REPORT OF THE
VIRGINIA DEPARTMENT OF TRANSPORTATION
IN RESPONSE TO HOUSE JOINT RESOLUTION 301
ON THE

Feasibility Of Using Recycled Glass In Asphalt

TO THE GOVERNOR AND
THE GENERAL ASSEMBLY OF VIRGINIA

HOUSE DOCUMENT NO. 25

COMMONWEALTH OF VIRGINIA
RICHMOND
1990

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EXECUTIVE SUMMARY

This report was written by Charles S. Hughes, Senior Research Scientist of the Virginia Transportation Research Council, in response to House Joint Resolution No. 301 which "requests the Virginia Department of Transportation to conduct a study of the feasibility of using recycled glass as supplemental aggregate in asphalt."

A literature review is included which documents experimental uses of waste glass from the 1970s to the present. The literature indicates that adhesion between the asphalt and glass has been a problem and that for the glass to be used effectively it must be crushed so that it will pass a 3/8-in sieve. Early results of the recent use of recycled glass in New York City indicate that glass percentages of 15 percent or less can perform satisfactorily. The study reported here was a laboratory study comparing mixes using 5 and 15 percent glass with a control mix that contained no glass. The study shows that mix properties do change with increased percentages of glass, but not adversely. This means that if glass is going to be used in an asphalt mix, the percent of glass should not exceed 15 percent, and the percent chosen must be included in the mix design process so that the mix properties can be determined. The propensity of moisture damage to occur is still a concern, although this type of failure was not found to be critical in the laboratory study. A cost analysis indicates that the cost of the recycled glass can vary considerably depending on crushing and haul cost. At the present time, unless some economic incentive can be provided for the use of waste glass, it probably cannot compete with the cost of sand. If waste glass is to be used in asphalt mixes, consistency of supply is another factor that must be addressed. However, the use of recycled glass in both highway embankments and in unbound aggregate base materials would be preferable to its use in asphalt because of the propensity of the asphalt coating to be separated from the glass in the presence of moisture. The consistency of supply is not as critical if glass is used in embankments, and the potential for moisture damage to occur at the asphalt/glass interface would be removed if glass is used in unbound aggregate layers.

INTRODUCTION

House Joint Resolution No. 301 (see the Appendix) requested that the Virginia Department of Transportation (VDOT) conduct a study of the feasibility of using recycled glass as supplemental aggregate in asphalt.

This request is a result of the state's objective to recycle 25 percent of the solid waste stream by 1995. Technically, because of the similarities between glass and conventional aggregates, glass would appear to be a potential supplemental material for aggregate in asphalt mixes. Attempts several years ago to use Glasphalt (100 percent glass in asphalt) met with little success because of incompatibility problems at the glass/asphalt interface.

A recently placed experimental pavement in New York used 15 percent glass as a replacement for sand in a conventional asphalt mix. The installation has not been in service sufficiently long to draw any conclusions. Limiting the amount of glass is likely to have the least deleterious effect on the asphalt mix and still consume large quantities of waste glass.

However, in addition to the technical feasibility of using glass, an economic evaluation is extremely important. At present, few sources of recycled glass exist; those that do exist require the glass to be separated by color. Once separated and crushed, the glass is sold for about $60/ton. At that price, glass is not competitive with conventional aggregate. However, HJR 301 requests that if the use of waste glass is technically feasible, VDOT specifications should be be amended to permit the use of recycled glass where available.

PURPOSE

The purpose of this study is to conduct a technical and economic evaluation of the feasibility of using recycled crushed glass as a supplemental aggregate in asphalt mixes.

SCOPE

Because of the time constraints imposed on this study, it was decided to limit the study to a laboratory investigation of glass in an S-5 surface mix. Criteria are well established for evaluating strength, resistance to deformation and resistance to moisture damage for surface mixes, whereas an evaluation of the use of glass in other potential mixes such as in base courses, patching mixes, etc. is more problematic. The evaluation of glass in surface mixes should indicate whether an evaluation with additional mixes is desirable or not.

STUDY

Literature Review

Considerable interest was shown in the 1970s to using waste glass as a part of the aggregate phase in asphalt mixes. This was suggested as a possible means for relieving the aggregate shortage in some areas, but mostly its use was considered a means to utilize the waste glass that would otherwise be discarded in landfills. The term glasphalt was coined to indicate this type of mix.

The results of these early experiments indicated the following:

1. Lime or other antistripping agents are needed in the mixes to attain and retain proper adhesion of the asphalt to the glass (1,2,3).

2. The glass should be crushed to pass a 3/8-in sieve. Larger particles, especially those that are elongated, have a tendency to crush during construction (2,3,4).

3. Glass particles cool more slowly than aggregate because of the differences in their thermal conductivity. This may be an advantageous property in cold weather as it allows more time for compaction (5). However, in warmer weather the mixes may tend to be unstable under the construction rollers; consequently, the rolling patterns may need to be revised (6).

4. Performance in a number of cases was reported as adequate (2,7,8). However, the loss of glass from the surface was reported in a Canadian trial (6).

5. The surfaces tested appeared to have adequate skid resistance (2,7,9).

6. Except for situations where the disposal of the glass is likely to be costly or the landfill space is limited, glasphalt does not appear to be economically feasible. Cost of conventional aggregates in most areas is less than the cost of collecting and crushing the glass (7,9,10).

7. Estimates are that one million bottles would be required for one lane mile of 3-in-thick pavement when the aggregate is 20 percent crushed glass (1). It was also estimated by a different source that 29.4 billion glass containers were used and discarded in the United States during 1966 (no more recent estimate has been found) (4).

Laboratory Study

The basic mix that was studied was an S-5 surface mix, which is the most widely used mix in the state. The basic mix gradation is shown in Table 1 and is plotted in Figure 1. The relationship between the gradation and the maximum density line is also shown in Figure 1. The aggregate was primarily a greenstone from a Charlottesville aggregate producer and 15 percent natural sand. Two glass contents were studied, 5 and 15 percent, and two asphalt contents were used, one based on a 50-blow compactive effort (Figure 2) and the other on a 75-blow compactive effort (Figure 3). Mixes using a 75-blow compactive effort to determine the optimum asphalt content are being used more often in Virginia because they require a lower asphalt content and thus are more resistant to rutting under heavy traffic conditions. However, they may be more sensitive to the use of glass than mixes with higher asphalt contents. The optimum asphalt content for the 50-blow compaction was 6.20 percent, and for the 75-blow, it was 5.75 percent.

Table 1

Gradation of Basic S-5 Mix Without Glass

Sieve Size	Percent Passing
1/2"	100
3/8"	95
#4	58
#8	39
#16	29
#30	19
#50	10
#100	6
#200	4.7

The glass was obtained from a contractor in New York City who has laid several thousand tons of mix containing 15 percent recycled glass in recent years. The gradation of the glass is shown in Table 2, and it follows the gradation recommended in the literature review. The glass material can be characterized as a coarse sand gradation.

