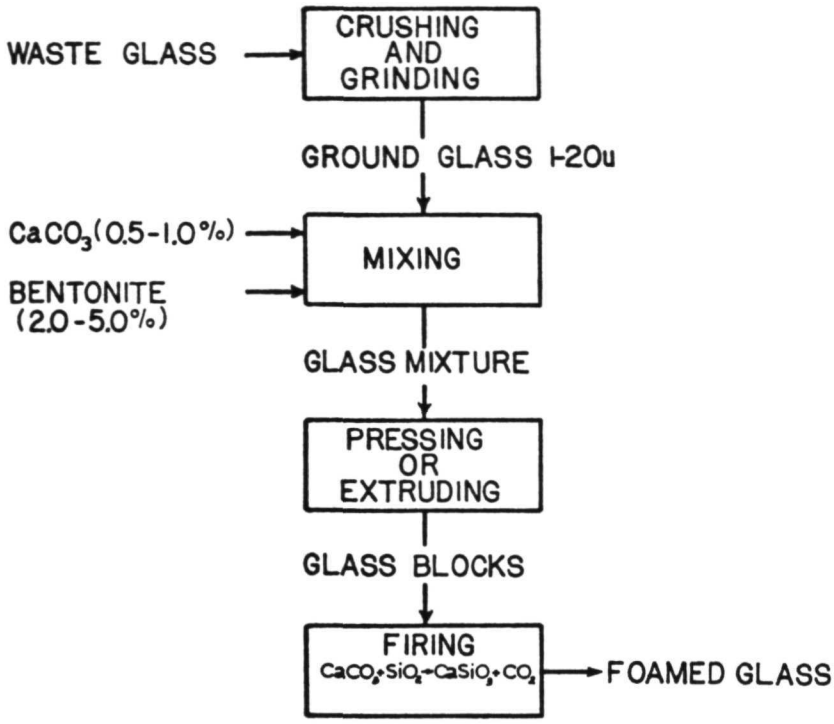

Figure 1—Steps in Producing Foamed Waste Glass.

plasticity of the mixture so that it can be easily extruded or pressed into blocks. The $CaCO_3$ acts as the foaming agent. As the dried mixture is placed into a furnace at approximately 800°C, the $CaCO_3$ reacts with the glass (largely SiO_2) as follows:

$$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$$

At this same temperature the glass particles begin to sinter. The sintering prevents the carbon dioxide gas from escaping by sealing off the passageways. The pressure of the gas can then expand the molten glass into a low-density cellular structure. This process is used to produce both large blocks or slabs and pellets of foamed glass. Figure 2 is a micrograph of a typical cell structure of foamed glass showing the closed-cell nature of the foam. The density of the foam ranges from ten to fifteen lbs/ft^3 with a compressive strength in excess of 100 lbs/in^2. The thermal conductivity is a function of the cell size with a minimum value of approximately 0.4 $btu/hr\ ft^2\ °F/in$ for 1.0 to 1.5 mm average cell size.[3]

II. Engineering Study

A. Experimental Methods

Clear soda-lime cullet was used throughout the experiments. Grinding was done in a two-foot diameter ball mill with steel balls. Each batch containing thirty to forty pounds of glass was ground for two hours. The final size ranged from one to twenty microns. Figure 3 shows a typical distribution of the ground glass. The $CaCO_3$ and bentonite were mixed with the glass in smaller rubber-lined ball mills (8-inch diameter) using alumina balls.

The standard size disk-shaped samples for foaming tests, each weighing 65 grams, were 6.5 cm in diameter. The dried samples were placed directly into a pre-heated electric furnace for a set length of time, and then were withdrawn directly to room temperature. In addition to these standard samples, larger samples

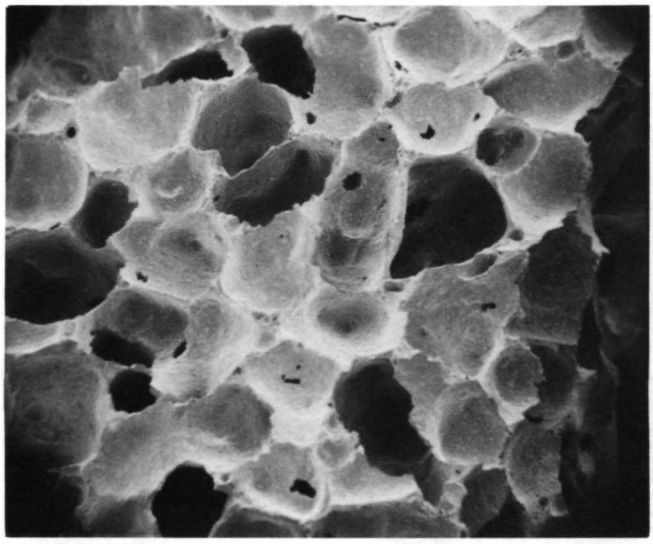

Figure 2—Micrograph of Foamed Waste Glass, 22x

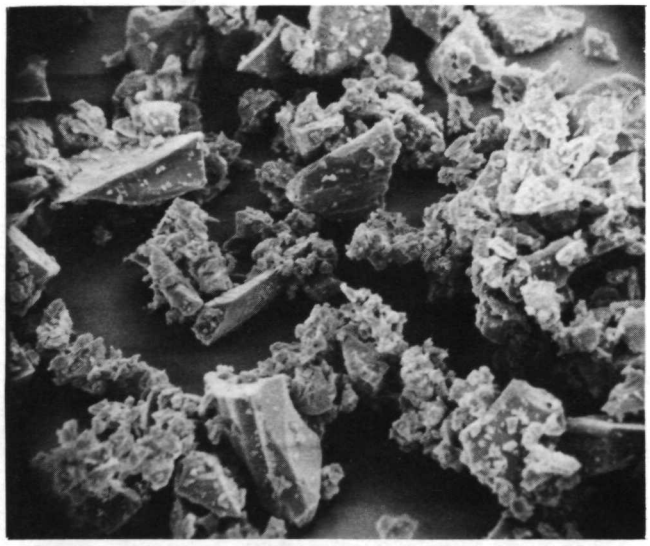

Figure 3—Micrograph of Ground Glass, 1000x

(9 inches by 5 inches by 1-1/2 inches) were prepared to assure that the relationships between the various parameters were consistent for different sizes.

The procedure for the solubility test was as follows:

1) Crush and sieve foamed glass sample to a -40 to +50 mesh size.
2) Wash with alcohol to remove fines from the surface of the particles.
3) Dry in drying oven at 120°C for twelve hours.
4) Weigh a sample approximately 7-1/2 grams to 10 grams.
5) Add 250 ml distilled water to sample (in 250 ml plastic beaker with lid).
6) Place beaker in 90°C water bath for six hours.
7) Filter and dry in oven at 120°C for twelve hours.
8) Weigh residue and determine loss.

The pellets used to produce the light-weight aggregate were produced by extruding the glass-$CaCO_3$-bentonite mixture through either a 1/8 inch or 3/8 inch die and then cutting into lengths of approximately 1/4 inch. This method was chosen since many commercial operations, which produce pellets, often utilize extrusion processes. These pellets were thoroughly dried and foamed by placing them directly into the furnace without any preheating. Tests to control the dimensions of the foaming glass were conducted by placing pellets of the glass mixture into a graphite mold and placing the mold directly into the furnace.

B. Results and Discussion

1. Parameters of the Foaming Process

During earlier investigation glass containing 1.0 to 2.0 percent $CaCO_3$ was foamed at temperatures ranging from 700°C to 800°C, often resulting in an open-cell foam structure. A closed-cell structure, which improves the insulative qualities of the foam, is obtained by foaming at temperatures near 800°C using approximately 0.5 to 1.0 percent $CaCO_3$. The cell size as a function of

the percent $CaCO_3$ and the foaming time are shown in Figures 4 and 5, respectively.

As shown in Figure 4, the type of $CaCO_3$ affects the foaming characteristics. Micrographs of the milled limestone and reagent grade $CaCO_3$ (Figures 6 and 7, respectively) show that the size distribution and structure are very similar; however, the foaming qualities are significantly different between the two. A high-purity precipitated $CaCO_3$ was also tested (shown in Figure 8) and found to be inferior to the milled limestone. Since the reactivity of the $CaCO_3$ is inversely related to the surface area, the precipitated $CaCO_3$ probably reacts before the surrounding glass particles can sinter to seal off the passageways.

2. Glass Solubility in Water

The solubility of glass in water decreases as the percent of bentonite increases (Figure 9). The solubility, however, is not affected by the $CaCO_3$ content. Bentonite is an aluminum silicate in the montmorillinite clay group which is characterized by its flatlike crystal structure and its ability to swell when placed in water. There are two general types of bentonite: high-swelling type and low-swelling type. All of the experiments used a high-swelling bentonite which can swell from 10 to 15 times its original volume.

The increase in the alumina content of the glass due to the addition of bentonite decreases the solubility of the glass. The minimum amount of bentonite needed to extrude the glass mixture is two percent. At this percentage, the solubility has decreased by 24%.

Bentonite content greater than approximately 6% lowers the quality of the foam by increasing density and decreasing cell uniformity. Since the clay expands with water, the samples would often crack while drying. Additional tests are needed using bentonite with different swelling characteristics (low-swelling) and different chemical compositions (high alumina content) to determine the optimum type and percentage needed.

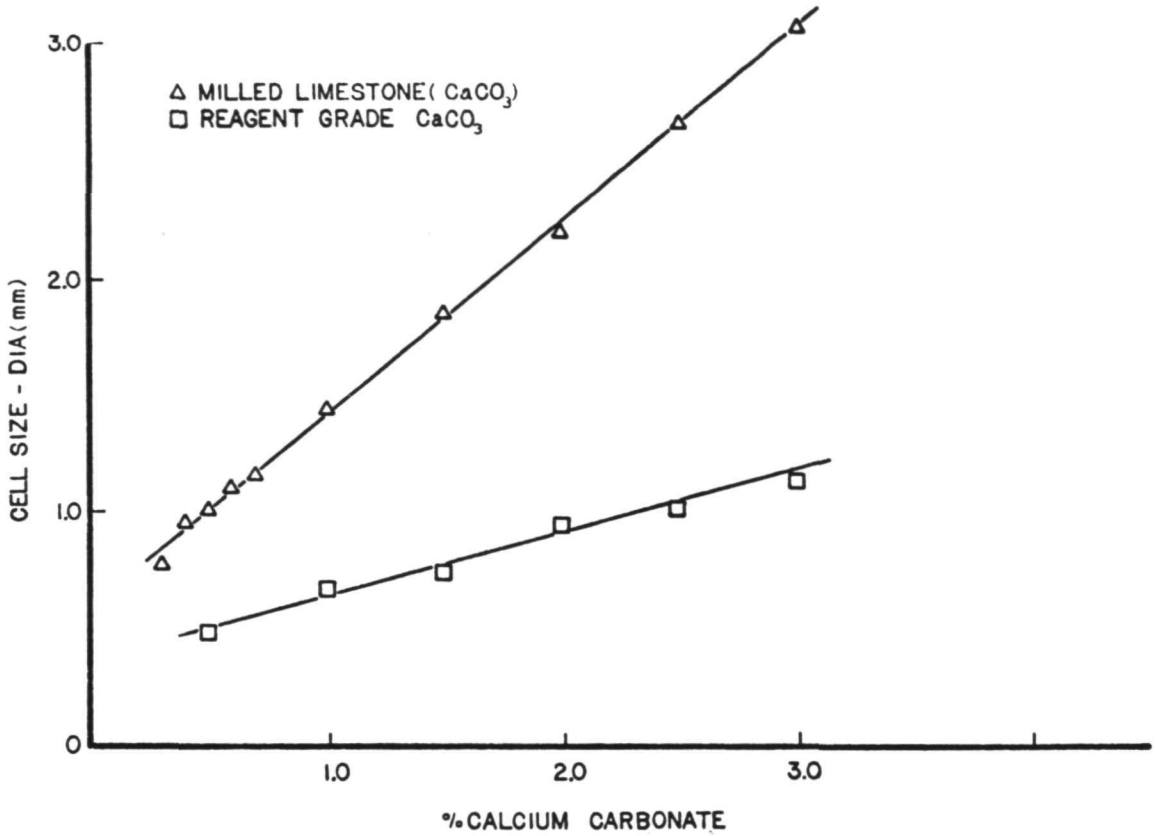

Figure 4—Cell Size versus Percent Calcium Carbonate.