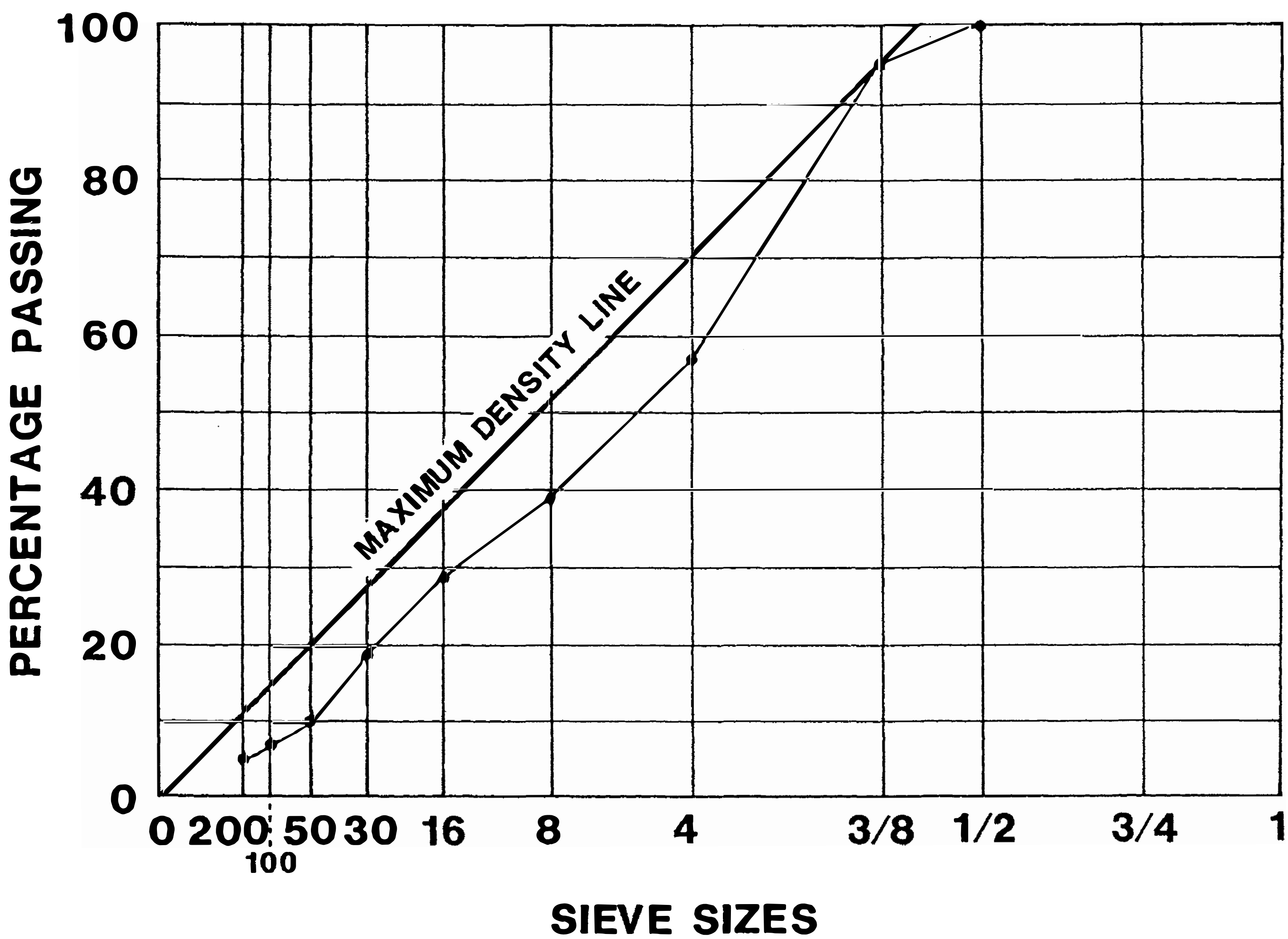

Figure 1. Relationship between gradation and the maximum density line.

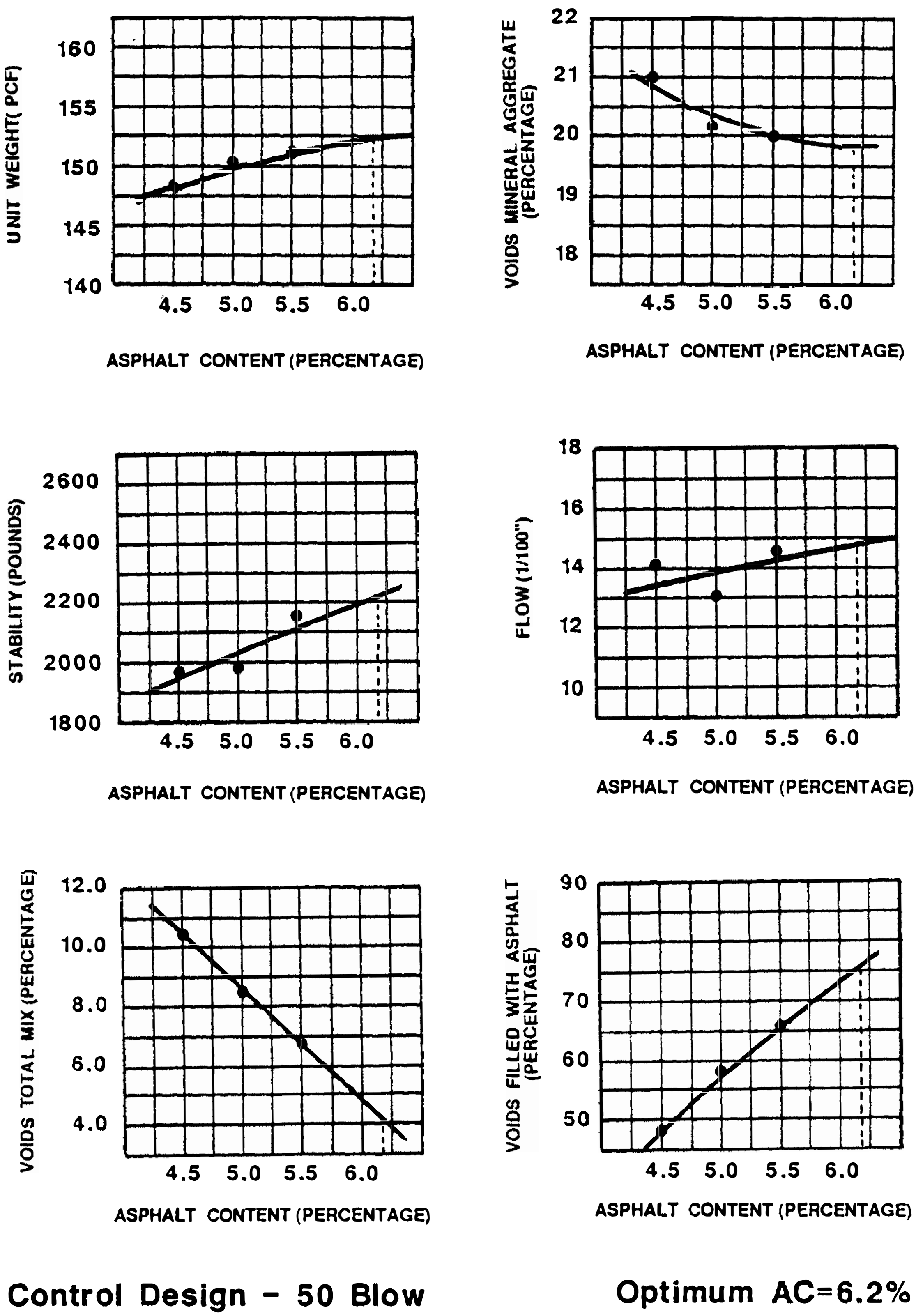

Figure 2. Design for 50-blow compactive effort.

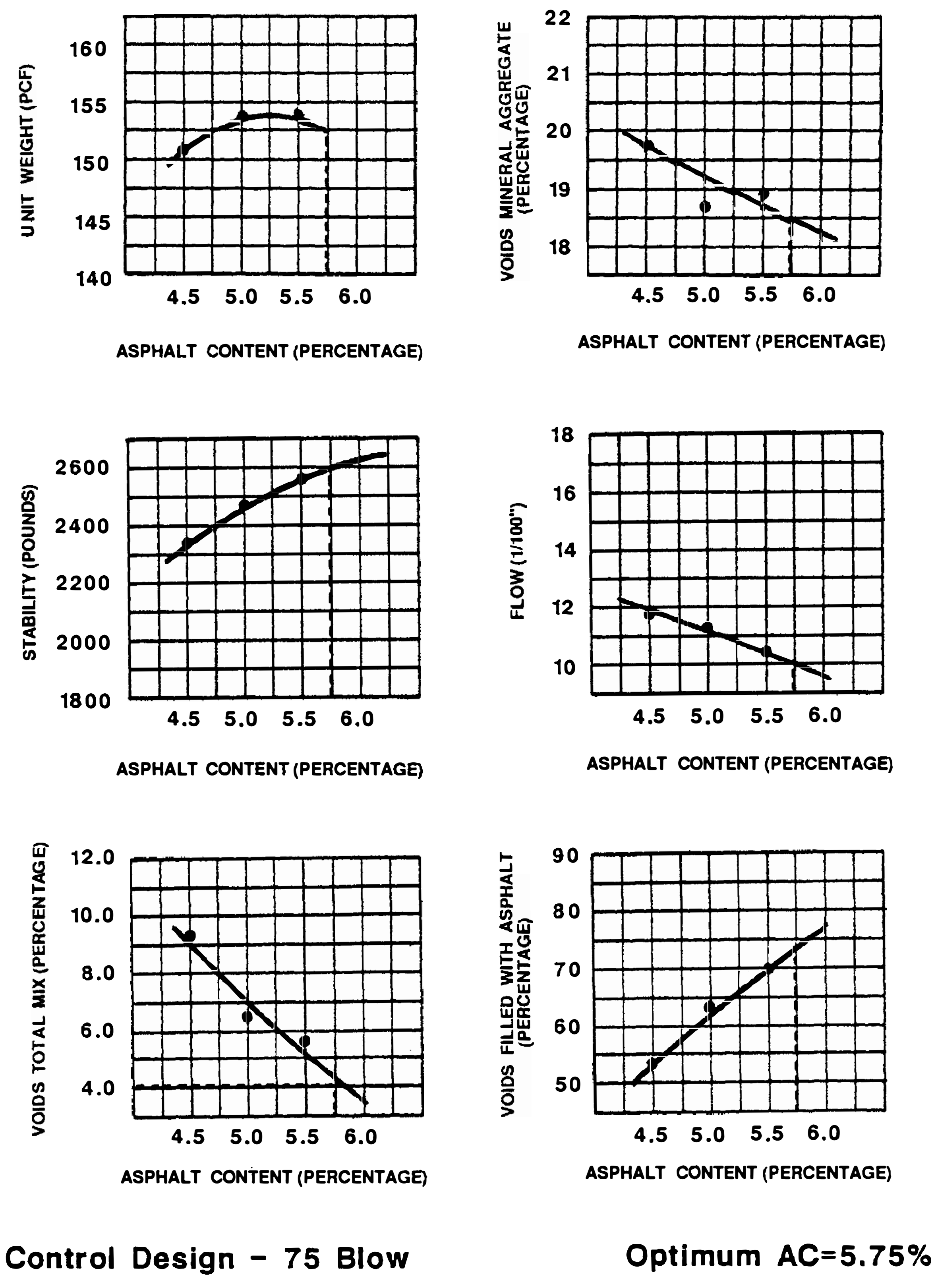

Figure 3. Design for 75-blow compactive effort.

Table 2

Gradation of Recycled Glass

Sieve Size	Percent Passing
1/2"	100
3/8"	98
#4	70
#8	32
#16	19
#30	10
#50	6
#100	4
#200	2.9

All testing was conducted using an AC-20 asphalt cement. The tests conducted included those for Marshall properties, indirect tensile strength, resilient modulus, and moisture damage.

Comparisons were made among the control mix, which contained no glass, and the mixes with 5 and 15 percent recycled glass. The glass was added to the mix replacing some of the sand and some of the greenstone aggregate; thus, the gradations of the mixes with glass were close but not identical to that of the control mix.

Marshall Properties

The graphs showing the Marshall properties are shown in Figures 4 and 5. Figure 4 shows the data for the mix containing 6.20 percent optimum asphalt content and Figure 5 shows the data for the mix containing 5.75 percent asphalt content. The mixes at both asphalt contents reflect the same trends with the increase in the percentage of glass: as glass is added, the unit weight tends to decrease, primarily because of the lower specific gravity of the glass. Neither stability nor flow undergo any significant changes. The void properties do change: the voids total mix (VTM) decreases with an increase in the percentage of glass; the voids in the mineral aggregate (VMA) decreases with an increase in the percentage of glass; and the voids filled with asphalt (VFA) increases with an increase in the percentage of glass. There are at least two possible causes of these trends: one is the particle shape and texture of the glass and the other is the slight change in gradation that occurred. It will be very important if glass is used in a mix to pay particular attention to maintaining the minimal VMA so as to allow enough room for the asphalt cement. However, there are no indications from an analysis of the Marshall properties that these percentages of glass are detrimental.