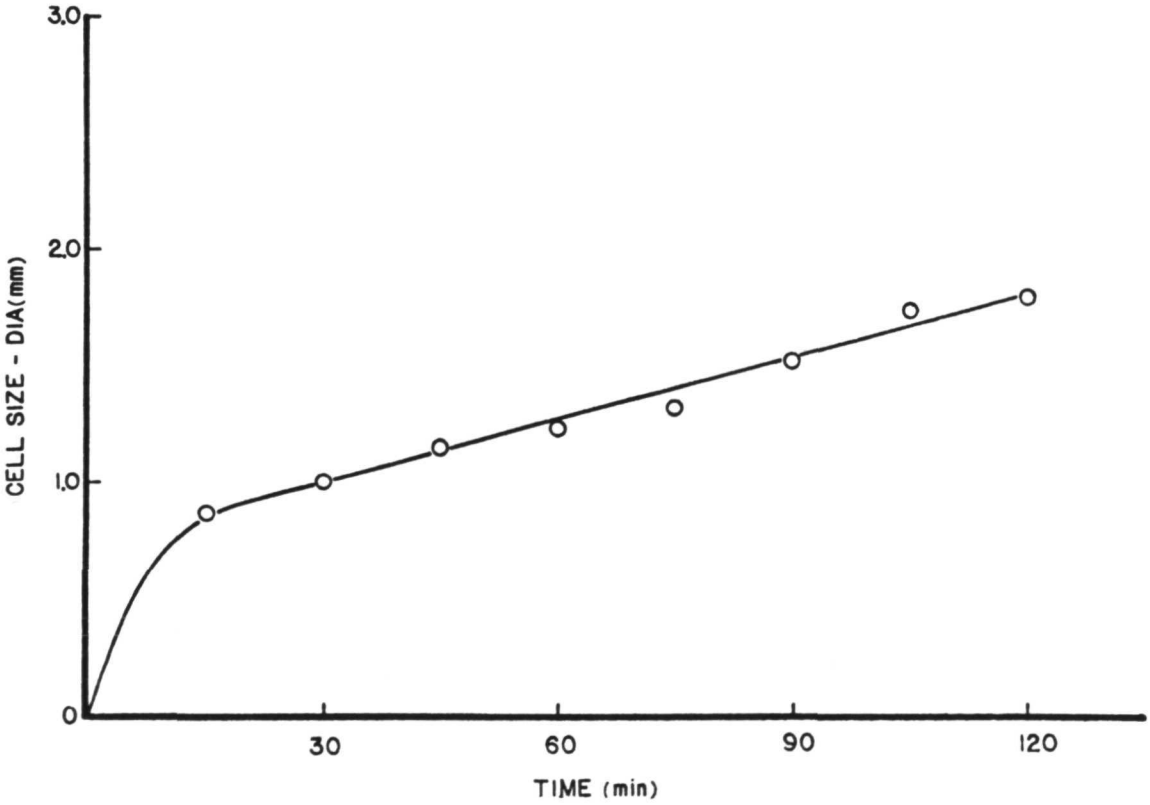

Figure 5—Cell Size Versus Foaming Time.

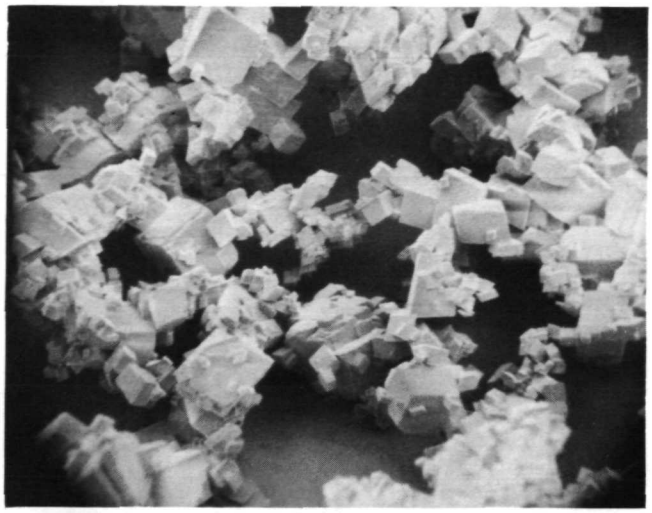

Figure 6—Micrograph of Milled Limestone, 1000x

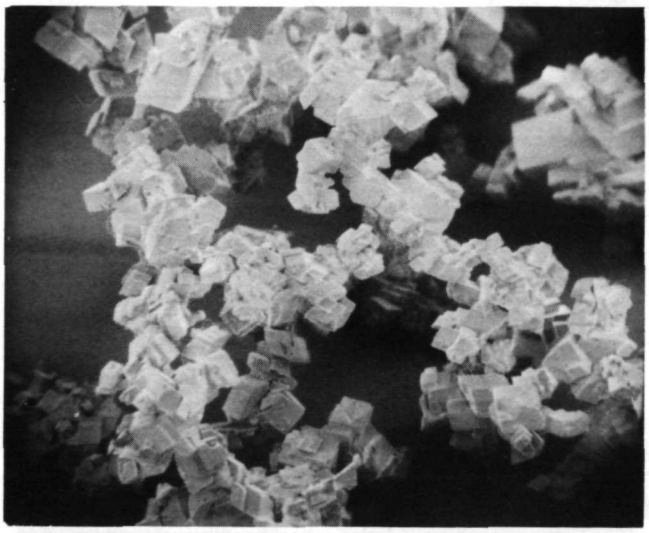

Figure 7—Micrograph of Reagent Grade $CaCO_3$, 1000x

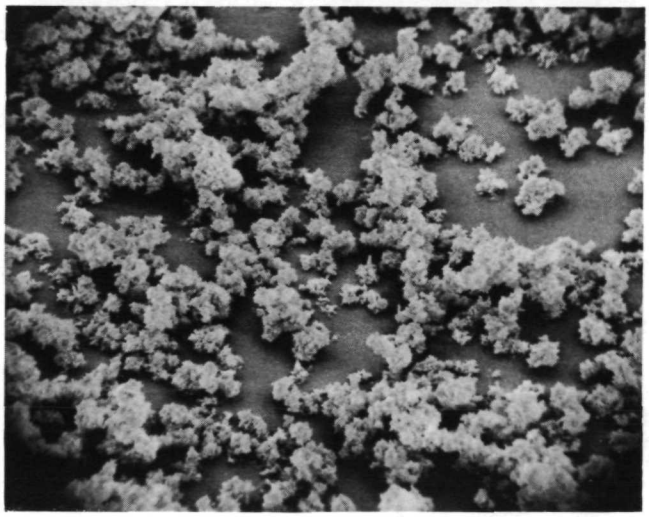

Figure 8—Micrograph of Precipitated $CaCO_3$, 1000x

3. Pellets

The cell size versus the foaming temperature for foamed pellets is shown in Figure 10. Foaming time is 20 minutes for each test. The bulk density ranges from 14 to 20 lbs/ft^2. Subsequent tests have shown that the heating rate of the pellets affects the cell size and the final density.

4. Dimensional Control During Foaming

The graphite mold with the glass pellets containing 1.0% $CaCO_3$ was heated to 800°C for one hour. The foamed brick conformed to the mold and has a relatively uniform cell structure throughout. The density of the foamed brick is 14 lbs/ft^3.

III. Economic Feasibility Study

In addition to the technical studies described above, a preliminary economic feasibility study was also conducted. Because of space limitations, only a very few of the results are reported here. Since the foamed glass is waterproof, vaporproof, incombustible, strong, rigid, and dimensionally stable, it is an ideal material for many building insulation applications. These applications include roof decks, ceilings, curtain and core walls, pipe insulation, refrigeration and cryogenic applications, and moderately high-temperature applications.

In most cases the foamed glass has been considered for use as solid blocks or slabs. Pellets of foamed glass can also be used as loose-fill insulation, light-weight aggregate, or combined with a polymer binder to produce a rigid material that can be more easily shaped and applied. Pellets with an open-cell structure can also be used as a soil conditioner. The function of the soil conditioner is to hold and distribute moisture, to prevent soil from becoming hard by creating a humus condition, and to allow easier drainage of excess moisture from the topsoil.