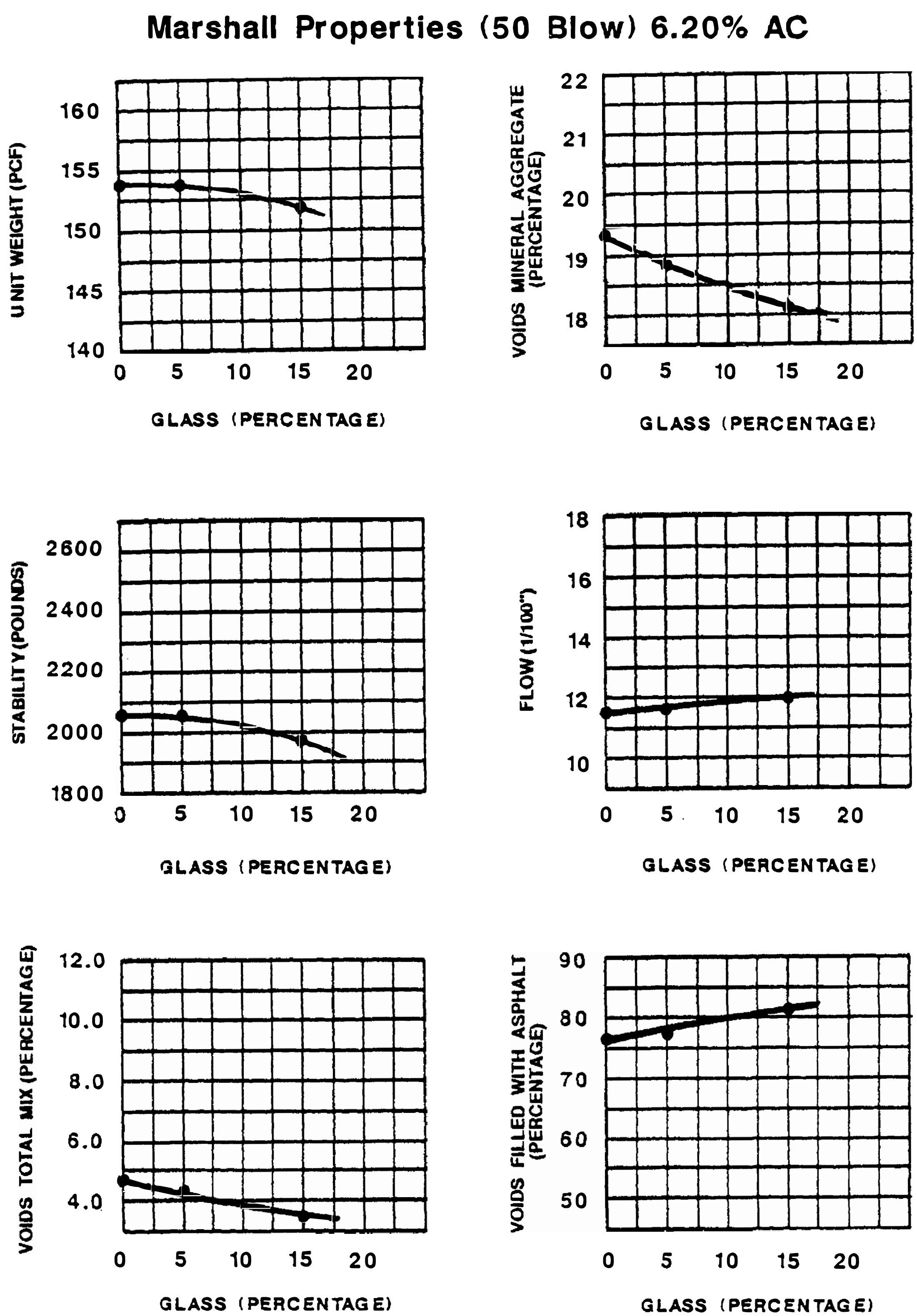

Figure 4. Marshall properties for high asphalt content mix containing glass.

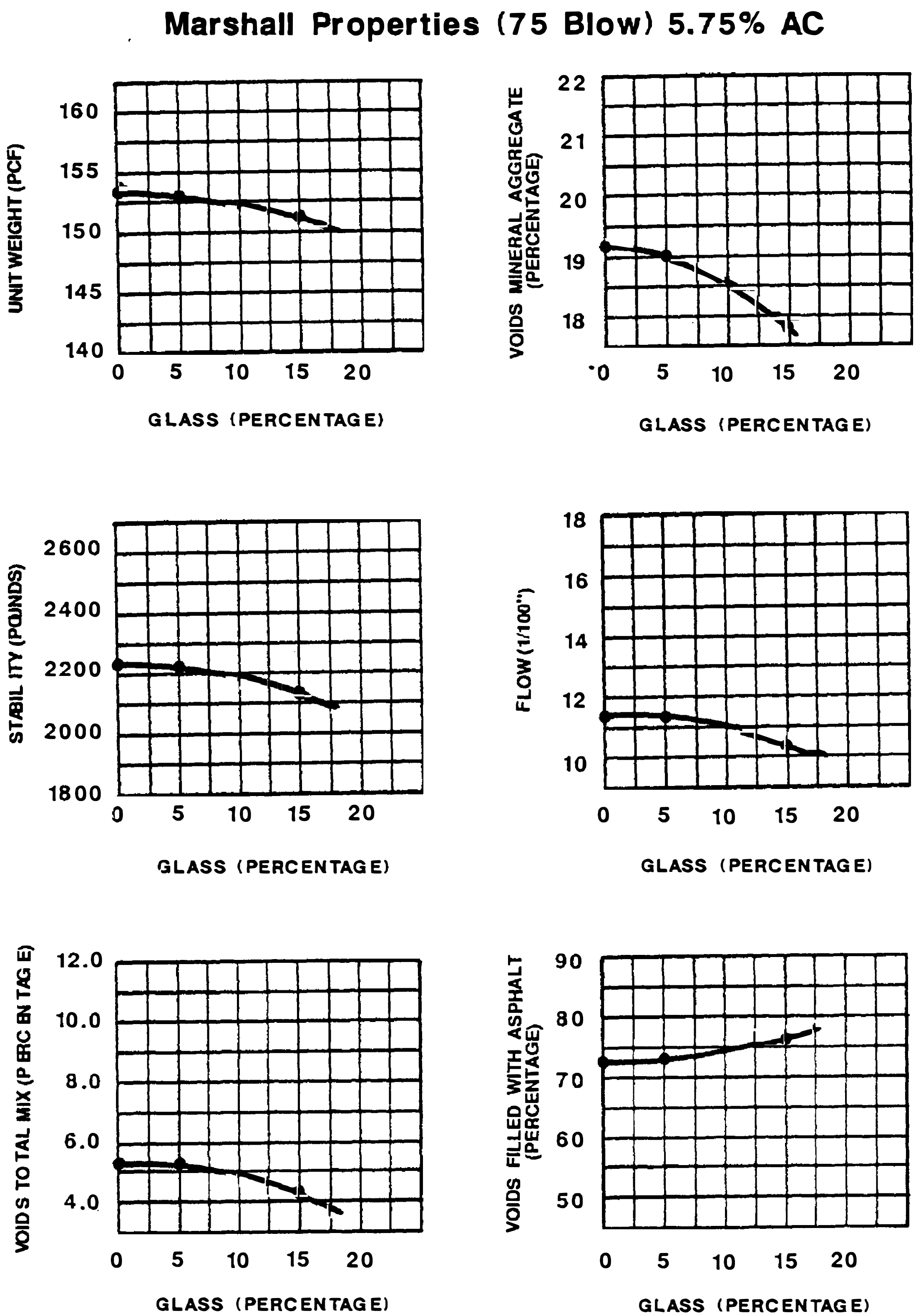

Figure 5. Marshall properties for low asphalt content mix containing glass.

Resilient Modulus

A nondestructive measure of the stiffness of asphalt mixes is the resilient modulus strength (M_R). The results of this testing are shown in Figure 6 where resilient modulus results performed at 72°F are plotted against the percentage of glass. The results at both asphalt contents indicate little or no change in M_R strengths as the percentage of glass is increased. The slight decrease in M_R with the addition of glass at the 5.75 percent asphalt is not thought to be significant.

Indirect Tensile Strength

A measure of strength is the indirect tensile strength. The results of this mix property also determined at 72°F with the addition of glass is shown in Figure 7. Again, no significant loss of tensile strength is evident with the percentages of glass tested.

Resistance to Moisture Damage

The major problem with the use of glass in asphalt mixes has been the incompatibility of the two materials at their interface particularly in the presence of moisture (3). The incompatibility usually occurs as the loss of adhesion between the asphalt and glass, often termed stripping. One percent hydrated lime was used as an antistrip additive to help prevent the loss of adhesion (3). VTM-62 was used to test the loss of adhesion or conversely the resistance to moisture damage. This test uses the ratio of the strength of a set of specimens conditioned by moisture divided by the strength of unconditioned specimens to produce a tensile strength ratio (TSR). TSR values range from 0, which indicates no resistance to moisture damage (total loss of adhesion), to 1.0, which indicates no susceptibility to moisture damage (no loss of adhesion).

The results of the conditioned strengths are shown in Figure 8, and the TSR values are shown in Figure 9. Both figures provide the same trends, i.e., the glass has little or no effect on either the conditioned strength or the TSR values. This is somewhat surprising in view of the conclusions of other reports that moisture damage tends to be a problem with the use of glass. Figure 10 is a photograph that does show some signs of moisture damage on the glass.

Evidently, because of the low percentages of glass used, the moisture damage that may occur does not severely affect either the wet strengths or the TSRs.

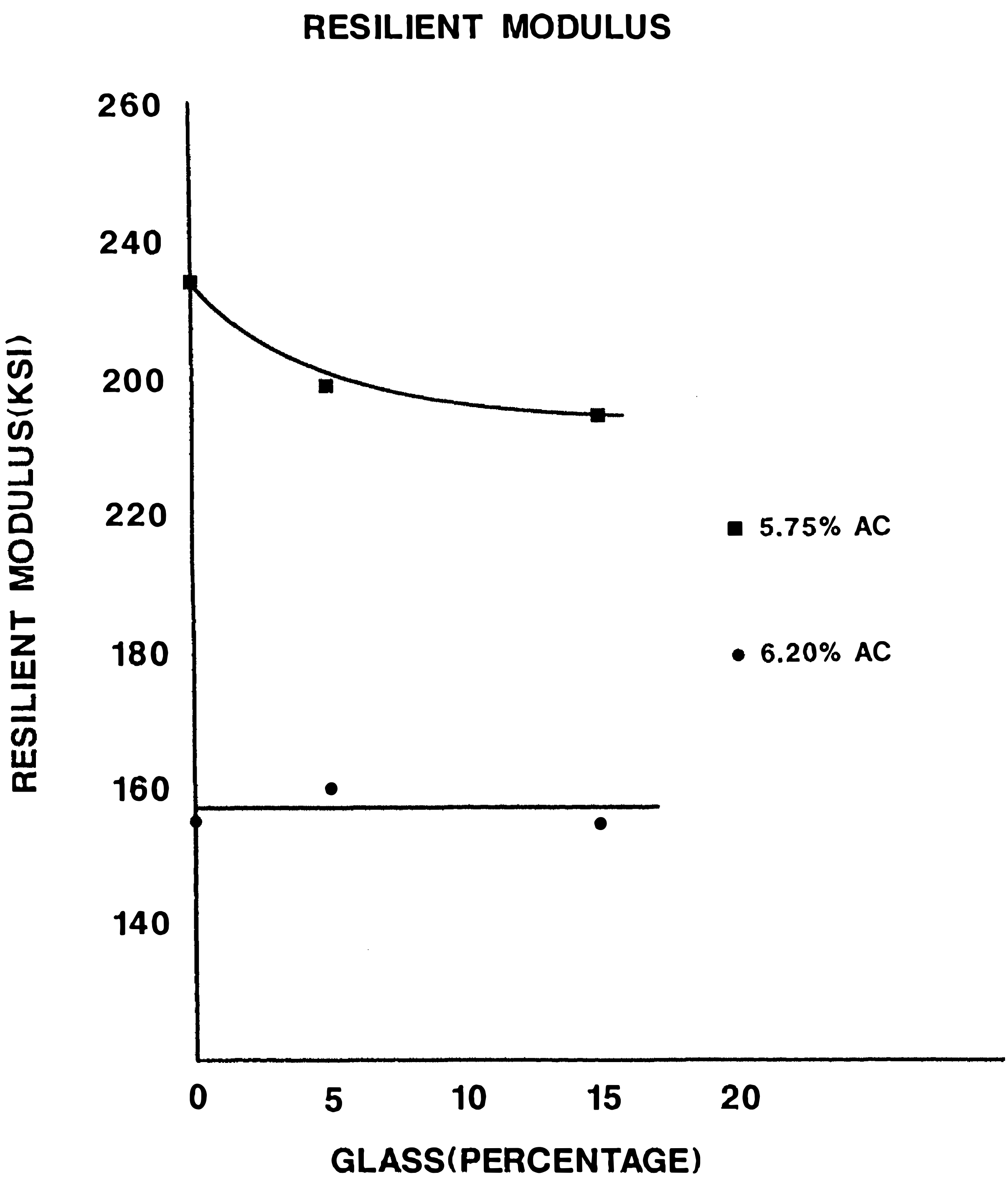

Figure 6. Resilient modulus of mixes containing glass.