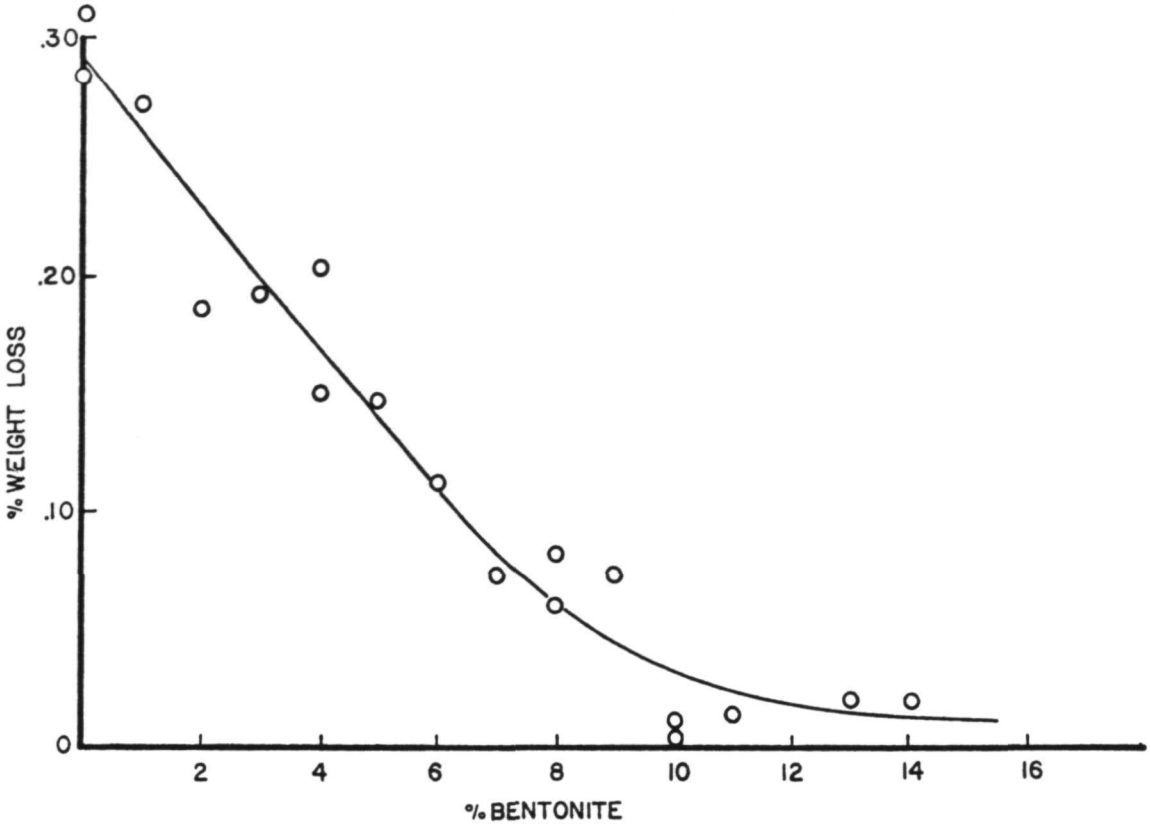

Figure 9—Percent Weight Loss (Solubility) Versus Percent Bentonite.

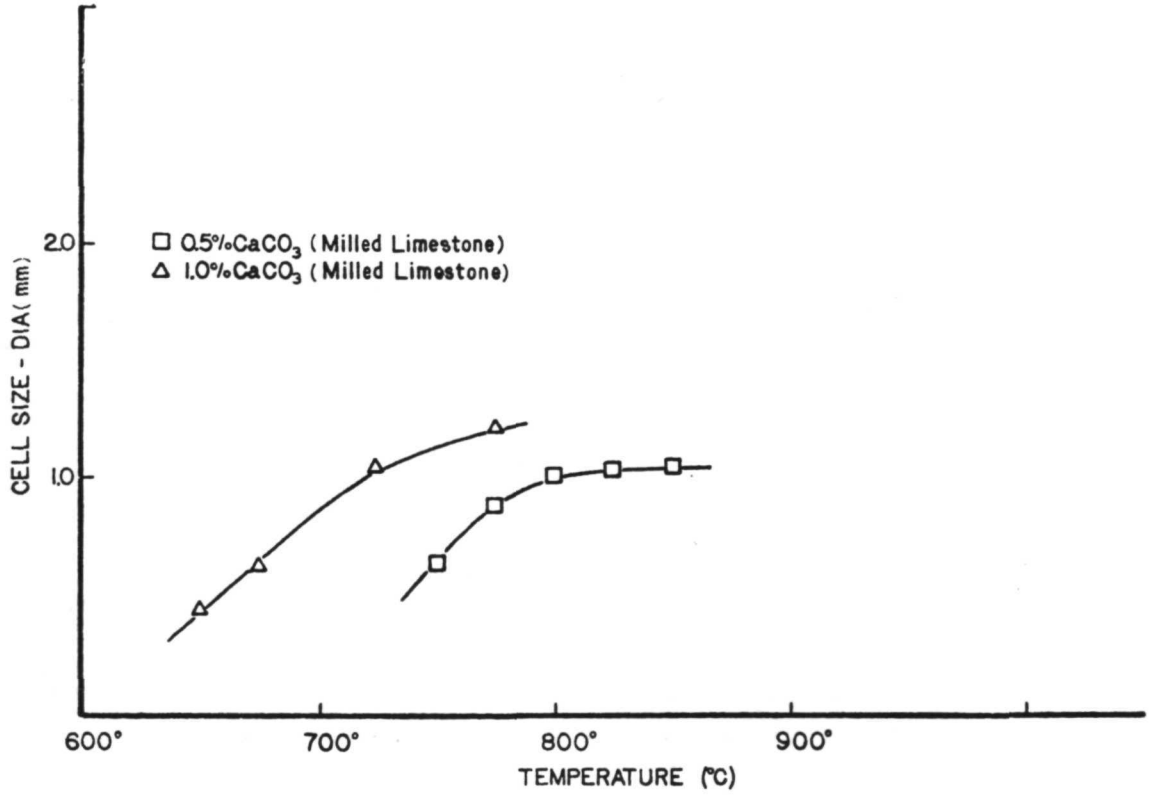

Figure 10—Cell Size Versus Foaming Temperature for Foamed Glass Pellets.

Plant and production costs for slab production were determined for four different daily outputs of 10, 20, 30 and 40 tons per day. A summary of the costs for these plants is shown in Table 1. A 20% rate of return on investment (before taxes) requires that the foamed glass slabs be sold at 10.0¢ per board foot for the 10 ton per day plant and 6.5¢ per board foot for the 40 ton per day plant. The corresponding figures for a 40% interest rate are 13.4¢ and 8.5¢.

Since the selling price of the commercially available cellular foam glass is approximately 20¢ per board foot, it appears that the method of foaming waste glass, as present in this report, is highly competitive with other similar products.

The cost to produce pellets of foamed glass is approximately 4.7¢ per pound and 3.3¢ per pound for plants having a daily output of 10 tons and 40 tons, respectively. The corresponding capital cost is $637,500 and $1,142,330, respectively.

Table 1.

COST OF PRODUCTION SUMMARY -- Slab Production

	Plant A	Plant B	Plant C	Plant D
Daily Output (tons/day)	10	20	30	40
Annual Output (bdft/year)	7,000,000	14,000,000	21,000,000	28,000,000
Total Plant Cost	$1,020,120	$1,349,390	$1,628,890	$2,069,990
Total Capital Costs	$1,217,590	$1,662,540	$2,058,370	$2,625,240
Annual Operating Costs	$ 452,420	$ 747,250	$1,030,540	$1,331,900
Cost per board foot	6.463¢	5.337¢	4.908¢	4,757¢

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3. H. P. Cahoon and I. B. Cutler, "Feasibility of Making Insulation Materials by Foaming Waste Glass," Proceedings Third Mineral Waste Utilization Symposium, U. S. Bureau of Mines and I.I.T. Research Institute, Chicago, March 14, 1972, p. 353-357.

FOAMED GLASS AND TILES FROM WASTE CONTAINERS

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1. Introduction

Some thirty billion glass containers are discarded annually in this country. Although this constitutes only six to seven per cent of the total solid wastes accumulated, some economically feasible methods to transform the large volume of waste glass containers into useful products are highly desirable. Besides waste glass containers, many other types of solid wastes are creating more serious pollution problems. For instance, in large feed-lots, where frequently more than 10,000 heads of beef cattle may be kept, the accumulation of manure creates not only problems of solid waste disposal but can lead to water pollution as well. It is estimated that one ton of manure is generated per head of animal per year and the largest feed-lot contains over 250,000 heads of beef cattle. The use of coal in power plants leads to air pollution from fly-ash. Perhaps even more serious is the problem of sludge generated in large cities. In the greater Los Angeles area, for example, 1,000 tons of sludge are being produced daily. What then can be done to minimize the pollution problems created by all the solid wastes generated?

In our attempts to solve the waste glass problem, the uniqueness of glass as a solid is exploited. The uniqueness of glass suggests that waste glass containers can be utilized to assist in the solution of other solid wastes problems. In other words, waste glass containers can actually become a desirable form of raw materials.

1. Introduction (cont'd.)

This report describes some of the work carried out in the past two years in our laboratory to convert waste glass containers with and without other solid wastes into useful products.

2. Uniqueness of Glass

Glass is a rigid liquid.[1] Its uniqueness arises from its ability to soften gradually on heating and to return to the solid state on cooling. The softening temperatures of glasses are easily controlled and are usually considerably lower than the temperatures necessary to form conventional ceramic bodies. In our work such uniqueness is exploited in two ways. The starting material is pulverized containers. In the first method, the pulverized glass containers are mixed with a small amount of foaming agent. The foaming agent is selected such that at the flow temperatures of the glass, the former decomposes or reacts with the atmosphere to generate a gas. The "fusion" together of the glass particles thus coincides approximately with the gas evolution or gas generation from the foaming agent. After appropriate times, the temperature is lowered and a foamed glass of low density is formed. The technique of manufacture of foamed glass is not new.[2-4] Its advantage in waste glass disposal is that because of the controllable density of foamed glass, a wide variety of products can be made and many of these do not require the waste containers be cleaned or color-sorted prior to use.

2. Uniqueness of Glass (cont'd.)

In the second method, the pulverized glass containers plays the role of a binder or high temperature glue. It is mixed with other solid wastes such as fly-ash, pre-treated sludge or pre-treated manure as the filler. The mixture is taken to some temperatures when the glass begins to flow, with or without pressure. High strength composite bodies can be made by this method. The simplest form which can be made is tiles. Again, such exploitation of glass as a binder is not new.[5,6] The technique has been successfully used in a variety of established ceramic products. Similar to the first method, the waste containers need not be cleaned or color-sorted prior to use.

3. Foamed Glass from Waste Containers

Glass containers of the common soda-lime compositions are one of the most chemically durable products. The foamed glass made from containers has essentially the identical chemical composition and is thus equally durable. The density of foamed glass is controllable over a wide range by controlling the amount of foaming agent, the temperature of foaming, the time and the heating and cooling rate. Its physical properties are mainly dependent on the density and the microstructure. By microstructure, we mean pore size and size distribution. Some of the foamed glass blocks made in our laboratory are shown in Figure 1.

3. Foamed Glass from Waste Containers (cont'd.)

The color is dictated by the starting mixture. However, the addition of conventional ceramic colorants can lead to products of various colors. Foamed glass is a superior heat and sound insulator. Because of its microstructure, it can be machined or nailed without cracking. Its flexibility in machining is shown in Figure 2. The cementing and surface-coating of foamed glass is shown in Figure 3. It is readily laminated between other solid sheets such as wood, metal and plastics. Large lightweight "ceramic tiles" are made by glazing foamed glass. A variety of non-flammable building products can thus be produced.