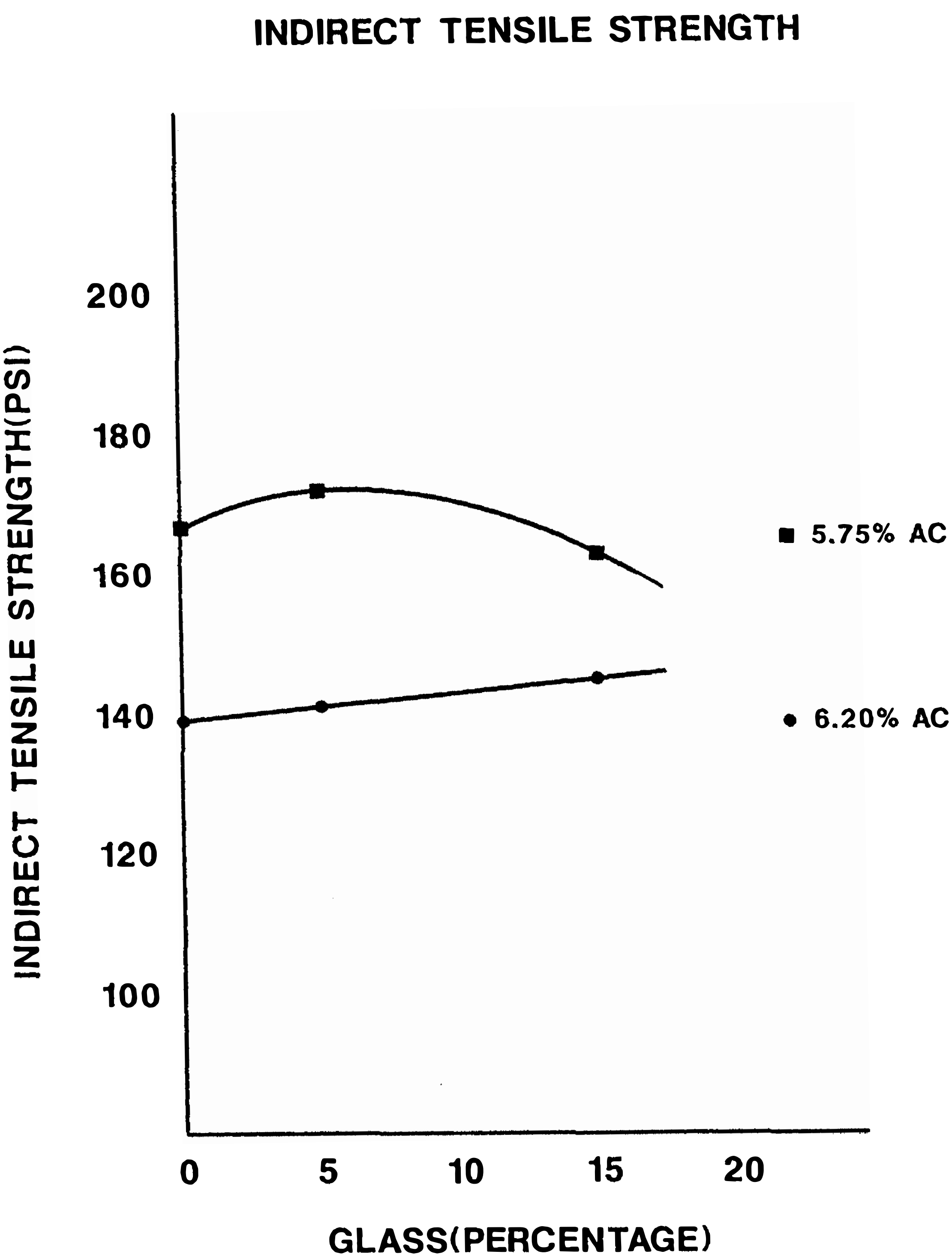

Figure 7. Indirect tensile strength of mixes containing glass.

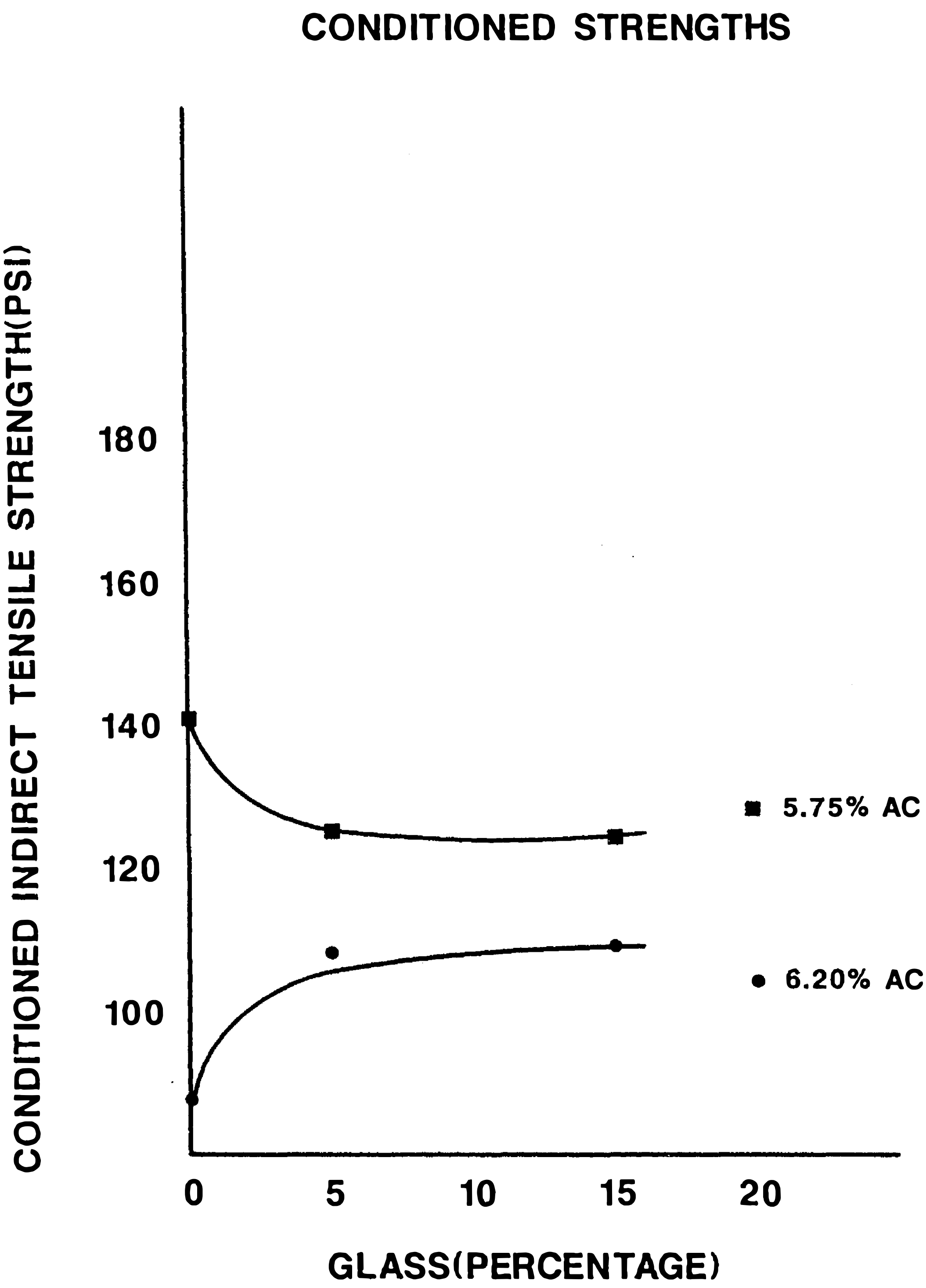

Figure 8. Indirect tensile strength of moisture conditioned specimens containing glass.

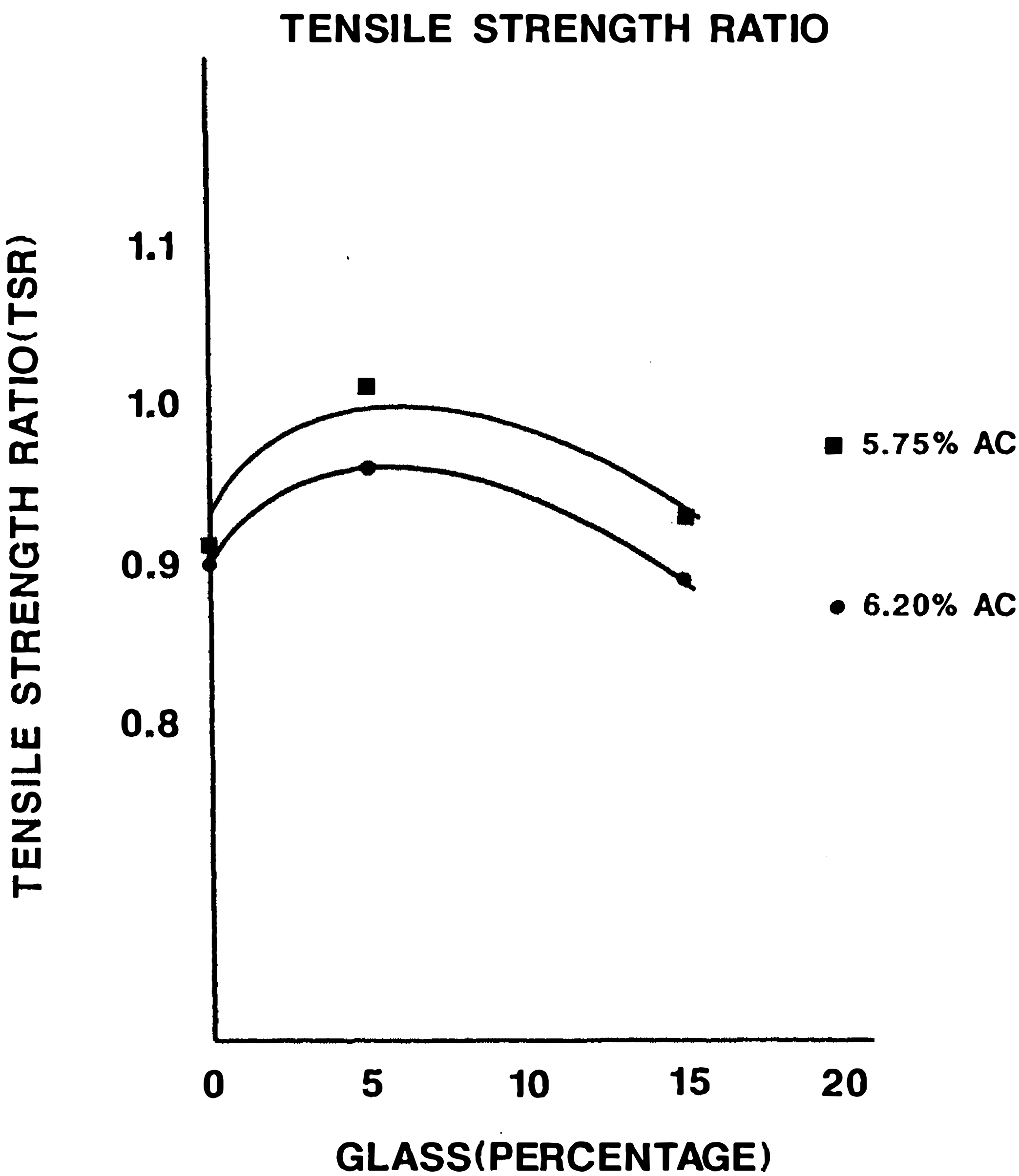

Figure 9. Tensile strength ratios of mixes containing glass.

Figure 10. Moisture damage removing asphalt from glass particle.

ECONOMIC ANALYSIS

As previously stated, color separated, crushed recycled glass sells for $60/ton. This cost is sufficiently high to remove this source from consideration as an alternative aggregate for highway use.

However, glass in mixed colors has very little value at present. The greatest value of the glass appears to be in cost avoidance, i.e., the cost of disposing of the glass. The Department of Waste Management states that cost avoidance in metropolitan areas is now about $20/ton and is expected to increase to as high as $35 to $50/ton by the end of the year.

Even if glass is made available without charge to asphalt mix producers, the cost will tend to be substantial. Hauling costs will run about $.15/ton/mi, and crushing cost will be about $3/ton (the cost to N. Y. contractors and the estimated cost in Va.). Quantity and consistency of supply will also be a factor. The larger the quantity available at one time, the lower the cost per ton. Byrant Salvage estimates the cost of crushing glass to be $20/ton for the small quantity of 20 tons per week. These costs will have to compete with the cost of fine aggregate and sand, which run about $8/ton.

The cost of recycled glass can vary widely depending on haul distance and crushing cost. Hauls of more than 30 mi and crushing costs of more than $3/ton very likely will preclude the use of glass unless some sort of incentives can be provided.