A summary of the properties of foamed glass made in our laboratory is shown in Table 1. Up to the present, the largest flat pieces made measures 3ft. x 5ft. x 3 in. Curved bodies such as half-tubes have also been produced. Based on our experimental observations, the production of larger sheets is possible. The ultimate production costs of foamed glass are dependent on a variety of factors such as the cost of waste glass containers, their availability as powder, the size, shape, and finish of the end-product, the production volume, and the particular continuous manufacturing method adopted. The costs per board foot can be significantly less than 10 cents if waste glass containers are obtainable for $10 per ton.

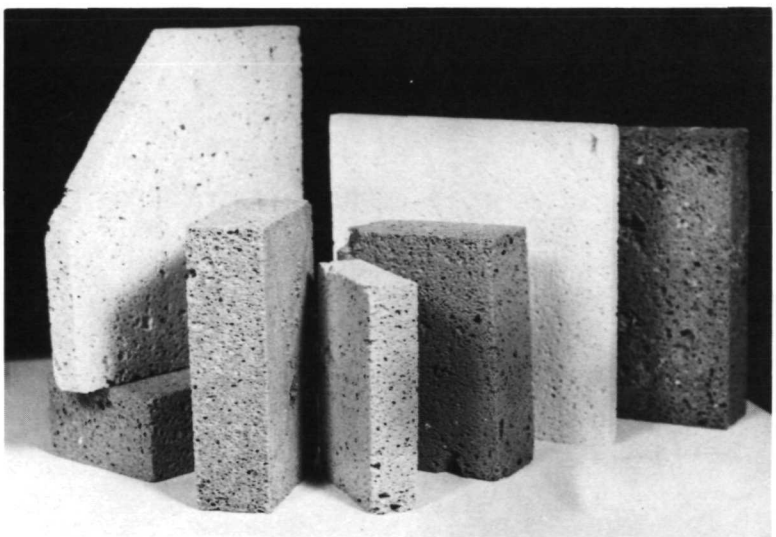

Figure 1—Foamed glass blocks of various colors made from waste glass containers.

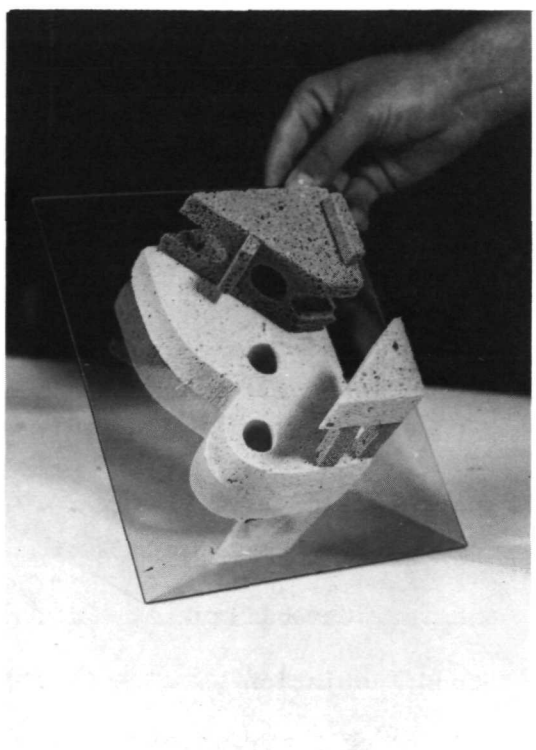

Figure 2—Flexibility of foamed glass in machining without fracture is shown in intricate shapes made.

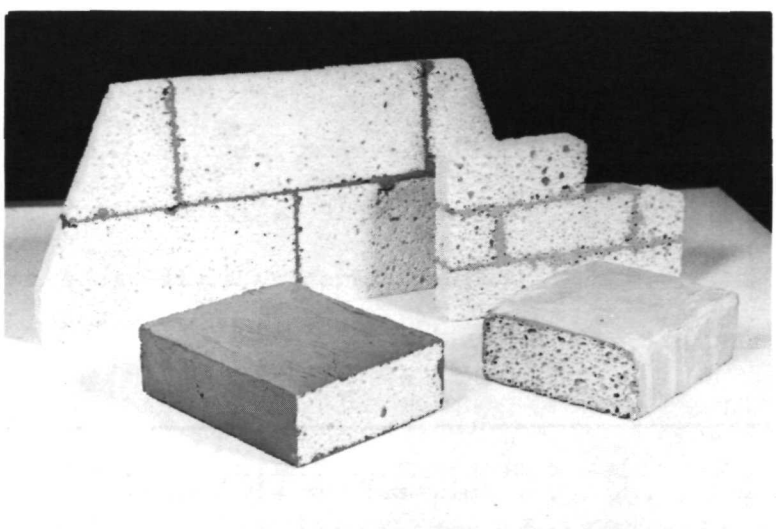

Figure 3—Cementing and surface-coating of foamed glass.

Table 1

Properties of Foamed Glass

*Density	0.15 to 1.5 g/cm^3
*Flexural strength	400 psi at 0.5 g/cm^3
*Compressive strength	500 psi at 0.3 g/cm^3 1000 psi at 0.5 g/cm^3
*Apparent impact strength	60 ft. lb. at 0.5 g/cm^3
*Incombustible	class A
*Useful temperature limit	1100°F long times 1400°F short times
*Coefficient of thermal expansion	7 to 12 x 10^{-6}/°C (dependent on density)
*Thermal conductivity	0.4 B.T.U./Hr/FT^2/°F/In. for 0.2 g/cm^3 density
*Chemical durability	same as bottle glass
*Sound insulation	noise reduction coefficient at 500 hertz is 0.7 for 5/8" thickness for 0.25 g/cm^3 density (similar to cellotex)
*Decoration	bulk and surface colors possible; glazed easily
*Machinability	can be drilled and sawed
*Miscellaneous	can be painted, glued, or plastered; readily accepts morter bonds; is non-toxic and odorless

4. Tiles from Waste Glass and other Solid Wastes

From the firing of mixtures of pulverized glass containers and a wide variety of other solid wastes, "ceramic" tiles have been made by conventional cold-pressing and hot-pressing methods. The largest tiles made in our laboratory measures 18 in x 12 in x $\frac{1}{4}$in. Preformed holes and overlapping edges have been made so that such tiles can be used as roofing tiles. By the addition of decorants and colorants, wall and floor tiles can be made. Some such tiles are shown in Figure 4 and Figure 5. A summary of the properties of such tiles is given in Table 2. The sources of glass and fillers tested are given in Table 3. The properties are dependent on experimental conditions such as temperature, time, pressure as well as glass to filler ratio. Based on laboratory-scale experiments, the projected manufacturing costs of roofing tiles can be as low as 10 cents per square foot for a thickness of $\frac{1}{4}$ in. This is considerably lower than that for currently available ceramic roofing tiles. An additional advantage is that because of its thinness and relatively lower density, the weight per unit area of such tiles is significantly less than that of available ceramic roofing tiles. This can lead to large reduction in labor costs for construction.

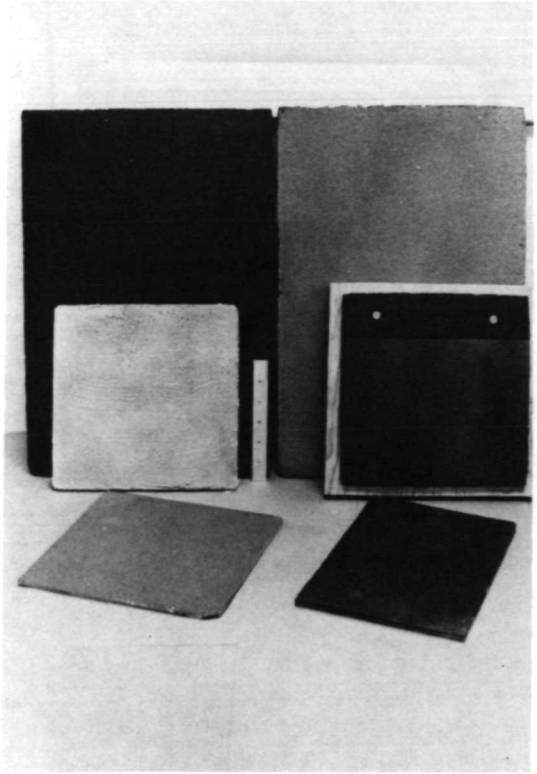

Figure 4—Roofing tiles made from waste glass and other solide wastes, the largest measures 18 in x 12 in x ¼ in.

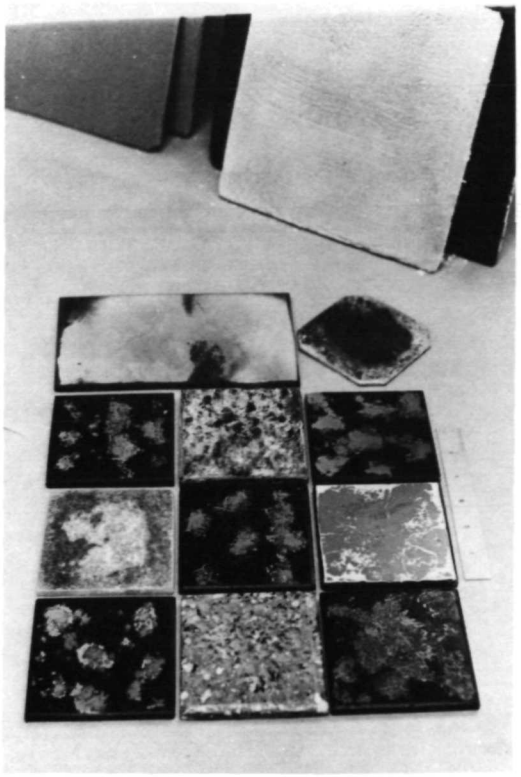

Figure 5—Decorated wall and floor tiles from waste glass and other solid wastes.

Table 2

Properties of Hot-Pressed Tiles

*Density, controllable	1.8 to 2.4 g/cm^3
*Incombustible	class A
*Flexural strengths	6000 to 8000 psi
*Apparent impact strength	95 ft.lb. at 1.8g/cm^3 density
*Abrasion wear index (Taber)	55 to 130 (min. acceptable is 35)
*Moisture absorption as per UBC Standard 32-12	2.2% at 1.8g/cm^3 density
*Wt. per area	4 lbs. per sq. ft. at 3/8" thickness
*Hardness, Moh scale	6
*Decoration	bulk and surface colors possible; glazed easily
*Miscellaneous	can be painted, glued, non-toxic and odorless

TABLE 3

Tiles from Waste Glass and other solid wastes

Glass Source	Filler Source
Containers	Municipal Sewage Sludge (Calif. and Ariz.)
Plate Glass Cullet	Municipal Incineration Ash (N.Y.)
Municipal Waste (Garrett Corp.)	Flyash (Penn.)
Lamp Tubing (G.E.)	Glass Polishing Waste
Glass Grinding Dust	Cattle Manure (Calif. and Colo.)
	Swine Manure (Ill.)
	Plastic Containers
	Brickyard Waste

5. Conclusions and Recommendations

A wide variety of useful building products can be manufactured from the utilization of waste glass containers. The processes described can assist in solving not only the waste glass problem but many other solid waste problems as well. Laboratory-scale experiments indicate that these products are economically feasible. The continuous manufacture of such products on a large scale must await the successful operation of appropriate pilot plants. Pilot plants must therefore by constructed as soon as possible. The two processes described here are based on the assumption of a guaranteed continuous supply of waste glass containers. Such a program of collection and supply of containers, in whole or in pulverized conditions, must therefore be developed.

6. Acknowledgements

The experimental program at the University of California at Los Angeles has been funded from grants from the Glass Container Manufacturers Institute, the Kershaw Feedlot of California and the Montfort Feedlot of Colorado for which we are deeply grateful.

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QUESTION AND ANSWER PERIOD THURSDAY MORNING, JANUARY 25, 1973

QUESTION:

What is the patent status on foam glass? Are students involved in the patents?

ANSWER: Dr. D. Mackenzie:

Most of the work has been done by undergraduates. Through the generosity of such organizations like GCMI , our students will do a project getting some pay. Also the company that has been formed to make foam glass employs many undergraduates.

The patents are held by the State of California through the University of California. The patents have been applied for and the licensing arrangements are very liberal. It is nonexclusive; mostly a matter of paying the University $1,000 and signing an agreement.

QUESTION:

What are the tiles composed of?

ANSWER: Dr. D. MacKenzie:

The best tiles we make are composed of glass and fly-ash. The other tiles are made of glass and some other refuse such as, for example, treated sewage sludge, treated manure, and incinerator residue. We can perhaps put a figure of $5 a ton on the refuse filler, which is quite reasonable. These kinds of inert materials make beautiful tiles. It is all inorganic material after going through the processing. Many municipal sludges make excellent tile. Further there is no danger of a health problem, since we take the material up to 1400° F.

QUESTION:

How much glass would you need in manufacturing your product?

ANSWER: Dr. D. Mackenzie:

That just depends on the market. All these products have a large market potential. Although there is plenty of glass around, a businessman must have a guarantee of so many tons of glass a day, such as 100 or 1,000 tons a day. Currently, we couldn't go to anybody to get these quantities. For places like Albuquerque, you need a minimum of 10 tons a day guaranteed--possibly up to 100 tons a day. For this sort of venture (i.e. having a guaranteed source of glass), we would not want to do business with organizations such as the Girl Scouts and so forth. It must be a sound business venture that is established to provide waste glass.

ANSWER: Mr. M. Steinberg:

Our glass came from the town of Huntington, Long Island, brought in by various social action groups. But I agree with Dr. MacKenzie that for a business operation you must have a guaranteed source of supply. I think that in a couple of years we will be seeing these larger quantities either through municipal efforts or through the EPA which is putting up demonstration plants in various cities across the country. They are multi-ton systems producing metals, glass and other materials and they will be looking for secondary products before long to use these materials--maybe in a year to two.

ANSWER: Mr. Cambourlies:

I am Mr. Cambourlies of Raytheon Company in Massachusetts. We anticipate that once we get going with our system (the Bureau of Mines Incinerator System) on a one-shift basis, we will have 30,000 tons of glass a year. This will occur perhaps early in 1975 in the Lowell, Massachusetts area. The system will serve a population of about one quarter of a million people. The plant capacity on a one-shift basis is 65,000 tons a year. We think that half of that will be glass since this is a residue tonnage from incinerators. I am not prepared to comment on the price expected since it will depend upon the use intended. However, it might be about $15 a ton, or maybe more, depending on specifications.

ANSWER: Dr. H. Alter:

Studies at the National Center for Resource Recovery show that the percentage of glass in household refuse may vary from 6 percent to 13 percent. These percentage figures must be divided by three to get the proportion of glass in total municipal refuse, since refuse consists of mixtures for household, commercial, industrial and demolition sources.

ANSWER: Mr. C. Weeden:

We have exactly this problem in England. That of getting a supply of waste glass in the quantity and condition required for processing. The manufacturers of secondary products do not wish to be required to put more work on their glass; they hope

to use it as it is. Some 80 percent to 85 percent of our 1.6 million tons a year goes into household wastes and is landfilled under very close control. The remainder is bought by the glass industry or is disposed of privately by packers and so forth. Thus any reclamation would have to be done by local authorities.

Cullet is sold back to the industry at a cost of about 3£ a ton, which is about $7.20 in American money. There is only one sophisticated plant for separating, near Yorkshire, where they do separate glass and color-sort and wash. The price then goes up to about 8£ a ton, or more than $19.00 a ton.

ANSWER: Mr. P. Scott:

We believe that foam glass will be competitive for everything except perhaps a sandwich wall construction which is a wood paneling with a foamed glass core.

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RECYCLING GLASS IN REMOTE AREAS

by

Harry M. Davidson

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Department of Environmental Health

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By remote areas I mean those cities which do not have a factory or glass recycling facility where the waste material collected can be used in the local market for the reproduction of containers or production of other by-products. Recycling is an unknown operation in most cities of the United States today. This is despite the fact that public interest in ecology and recycling is at an all time high. Now why haven't the means to establish these recycling operations been found and accepted in most cities?

Demand is the moving force behind any use for a raw product or finished product. If each city had a factory that could utilize waste glass, this recycling would be a means of supplying this demand.

The lack of local demand has forced the complication of transportation into this recycling puzzle. Until recently the cost of transportation for any distance over 100 miles has been too high to warrant even considering gathering a waste product. The reason for this has been the ICC freight rates for recycling materials being higher than those even for raw ore products. As a result, many enthusiastic environmentalists have taken one look at the economic picture and have been turned off by the high costs of transportation. Economic location studies have taken us a step further and have found the transportation cost unique to a particular location in order to justify the efforts of recycling. Once this has been determined, then attempts to obtain favorable

freight rates have gone forth. In the case of Albuquerque, the initial rates for rail were $18.00 a ton. The initial rates for truck transportation to the nearest location, in Texas almost 350 miles away, were also prohibitive.

It was found, however, that the trucking firms that bring new bottles to the local bottling plant were going back empty. As a result of extensive negotiations, a favorable back-haul freight rate for this particular material was obtained to a specific location. In other words, a customized back-haul freight rate. Besides the freight rates for hauling the material being returned, the containers for returning materials must also be considered. One means is scrap steel barrels, such as the standard steel 55 gallon drum. In the Albuquerque area these barrels have been obtained from several sources. However, if there are no readily available sources for these containers, then other available containers in a particular locality can be utilized. It is extremely difficult to buy or justify the cost of new containers for this operation.

Using pallets strapped together with steel banding and lined with cardboard is another means. The same pallets that are used to bring the bottles into the bottling plants can be used for this other process. The use of pallets and barrels, however, is in itself a recycling process. This recycling of containers prevents these materials from ending up in the dump.

Once it has been established that there is a market for the collected waste material and that there is a means of moving it from a remote location to where it can be recycled, then we must

determine how the waste material will be gathered. The most effective means is for the municipal government or the contractor that collects the city's garbage to install a complete recycling process. Thus the waste materials of the city are processed by taking off the ferrous metals, non-ferrous metals, and the glass as prime items to be salvaged.

The balance of the city's waste has a high content of paper which can be removed by several processes. There is also a means whereby this paper waste can be recycled. However, this process requires heavy capital investment for high volume, high energy equipment. The municipal government and/or a private contractor must be willing to invest this money and have reasonable assurance it will pay for itself.

One other possibility is that of special collections, which is a service that would go to cafes, restaurants and bars to pick up the beer bottles or other beverage container bottles that are waste products after the contents have been sold. This type of special collection is difficult, if it is attempted as a separate collection. In the past it has been operated concurrent with a delivery process from the wholesaler in which the same truck and operator that bring in the full containers remove the empty containers.

The citizen collection of waste materials is the next possibility. Coors Company, for example, is buying back its aluminum cans and bottles. The distributor pays a price to anyone who brings these materials to a collection center. There is a distinct advantage in this type of operation in that it does not

require the capital investment and salaries to accomplish the collection process. However, citizens are being rewarded for their labors by receiving a price for the bottles, cans, etc. This also bypasses the municipal or retail collection point. One of the main objections of grocery stores and package stores is that they do not want to be bothered with dirty bottles, considered to be an unsightly collection of trash.

The third facet is the citizen action group. The key to this type of operation is an interested individual who will devote for all practical purposes full time to the operation of this type of a process. The initial steps in this area were such things as men's service clubs such as Lion's, Jaycee's, etc., in conjunction with bottlers such as Royal Crown, Coca Cola, etc., holding special drives in which containers are picked up throughout the community, usually off vacant lots, etc., and returned to a collection point on a specific Saturday and a reward paid for this collection. This can show very dramatic results. However, it is not expected that this type of a one-shot operation will do much more than educate the public as to the availability of these waste materials.

In order to make any type of a long-range operation feasible, there must be a location, an operating agency, and a means of operating this facility on paid labor rather than volunteer labor. One of the major considerations among these facilities is its location. The operational needs and space must not be underestimated. Adequate space to accommodate the volumes that will be forthcoming must be provided in the initial site selection. Frequently these sites are obtained by donations from a municipal

government or from the purchase of a piece of land by some manufacturer or wholesaler. Under these circumstances, the availability of a large piece of land is difficult. The tendency is to underestimate the amount of space that will be needed.

A similar problem is underestimating the volume that will be collected or obtaining equipment inadequate for the operation. If adequate equipment is available by donation from interested parties or government agencies or on long term lease, this helps get the ball rolling. Another possibility, at least for the initial phase of an operation, is for the shops at high schools, at technical vocational schools, or universities to design special equipment or take secondhand equipment modified to do the job.

Another important factor in your equipment is security. The area must be properly enclosed with fences of sufficient size to be good security barriers. Also these fences can be used as a sight barrier to keep the neighbors happy. It can also be used to prevent the wind from blowing material into the neighboring areas and causing public complaints. However, a three-strand barbed-wire fence will not do the job.

One other factor in site location is that there will be public opposition to placing this facility in some areas. If it is adjacent to residential areas, the old idea of not wanting a dump next door to your house is the reason. Another site selection factor is that it must be easily found by housewives. When the children collect their cans and bottles and want to turn them in, if Mama can't find the way down to the place, that'll probably be the last time the children will be involved in this

exercise. So it must be found on streets that are known to the public and are easily accessible from freeways and main thoroughfares.

Once your facility is in operation, it is imperative that the operation be managed in an efficient manner. It is important that the entire area be kept as clean as possible, especially the areas where the public comes in and unloads their materials or are involved in any way. Again, as the mother is driving the station wagon full of cans and bottles down to the area, if they come into an unsightly place, they will not come back again. Furthermore, it is recommended that the area be paved in order to facilitate cleaning and maintenance.

When moving waste materials within the center, be sure to use cardboard barrels or steel barrels or pallets. The selection of equipment for this movement is critical so that it can be handled with as much ease as possible.