The following conclusion taken from a 1975 report (9) is still applicable.

> The economic feasibility of using waste glass as an aggregate in asphaltic concrete is dependent primarily upon the development of resource recovery systems which can separate glass along with other recyclable components and generate enough revenues from their sale plus disposal and processing fees to produce an acceptable return on equity. At the present time it appears that such a system can be economically viable in a limited number of municipalities. The maximum contribution to reclaimed product revenues would result if the glass were color sorted and marketed as cullet. However, if an acceptable level of color sorting is not possible or if there are no local markets for the cullet, use of the waste glass as aggregate should be considered.

GENERAL DISCUSSION

The use of glass in asphalt appears to be technically feasible although some intuitive skepticism still exists concerning the ability of the glass to resist moisture damage. If glass is used in asphalt mixes, the following steps should be taken.

1. Use only glass that is not acceptable for higher levels of recycling, i.e., uses in the glass industry.

2. The glass should be crushed to a -3/8" size with no more than 6 percent -#200.

3. The mix design must have a target value for the percent of glass to be used, and the maximum percent of glass should not exceed 15 percent.

4. Moisture damage tests must be conducted using the target percent glass and the optimum asphalt content and must produce a TSR value of 0.9 or higher. This is a more severe resistance to moisture damage requirement than for mixes not using glass, but it is thought to be reasonable because of the propensity for the glass to suffer moisture damage.

An alternative use of glass in highway construction would be the use of glass in embankment construction and unbound aggregate base layers. Although this consideration is beyond the assigned scope of this study, it would not be professional to omit mentioning alternative uses of glass in the highway industry. The use of glass in embankments would require the glass to be crushed, but the size of glass would not be as critical as in either aggregate base or asphalt mixes. The advantage of using crushed glass in aggregate base as opposed to asphalt mixes is that the potential for moisture damage to occur at the asphalt/glass interface would be removed. An example of the amount of glass that could be used in one lane mile of a highway with 6 in of aggregate base using 20 percent crushed glass would be 440 tons. This relatively large amount of recycled glass raises another concern that must be considered if glass is specified: the consistency of supply. It is very difficult to use the glass in either aggregate base or asphalt mixes if the supply is not consistent. The ingredients of the other materials must be designed around the amount of glass used; thus, changing the percentages of glass will require mix design changes for the other ingredients. Changing percentages of glass in an embankment should not be as critical.

CONCLUSIONS

Based on this limited study, the use of glass in asphalt mixes is technically feasible if several restrictions are observed. If the amount of glass is restricted to 15 percent or less, and it is crushed to the gradation limits mentioned above, the following conclusions apply:

1. The use of glass tends to reduce the VMA and VTM and increase VFA from Marshall-compacted specimens; thus, the optimum asphalt

content must be determined with the target percent of glass to be used.

2. Neither resilient modulus nor indirect tensile strengths are adversely affected by the addition of up to 15 percent of glass.

3. Although both wet strength and TSR moisture damage values were unaffected by the percentage of glass, some separation at the asphalt/glass interface was observed.

4. The cost of glass (including crushing to the proper gradation and the haul cost) will vary considerably. Probable cost will be at least equal to that of sand, thus, there is little monetary incentive to use recycled glass at the present time, particularly when it appears it may be more susceptible to stripping than many of our natural aggregates.

RECOMMENDATIONS

Based on results of this study and on practical engineering considerations, it is recommended that the following special provisions be developed.

1. To allow crushed recycled glass to be used with soil and rock as fill material in embankments.

2. To allow crushed recycled glass to be added to unbound aggregate base.

3. To allow a maximum of 15 percent crushed recycled glass to be used in asphalt mixes. Gradation controls are to be 100 percent passing #3/8 sieve and a maximum of 6 percent passing #200 sieve and with a TSR of the mix to be 0.9 or better.

Further, if and when glass is found to be economically feasible to use in a surface course mix, an experimental section should be laid prior to extensive use of it.

ACKNOWLEDGMENT

Appreciation is expressed to Frank Fee, West Bank/Elf Asphalt, and Dick Petrarca, Bismasco, N. Y., for their help in obtaining the glass that was used in this study as well as for economic data. Milton Rothweiler of Luck Stone also provided data used in the economic analysis. Thanks are also extended to Mike Murphy of the Department of Waste Management for the information he furnished. Woodrow Halstead is thanked for his efforts in writing the literature review.

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APPENDIX

1989 SESSION
ENGROSSED

HP9030404

HOUSE JOINT RESOLUTION NO. 301

House Amendments in [ ] - February 1, 1989

Requesting the Virginia Department of Transportation to conduct a study of the feasibility of using recycled glass as supplemental aggregate in asphalt.

Patrons—Almand, Marshall and Stambaugh; Senator: DuVal

Referred to the Committee on Roads and Internal Navigation

WHEREAS, the Commonwealth has established a statewide objective of recycling twenty-five percent of the solid waste stream by 1995; and

WHEREAS, a successful recycling program requires a market for recyclable or reusable material recovered from the solid waste stream; and

WHEREAS, the Commonwealth has declared its commitment to aid in the identification and establishment of markets for recyclable materials; and

WHEREAS, the House of Delegates and the Senate have jointly encouraged state agencies to procure recyclable and recycled products and materials; and

WHEREAS, glass is an abundant and easily recycled material in the solid waste stream; and

WHEREAS, the existing markets for glass recycling require substantial transportation costs; and

WHEREAS, existing markets require that glass be separated by color, thereby significantly contributing to cumbersome collection methods and deterring voluntary separation; and

WHEREAS, the Commonwealth is one of the largest purchasers of asphalt and through its definition of technical standards for procurement of asphalt exerts a major influence on the type of materials used in the manufacture of asphalt products; now, therefore, be it

RESOLVED by the House of Delegates, the Senate concurring, That the Virginia Department of Transportation is requested to conduct a technical and economic evaluation to determine methods whereby recycled glass can be successfully used as a supplemental aggregate material in asphalt; and, be it

RESOLVED FURTHER, That if recycled glass is determined to be technically and economically acceptable as a supplemental aggregate, the Virginia Department of Transportation is requested to amend its standards for procurement to [~~require~~ permit] such use where recycled glass is made available.

Upon completion of this study the Department of Transportation shall report its findings to the Governor and the 1990 General Assembly as provided in procedures of the Division of Legislative Automated Systems for processing legislative documents.

Official Use By Clerks

Agreed to By The House of Delegates		Agreed to By The Senate	
without amendment	☐	without amendment	☐
with amendment	☐	with amendment	☐
substitute	☐	substitute	☐
substitute w/amdt	☐	substitute w/amdt	☐
Date: ________		Date: ________	
Clerk of the House of Delegates		Clerk of the Senate	