To keep the public interested in the recycling campaign, it will be necessary to have a continuing public relations and communications program. You will have a number of human interest stories to tell because you'll be working with various schools, churches, youth groups, and similar civic or public service organizations. They will be using the money received for some worthy cause, and this will form the basis of a news story which in turn will encourage further public support.

In conclusion, the operation will be a success only if it is operated by an interested person. This person must not only be a good business manager in operating the facility, but must be

able to relate to all the people that come in contact with this facility. It is one thing to be an efficient person when dealing with businessmen, community leaders, etc., but if a manager does not establish a fine rapport with all the people - the housewives, the young people, and others - that bring the material to the recycling center, they may soon stop.

A recycling center will not be as successful if it is designed to operate to recycle only one kind of waste material - such as glass containers. Plans should be made at the outset to handle steel cans, aluminum cans, cardboard, and glass and any other product that can be recycled in that area. Also having a diverse number of products will help spread the costs so that the volume can be increased and the entire operation can be economically feasible. Always plan for expansion in your equipment, your space, and your interest in products. Once a recycling center has been underway for sometime, it will have a beneficial educational effect also. For example, it teaches young people not to be litterbugs, that they themselves should not throw away their discarded items; also, that there is a use for discarded items and an economical reward for returning them. The recycling center can help educate the public to the point that they would become favorably inclined to vote funds for developing municipal resource recovery systems.

So, we have come full cycle. We started out by determining what materials are available for recycling in a remote area; and we have determined how this material can be moved to the place where it can be processed for recycling. Usually this type of

operation can be started as a citizen action project. However, it must then develop into a prolonged operation which can support itself economically and, with further public education, can evolve into a municipal refuse recycling operation. Only by this final process can this type of an operation serve the needs of the public.

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ANALYSIS OF ECONOMICS AND MARKETS FOR SECONDARY GLASS PRODUCTS

by

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for

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The Glass Containers Manufacturers Institute engaged Midwest Research Institute to conduct an independent technical and economic evaluation of products made from waste glass, with primary emphasis on products applicable to the construction industry.

A list of 14 potentially attractive products made from reclaimed glass was developed by GCMI and submitted for preliminary evaluation. The 14 products subjected to this initial screening included two types of mineral wool; terrazzo, decorative blocks; two types of building panels; three types of brick; glass spheres and beads; lightweight aggregate; tile; slurry seal; and pozzalan. Each product was comparatively rated on the basis of its expected performance, cost, development status, markets, and competitive position. The preliminary screening showed seven of the products to be clearly superior to the others in terms of their overall potential. Of the seven, five were selected by GCMI for in-depth technical and economic evaluation. The five selected products were: (1) GCMI building panels; (2) glass wool; (3) terrazzo; (4) slurry seal; and (5) USBM brick. Brick production was found to be economically unattractive

except under very unusual local conditions. Subsequently, a process aimed at producing ceramic products (tile and foamed glass panels) from reclaimed glass and cow dung was added.

These five products were then evaluated by a procedure which considered, for each product, its development status, performance characteristics, ability to meet specifications, manufacturing costs, probable selling prices, market potential, and competitive situation with respect to existing products. The findings can be briefly summarized as follows.

Building panels made from waste glass and building rubble should offer an extremely attractive product for manufacture in selected areas at a moderate scale of operation. The comparative low cost and decorative quality of the panel will make it price competitive with panels costing far more to produce, while being cost competitive with inferior quality panels.

In marketing insulation, the glass wool manufacturer who uses recovered glass in his operation will hold about a $10/ton cost advantage over firms employing traditional raw materials and production methods. However, the competition is large, strong, and firmly established in the marketplace.

Preliminary analysis of ceramic products made from glass and cow dung appear attractive enough from a cost-of-production standpoint to warrant further investigation.

The terrazzo market constitutes a premium-priced market for suitably sized and color classified glass chips, and could well result in a

highly profitable small-scale operation. Even at $50/ton, glass chips can compete effectively on a cost basis with the commonly used marble chips.

Slurry seal, with strong promotion, could capture 30 percent of the municipal road surfacing market, amounting to more than 400,000 tons of recovered glass annually. What slurry seal with waste glass lacks in economic advantages over conventional surfacing materials, can be more than made up for by technical, social, and political influences favoring the recycling concept.

Basis for the Economic Evaluations

The products manufactured from reclaimed glass can be evaluated in the same manner as any conventionally manufactured product, with the main difference being simply a direct substitution of glass for some other raw material. The economic analysis for these products encompasses three distinct tasks: (1) estimation of total capital requirements; (2) estimation of total manufacturing costs, including annualized capital costs; and (3) measurement of the economic desirability of the project in terms of its anticipated profits and profitability.

For estimating purposes, the capital requirements associated with the manufacture of the proposed secondary glass products are divided into three categories: (1) fixed investment; (2) amortized investment; and (3) recoverable investment.

Fixed investment, or investment in fixed plant, includes structures, improvements, production equipment and machinery, and other production-related

plant facilities. Structures and improvements, in turn, include buildings for manufacturing, storage and warehousing, landscaping, roads, fences, provisions for employee services, and all related items. Production equipment covers all equipment used directly in the manufacturing operation. Other fixed investment requirements include expenditures for controls and instrumentation, pollution abatement devices, and service and support facilities.

Amortized investment refers to one-time capital expenditures that cannot be depreciated over the project's life but that can be recovered through amortization over a shorter period. This category includes engineering, research and development costs, and start-up expenses. Engineering and R&D are estimated at about 12 percent of the fixed plant investment, while start-up costs allow for the out-of-pocket expenses incurred during two full months of plant operation.

Two major items--land and working capital--can be neither depreciated nor amortized, but must nevertheless be provided for; these are referred to as recoverable investment. Land costs can vary substantially even in the same geographic area, and these estimates are, at best, only guesses. An allowance for working capital, providing adequate coverage for merchandise sold but not yet paid for, inventory in warehouse paid for but not yet sold, and work in progress, must also be made. Working capital is estimated at three month's direct operating costs.

Manufacturing costs encompass both direct, or production-related, costs and indirect, or time-dependent, costs. Direct production costs are

made up of labor, materials, utilities, and variable overheads. Labor requirements for each of the various manufacturing operations were estimated in man-hours per unit of production, and costed out at a typical $5.00/hour wage rate. Variable overheads are expected to run about a third of this amount, to cover direct supervision, payroll loadings, and other production-related expenses. Materials used in the manufacturing operations made up the balance of the direct or out-of-pocket production costs.

Indirect costs are related to the passage of time rather than being directly attributable to the level of production; they include fixed overheads and capital charges. Fixed overheads cover administrative and office salaries and other operating expenses not directly related to the manufacturing operation. Capital charges, on the other hand, are directly related to the amount of money tied up in the operation.

Capital charges include amortization of engineering, R&D, and start-up costs over a 5-year period at 8 percent interest; a 17 percent allowance for depreciation, interest, property taxes, insurance and general administrative charges on the capital tied up in depreciable plant items; and 8 percent interest on land and working capital.

Regional variations can have significant effects on manufacturing costs, and such variations must be anticipated whenever an operation is proposed for a specific location. In general, manufacturing operations located in the Middle Atlantic, East North Central, and Pacific states will experience the highest costs of production, while minimum costs would be

expected in the south central parts of the U. S. However, the areas where costs are highest may also constitute the best markets for a manufactured product, so no generalizations are possible regarding optimum plant locations without first conducting a detailed cost and market analysis for the specific locale.

Manufacturing costs will also vary with the scale of operations conducted at the proposed plant, while the production volume must, in most cases, be carefully scaled to the local or regional markets. These factors should be thoroughly investigated for each location being considered.

The next five sections summarize some of the important findings regarding each of the secondary glass products. The first three products discussed--building panels, glass wool, and ceramic products--all fall in the category of "manufactured" items, and the economics are handled as described. The last two--slurry seal and terrazzo--employ reclaimed glass as raw materials in a finished product, but the important economic considerations are tied in with the products' ultimate use or application, of which the reclaimed glass "product" is but a small part.

Economics of Building Panel Production

The CSMRI building panels, made from waste glass and building rubble, offer significant advantages and economies over the slip-cast and pressed panel methods of panel production. The proposed panel has utility both for structural and decorative purposes. Structurally, it can be made to compete effectively with conventional brick and precast

concrete panels, while aesthetically the facing panels could compete with currently available decorative architectural wall panels costing considerably more.

Table I summarizes the economics of production for the proposed building panels. A total capital requirement of $6 million is estimated for the 242,000 panel, 9,680,000 sq. ft./year plant. Total manufacturing cost is expected to run $0.825/sq. ft., or $33.00 per 40 sq. ft. panel.

The outlook for sales of decorative wall panels for use in new building construction is quite favorable over the next decade, with about a 7.25 percent annual growth rate anticipated for the U. S. as a whole. Growth in wall panel markets will be most rapid in northeastern (New England and Middle Atlantic) and southern (South Atlantic, East South Central and West South Central) regions.

Some 805 million square feet of architectural wall panels will be used in building construction during 1972, with about two-thirds of the total being put in place during the last half of the year, and peak demands occurring during the August-September-October period. The market, then, is strongly seasonal as well as regional.

By 1980, demands for prefabricated wall panels are expected to increase to 1.4 billion square feet. The Middle Atlantic, South Atlantic and Pacific states will account for more than half of this total.

Wall panels are currently being produced in more than 200 different plants throughout the U. S., reflecting the strong local nature of the business. Because of the expense involved in handling and shipping, most

TABLE I

THE ECONOMICS OF BUILDING PANEL MANUFACTURING FROM RECLAIMED GLASS
(242,000 panels per year)

CAPITAL REQUIREMENTS	
Amortized Investment	$ 1,350,000
Fixed Investment	2,950,000
Recoverable Investment	1,700,000
Total Capital Requirement	$ 6,000,000
MANUFACTURING COST	
Direct Production Cost	$ 5,804,000
Indirect Costs	
Fixed and General Overhead	$ 1,200,000
Capital Charges	975,000
Total Indirect Costs	$ 2,175,000
Total Manufacturing Cost	$ 7,979,000
Per Sq. Ft.	$ 0.825
PROFITABILITY	
Net Sales Revenues @ $1.25/sq. ft.	$12,100,000
Total Manufacturing Cost	7,979,000
Net Profit before Taxes	$ 4,121,000
Income Taxes	2,060,000
Net Profit after Taxes	$ 2,061,000
Total Capital Requirement	$ 6,000,000
Profit Margin (Net Profit/Net Sales)	17.0%
Capital Turnover Rate (Net Sales/Total Capital)	2.02 times
Return on Investment (Net Profit/Total Capital)	34.3%

panels are used within 70 miles of their point of manufacture. Location of a plant site, therefore, is extremely critical.

Only the New England and Middle Atlantic regions have overall density-of-use patterns sufficiently high to justify production at the 10 million square feet per year scale. Large metropolitan areas in the other regions, though, could conceivably support a manufacturing operation of from 3.0 to 8.0 million square feet annual capacity.

A variety of decorative wall panels are offered for a wide range of applications and at a wide range of prices. Prices of prefabricated building panels start at around $1.00 per square foot and range upward to about $5.00 per square foot, depending on the products' appearance, characteristics and specifications.

Conventional tilt-up reinforced concrete panels can be fabricated at the building site for less than $0.85 per square foot. Attractively finished foam-filled metal-skin building panels, some of them fire-rated, can be bought for $1.10 to $1.50 per square foot. A variety of other factory-built panels are available for around $1.00 per square foot, most of which have a "temporary" appearance and would not be considered in quality building construction.

The proposed 4 ft. x 10 ft. wall panels would probably compete directly with products currently selling in the $1.50 to $3.00 per square foot range. However, sales potential in this price range is too low to permit large-scale production. To even approach the 10 million square feet per year level will require competing with the lower-priced panels.

In order to provide adequate margin for an attractive net after-tax return, the panels should probably be priced somewhere in the $1.25 to $1.75 per square foot range. This should afford a satisfactory return on an adequate volume, as indicated in Table I. A lower price would narrow the profit margin to an uncomfortable level, while a higher price would be apt to reduce volume below an acceptable level.

An alternative that should be considered whenever a specific plant location is being investigated would be to thoroughly reexamine the economics of production. It is entirely possible that a more feasible operation could be developed with a smaller plant and a higher-priced product. The desirability of, say, a 1,000,000 square foot per year plant and a $3.50 per square foot net selling price could be determined only on an individualized local basis.

Nevertheless, the proposed panel may be an extremely attractive product for manufacture in carefully defined areas at a carefully determined scale of operation.

Economics of Mineral Wool Production From Reclaimed Glass

Mineral wool made from recovered glass is, in most respects, directly comparable with and substitutable for (or by) mineral wool made by conventional means. Consequently, the maximum selling price for the product is determined by the selling price of competitive products, and any economic advantage to be realized from its production must be in the form of lower manufacturing costs.

The basis for the economic evaluation is a 60 ton per day glass wool plant, operating 250 days per year and producing 15,000 tons of glass wool annually in the form of loose pouring wool and as blankets and batts.

Capital requirements for the plant are summarized in Table II. As indicated there, an estimated $1,000,000 investment will be required in fixed plant facilities, with amortized and recoverable investment items accounting for another $1,270,000. The total capital requirement, then is $2,270,000, which when amortized, depreciated or otherwise converted to an equivalent annual basis, results in capital charges of $343,000 per year.

Estimated manufacturing costs are also shown in Table II. Direct production costs account for nearly three-fourths of the total manufacturing costs. Indirect costs, consisting of overhead expenses and capital-related charges, make up the balance of the annual costs of operation, resulting in a total manufacturing cost of $161.60 per ton of marketable product at the 15,000 ton operating level.

Regional variations in manufacturing costs are due primarily to differences in utility costs and labor rates, ranging from about $140 per ton up to $222 per ton for the 60 ton per day plant. Similar variations would be expected for plants having different capacities.

In marketing its product, the glass wool manufacturer who uses recovered glass in his operation should realize about a $10 per ton cost advantage over competitive firms employing traditional raw materials and production methods. This will allow him several options:

TABLE II

THE ECONOMICS OF GLASS WOOL PRODUCTION FROM RECLAIMED GLASS
(15,000 tons per year)

CAPITAL REQUIREMENTS	
Amortized Investment	$ 420,000
Fixed Investment	1,000,000
Recoverable Investment	850,000
Total Capital Requirement	$2,270,000
MANUFACTURING COST	
Direct Production Cost	$1,780,000
Indirect Costs	
Fixed and General Overhead	$ 300,000
Capital Charges	343,000
Total Indirect Costs	$ 643,000
Total Manufacturing Cost	$2,423,000
Per Ton	$ 161.60
PROFITABILITY	
Net Sales Revenues @ $200/ton	$3,000,000
Total Manufacturing Cost	2,423,000
Net Profit before Taxes	$ 577,000
Income Taxes	288,000
Net Profit after Taxes	$ 289,000
Total Capital Requirement	$2,270,000
Profit Margin (Net Profit/Net Sales)	9.6%
Capital Turnover Rate (Net Sales/Total Capital)	1.32 times
Return on Investment (Net Profit/Total Capital)	12.7%

(1) Price his product lower than competitors in order to achieve more rapid market penetration; or

(2) Realize a higher unit profit by pricing his product competitively with higher-cost producers; or

(3) Compete over a wider geographic range than would otherwise be possible, by using his $10 per ton cost advantage to absorb shipping costs.

Glass wool production is currently dominated by four large firms: Owens-Corning Fiberglas Corporation, with gross revenues of around $500 million; Johns-Manville Corporation, with sales of approximately $600 million; half which is in glass fiber; PPG Industries, Inc., whose revenues exceed $1 billion, $75 million in glass fiber; and Certain-Teed Products Corporation, the smallest of the four with annual glass fiber sales of about $250 million. It will be necessary for any new company to compete with these giant, well-established firms.

With an expected net selling price averaging $200 per ton--a reasonable composite value covering bagged pouring wool, batts and blankets in whatever proportion the building market demands--glass wool manufacturing appears to offer a moderately attractive profit opportunity for a new producer. As indicated in Table II, the resulting profit margin is a strong 9.6 percent on sales; the return on the total capital employed in the business is 12.7 percent, which is not unreasonable for a product with proven market acceptance.

The market for mineral wool for structural insulation is sizeable but not growing rapidly. Overall, an increase from its 705,000-ton 1972 level to 904,000 tons in 1980 is expected, representing an average growth rate of just over 3 percent annually.

Economics of Ceramic Product Production

Preliminary analysis of both of the ceramic products (tile and foamed glass panels) included in this category merit close attention. While there is not yet sufficient information available to evaluate their acceptance in the marketplace, the economics of production appear to be quite attractive. The range of possible products employing this process, ranging from shingles, blocks and bricks, to insulation, wall panels, acoustical tile and other building products, is most impressive.

Table III summarizes the pertinent economic considerations for the ceramic tile and the foamed glass panel, the only products covered in this analysis.

In both cases, capital requirements are relatively modest, totaling just $232,000 for the tile plant and $295,000 for the foamed glass panel operation. Total manufacturing costs run $0.131/sq. ft. for the tile, and $0.041/board ft. for the foamed panels.

Current retail prices on ceramic tile that would be comparable in appearance and performance to the proposed tile product range from $0.65/sq. ft. up. Even the cheapest plastic tile sells for around $0.18/sq. ft. There is sufficient margin between these retail selling prices and the $0.131/

TABLE III

THE ECONOMICS OF CERAMIC PRODUCTS MANUFACTURED FROM RECLAIMED GLASS AND COW DUNG

	Tile[1]	Foamed Glass[2]
CAPITAL REQUIREMENTS		
Amortized Investment	$ 45,000	$ 59,000
Fixed Investment	132,000	172,000
Recoverable Investment	55,000	64,000
Total Capital Requirement	$232,000	$295,000
MANUFACTURING COST		
Direct Production Cost	$171,000	$231,000
Indirect Costs		
Fixed and General Overhead	$ 11,000	$ 15,000
Capital Charges	38,000	49,000
Total Indirect Costs	$ 49,000	$ 64,000
Total Manufacturing Cost	$220,000	$295,000
PROFITABILITY		
Net Sales Revenues	$337,000	$432,000
Total Manufacturing Cost	220,000	295,000
Net Profit before Taxes	$117,000	$137,000
Income Taxes	58,000	68,000
Net Profit after Taxes	$ 59,000	$ 69,000
Total Capital Requirement	$232,000	$295,000
Profit Margin (Net Profit/Net Sales)	17.5%	16.0%
Capital Turnover Rate (Net Sales/Total Capital)	1.45 times	1.46 times
Return on Investment (Net Profit/Total Capital)	25.4%	23.4%

[1] Tile: production rate, 1,685,000 sq. ft./yr.; selling price, $0.20/sq. ft.

[2] Foamed Glass: production rate, 7,200,000 bd. ft./yr.; selling price, $0.06/bd. ft.

sq. ft. manufacturing cost to allow considerable flexibility in pricing and marketing.

A similar situation exists on the foamed panels, although the lower quality wood fiber panels may be available for as little as $0.20/board ft., and vinyl-coated fiberglass panels commonly retail at around $0.22. Still, the margin between these price levels on conventional--and probably much inferior--products and the $0.04/board ft. manufacturing cost of the glass/cow dung panel remains comfortable, and the possibility of other products enhances the attractiveness of the whole concept.

Economics of Glass Chips for Terrazzo Floors

Terrazzo flooring is an application-oriented rather than production-oriented outlet for recovered glass. The economics are all in favor of glass where it can be substituted for the high-cost decorative marble chips presently being used in most terrazzo floors.

Since the architect or building owner considering a terrazzo floor is looking primarily for aesthetic beauty, long-life and minimum maintenance, and weighs these factors against total cost in place, comparative cost estimates have been developed for a "typical" terrazzo floor. This typical floor is assumed to consist of a 3/4-inch thick terrazzo surface, blocked into 5-ft. squares on a 1-1/4-inch thick concrete underbed. The resulting cost estimates are shown in Table IV.

TABLE IV

COST OF INSTALLING TERRAZZO FLOORS
(Based on 3/4 in. Terrazzo blocked into 5 ft. squares on 1-1/4 in. concrete underbed)

Element of Cost	Cost in Place ($/100 sq. ft.) Marble Chips	Glass Chips ($12/ton)	Glass Chips ($50/ton)
Labor	131.00	131.00	131.00
Materials, equipment and supplies	40.00	40.00	40.00
Decorative chips	21.00	3.60	15.00
Contractor's overhead and profit	64.00	58.20	62.00
Total Cost Per 100 sq. ft.	256.00	232.80	248.00
Competitive Advantage ($/100 sq. ft.)	--	23.20	8.00
(%)	--	9.1%	3.1%

Labor, as would be expected, is the largest cost item in the construction of a terrazzo floor, accounting for about half of the total cost in place. The decorative chips, while being the most striking feature of the floor, nevertheless amount to but a small part of the floor's total cost: just $0.21 per square foot out of the total cost of $2.56 per square foot. Substitution of glass chips at $12 per ton for marble chips at $3.50 per 100 pounds will reduce the net cost of the floor by $23.20 per 100 square feet. Even at $50 per ton, glass chips show a competitive cost advantage over the marble.

Unit costs, as usual varying mainly according to labor costs, range geographically from a low of $205 per 100 square feet to a high of $284 per 100 square feet for the conventional terrazzo floor with marble chips.

The total market for terrazzo flooring in new construction in the U. S. is estimated to be 234 million square feet in 1972, growing to 407

million square feet by 1980. This represents better than a 7 percent annual growth rate in the demand for terrazzo, well above average for a construction material.

If glass were to capture the entire 1980 market for decorative chips in terrazzo, this market would consume 1,200,000 tons of glass chips. Since terrazzo floors are specified largely on an aesthetic basis, though, it is unlikely that glass chips could capture more than a 10 to 20 percent share of the total market for decorative chips. Still, this can be a premium priced market for suitably sized and color-classified recovered glass, and could well result in a highly profitable small-scale operation.

The Economic Aspects of Slurry Seal

Since slurry seal with glass involves essentially a direct substitution of materials for those normally used in conventional slurry seal its economic attractiveness must be considered relative to those materials which it replaces.

To a municipal public works agency, the main criteria for selecting a road surface is net cost in place. A higher cost road surface could presumably be justified if it had a longer useful life or if it required lower expenditures for maintenance than competitive materials. This, however, is not necessarily the way decisions are made by municipalities.

Choice of the cheapest available solution to existing problems may be almost mandatory because of severe budget restrictions. Long-term benefits may be totally ignored in such a case, with future benefits

sacrificed for the sake of short-term economy. The public generally does not object--in fact, it usually demands that road and street repairs be on an as-needed basis. Taxpayers do object to large capital expenditures for any purpose, and when their approval is required for bonds to finance new road construction, their preference usually is found to be with the lowest cost alternative.

To illustrate this cost relationship, Table V compares the cost of placing 1/4-inch thick general surface glass slurry seal with the cost of using a comparable conventional material, showing the effect on total cost of the substitution of glass at no cost and at $12.00 a ton. These differences would be adjusted, of course, when the proportion of 40 percent glass and 60 percent rock aggregate studied in laboratory tests is used.

TABLE V

COMPARATIVE COST OF SLURRY SEAL WITH GLASS AND CONVENTIONAL MATERIALS
(General surface, 1/4 in. thick)

	Cost in Place ($/1,000 sq. yds.)		
Element of Cost	Conventional Materials	Glass ($0/ton)	Glass ($12/ton)
Labor	135.00	135.00	135.00
Equipment	52.00	52.00	52.00
Materials	38.00	33.00	51.00
Contractor's Overhead and Profit	75.00	73.30	79.30
Total Cost Per 1,000 Square Yard	300.00	293.30	317.30

If glass is available at no cost, slurry seal can be placed for an estimated cost of $6.70 per 1,000 square yards less than a conventional surface. At a glass cost of $12.00 per ton, slurry seal is expected to cost $17.30 per 1,000 square yards more than a conventional surface. The only difference is assumed to be in the direct cost of materials, which is reflected in the contractor's allowance for overhead and profit and generally applied as a percentage to his total estimated out-of-pocket job cost.

The cost of applying slurry seal with glass and conventional materials on a regional basis varies substantially, although the cost differentials stay about the same. Costs range from a low of $231/1,000 square yards in the East South Central states to a high of $332 in the Middle Atlantic region.

To overcome resistance to even a $17.00 per 1,000 square yard price differential may require a major effort, even though the physical and performance benefits of slurry seal appear to justify such a small incremental cost difference.

In penetrating the market for road surfacing materials, slurry seal with glass does have one great advantage which could be overwhelming in some cities: the municipality that recovers the scrap glass is also responsible for maintenance of its roads and streets. Thus, the same entity controls both the supply of raw materials and the demand for road surfacing materials. In this situation, zero-cost glass, and a resulting cost advantage for slurry seal, is a distinct possibility.

Municipalities in the United States are responsible for maintaining 530,000 miles of roads and streets. About 930 million square yards of these roads are surfaced or resurfaced each year; this is the chief market in which slurry seal will compete.

With a strong promotional program, including documented evidence of superior performance, slurry seal could capture 30 percent of this municipal market, or 279 million square yards per year. At a glass consumption rate of 1,500 tons per million square yards, this market would consume over 400,000 tons of recovered glass annually.

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CONFERENCE SUMMARY

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A NEW PARTNERSHIP

Keynote Address by

Richard L. Cheney, Retired President

Glass Containers Manufacturers Institute, Inc.

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A NEW PARTNERSHIP - KEYNOTE ADDRESS

by

Richard L. Cheney, Retired President
Glass Container Manufacturers Institute, Inc.

Good evening --

I am pleased to join with those who organized this exciting symposium in extending to all of you a heartfelt welcome.

It has been my privilege today to hear some excellent papers on a broad range of subjects important to the future of the glass container industry. I have attended with pleasure discussions by leading authorities on innovative solutions to our nation's solid waste management problem.

As I have listened to your presentations and studied your agenda, I have become deeply impressed with a remarkable fact that is being dramatized at this symposium. This point that so impresses me is the very wide range of professions and technical disciplines represented here today.

I see listed on the agenda for these meetings representatives of government, business, industry and several of our great universities. Among those listed are civil, mechanical and electrical engineers, scientists from many fields, academicians, economists and governmental and industrial administrators.

This is an impressive roster to be dealing with a rather limited segment of the overall solid waste management problem -- namely, the development and marketing of secondary products made of glass salvaged from municipal refuse. But I think there is a very fundamental reason for this gathering of brain-power. I do not mean in any way to slight the immediate purpose of this symposium when I say that to me it has a far greater implication than its stated objective.

You as a group here this evening in truth are the representatives of a new partnership that is forming between government, industry, the universities and the scientific community to develop logical, long-range solutions to a set of problems that in their broadest ramifications involve the survival of civilization as we know it today. We have here tonight in embryo the kind of coalition of skills and abilities that won World War II and put man on the moon. It is heartening to know that this new partnership is alive and functioning. It augurs well for the future of mankind.

There is no need for me to touch on the work that you gentlemen and the institutions you represent are doing in the field of waste glass recovery and re-use. But I think it will be meaningful to examine in more detail the implications of this effort within the broader perspective of the progress that is being made in the related areas of solid waste management, environmental improvement and resource and energy recovery. The inter-relationship between these seemingly diverse activities is fundamental to a true understanding of our long-range objectives, which is what I would like to talk briefly about tonight.

In tackling the immediate solid waste management problem, through the salvage-and-recycle concept, you really are tackling a whole nest of problems. Most immediately you are seeking to ease the problems of the over-crowded landfill and the obsolete incinerator. Of a little longer-range importance, you are contributing to environmental improvement by helping to alleviate the pollutions that are a by-product of most traditional refuse disposal systems.

And for the long haul, you are showing the way to practical techniques for the recovery of the resources and energy that are contained so abundantly in the outcasts of modern civilization. This in the long run no doubt is the over-riding objective.

I would like to make two forecasts here tonight:

First, that the commanding factor finally compelling total implementation of the resource recovery concept will be the need to conserve our remaining available virgin raw materials and energy. This need, as we all know, will not come overnight. Some natural resources remain in abundant supply -- some are becoming scarce today. Geography, population density and land availability will be factors in the sure but nonetheless gradual move away from wasteful disposal toward total conversion to a salvage-and-recycle economy.

But, and here is my second prediction, the day will surely come here in the United States -- and no doubt also throughout the world -- when it will be necessary to make it mandatory national policy to recover all salvageable materials for recycling and to convert what is left into energy. Such a policy will be a condition of survival for our high standard of living civilization.

And finally, for good measure, implementation of the resource recovery concept in the years ahead, will produce as a most welcome by-product a whole new industry -- an industry that eventually will attain vast proportions, providing jobs and income for tens of thousands of people. It will far outpace any slack in employment that may develop in the mines, in the oil fields, in the forests and in other primary resource industries.

You here tonight, together with your countless colleagues throughout America and the world, are truly harnessing your skills and energy to a task of monumental importance.

Where do we stand today in this vast scheme of the future? Let's take stock. The search for solutions to the solid waste problem has passed through several phases in the past decade. First was recognition and definition of the problem. Then began the period of citizen participation through recycling drives and pressure for governmental action. This phase was coupled with intensive research efforts by government and industry to develop long-range solutions and the conclusion that the only logical course for the future is large-scale, mechanized recovery and recycling of reuseable, marketable components of refuse. Research has demonstrated that most components of refuse can be recycled or converted into energy. The federal government, several states and a growing number of municipalities have taken forward looking action to implement these conclusions.

We are now in the period of implementation -- in a period of transition from citizen recycling, the laboratory and the pilot plant to full-scale

operation. We are on the threshold of major breakthroughs in refuse disposal and resource recovery technology.

Two demonstration projects -- at Franklin, Ohio, and St. Louis -- are operating. The Franklin project is primarily focused in materials recovery. The St. Louis demonstration is converting refuse to energy for generation of electricity.

Hempstead, N.Y., Lowell, Mass., Baltimore, Md., San Francisco, San Diego County, Calif., Delaware and others have well developed plans that are well into the realization stage. Connecticut and New York have enacted legislation looking toward coordinated state-wide waste management and resource recovery systems.

The projects being established today vary widely in concept and technology. They are geared to specific local situations and to demonstration of different approaches and technical solutions. But they all have one thing in common -- the conversion of refuse into reuseable materials or energy. Together they provide a blueprint for solid waste management and resource recovery on the municipal, regional and state-wide levels. These are the opening moves in a vast social, economic and industrial conversion that will be progressing for a great many years to come.

Concurrent with the emergence of the new resource recovery technology is the development of markets for recovered materials and energy. This brings us squarely back to the purpose of this symposium. The use of salvaged materials,

just like their recovery, often calls for new technology. You can't just dump a load of salvaged glass into a furnace without first learning a lot of things. How much of it can the basic raw material batch tolerate? How free must it be of contaminants? How does it affect the melting process -- and the finished bottles and jars?

Similarly, a great many things must be determined before we replace crushed stone with crushed glass in asphalt, or slurry seal, or terrazzo flooring. Before we can use waste glass in making bricks, and blocks and other building materials, we must know how well the new materials will wear. Will they withstand heat and cold? How resistant are they to impact, abrasion or pressure? Are they economical to manufacture? And, are there markets for the new products once they have been developed?

You gentlemen at this symposium are providing many of the answers as regards the secondary uses of salvaged glass. Others at other places are providing answers to these questions as they apply to other salvaged materials -- paper, steel, aluminum, plastics -- you name it.

Development of markets, like implementation of the resource recovery technology, will be a gradual process and the two will move forward hand-in-hand. It is only logical, for example, that emphasis will first be placed on resource recovery in those areas where there are markets for the recovered materials -- just as the last stand of the traditional landfill will be in places where markets for secondary materials are spotty and land is plentiful.

But the growing pressure of necessity will help create the markets just as it eventually will force upon us the total implementation of the resource recovery concept.

This, briefly outlined, is the mission of the new partnership between government, industry, the universities and the scientists. It is to finish over the years ahead a job already well begun. It is to provide for America -- and I trust for all the world -- an assurance that future generations will be able to enjoy the kind of civilization characterized by a high and fruitful standard of living that we enjoy today. Indeed, it is not setting our sights too high to envision your efforts leading to an even brighter tomorrow.

Thank you.

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IN SECONDARY PRODUCTS
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