**FINAL REPORT**

# EFFECT OF GLASS CONCENTRATION ON STRIPPING OF GLASPHALT

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## ABSTRACT

Virginia allows up to 15 percent glass to be used in asphalt concrete. However, a literature search revealed that there is not much test data to substantiate this quantity. Because of the smooth surface texture of glass particles and the associated risk of stripping, it is desirable not to incorporate too much glass. The purpose of this laboratory study was to determine the maximum amount of glass that can be used in glasphalt without sacrificing stripping resistance. Two mixes, each containing chemical and hydrated lime antistripping additives, were made at several glass contents. The tensile strength ratio (TSR) test (AASHTO T283) was used to assess stripping resistance of the mixes. Both additives produced adequate stripping resistance with the exception of the mix containing 20 percent glass and chemical additives. Based upon the results of the TSR stripping test as a performance indicator, it was found that using up to 15 percent glass in glasphalt is acceptable.

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## INTRODUCTION

It has been estimated that approximately 70 percent of the nations' landfills will deplete their space by 2000.[1] Communities and solid waste disposal companies are searching for ways to dispose of materials that would otherwise have to be placed in these landfills. Examples of waste materials that are now being used in highway construction include scrap tires, glass, and roofing shingles. Factors other than material properties that foster interest in recycling are environmental issues, legislative activity, economics, and construction material shortages. Virginia has experimented with approximately 14,000 metric tons of asphalt concrete containing ground scrap tire rubber in an attempt to gain some experience with it and to determine whether it is less costly than conventional materials.

Glass can be recycled for glass manufacturing; however, it must be sorted by color. The mixed-color glass must be disposed of in landfills and the disposal cost is quite high in some areas. Around 1970 the University of Missouri-Rolla started an extensive research project funded by the Environmental Protection Agency that involved approximately 30 test sections of asphalt concrete containing glass. This type of asphalt concrete became known as glasphalt. In a 1994 synthesis only six state highway agencies reported any construction using glass in asphalt paving but ten agencies had performed some research on the utilization of glass.[2] A 1995 Texas report identified five states with specifications for using glass in asphalt.[3] Baltimore, Md. was one of the first cities to use glasphalt, but has recently discontinued its use because of high processing costs. New York City still continues to use about five percent of fine sand-size glass in its mixes. Most glasphalt pavements have contained less than 15 percent glass.

Performance of building materials is one of the most important aspects that engineers must consider. When waste materials are used, the performance should be equal to or better than that of conventional materials. Since glass has a very smooth surface, the asphalt cement may fail to form a durable permanent bond, especially in the presence of water. Some of the early field projects in New York and Baltimore showed stripping, which has been a concern in other studies.[4] A recent technical assistance report showed stripping to be a major concern in Virginia;[5] therefore, any addition of a material that would result in more stripping may be undesirable. A laboratory feasibility study by Hughes in 1990 demonstrated that stripping in glasphalt may not be a problem; however the study was limited to one aggregate and only hydrated lime was used as an antistripping additive.[6]

In 1992, the Virginia General Assembly passed Senate Bill 469 which directed that a Committee to study the use of waste materials be formed. The Recycled Materials in Highway Construction Advisory Committee was comprised of professionals representing the Virginia Department of Transportation (VDOT), the road construction industry , the waste disposal industry, recycling organizations, Virginia Department of Waste Management and local governmental organizations. The committee discussed many materials that could possibly be used in road construction and made recommendations to VDOT. Initially there was considerable interest in using glass in asphalt, and a decision was made by the Virginia Transportation Research Council Asphalt Research Advisory Committee to conduct a study of this issue. The study was to involve the installation of one or more field test sections and a laboratory study to evaluate stripping. The Committee recommended that only limited use of glass in asphalt pavement be considered because of unknowns concerning performance. This report covers the laboratory testing of glasphalt. The results of the field tests were published in a separate report.[7]

## PURPOSE AND SCOPE

The purpose of this phase of the investigation was to determine the maximum amount of glass that can be used in asphalt concrete without sacrificing stripping resistance. A laboratory study was conducted on two mixes at various glass contents.

## METHODOLOGY

Although some of the literature identifies 15 percent as the maximum amount of glass that should be allowed in asphalt concrete mixes, there is very little test data to substantiate this quantity. Some user agencies allow only five percent of glass to be used. It is cautioned that the maximum allowable percentage derived from this study should apply only to the gradation of glass used and the type of surface mixes that were tested. The gradation of glass that was used in the lab tests was chosen because it was used in the Virginia test sections and appeared to be available without requiring extra crushing.

The variables and number of tests are listed in Table 1. Two surface mixes were used, one of which was moderately susceptible to stripping. The other one was believed to be very susceptible to stripping because of previous stripping tests. A single chemical additive and hydrated lime were used in each mix. Four levels of glass, ranging from 0 to 20 percent, were used. The allowable Tensile Strength Ration (TSR) of 0.85 and trends of wet strength curves were used to determine the maximum amount of glass that could be safely used.

A total of 48 tests were performed for two mixes requiring 384 specimens. Each test required four specimens tested in a dry condition and four specimens tested in a wet condition.

The TSR test is quite time consuming. Since 48 tests required an immense amount of time, using more than two replicate tests was not practical.

**Table 1. Number of TSR Tests Performed Per Mix**

| Percent Glass | Antistripping Additive | | | Total |
|---|---|---|---|---|
| | None | Chemical | Hydrated Lime | |
| 0 | 2 | 2 | 2 | 6 |
| 5 | 2 | 2 | 2 | 6 |
| 12 | 2 | 2 | 2 | 6 |
| 20 | 2 | 2 | 2 | 6 |
| Total | 8 | 8 | 8 | 24 |

## Tests

### *Routine Tests*

The mixes were designed by the 75-blow Marshall design method in accordance with Virginia Test Method (VTM) 57.[8] The 75-blow design yields thinner asphalt films than the 50-blow design. It was desirable to simulate the worst condition under which glasphalt might be constructed; the author felt that the thin asphalt films would be more susceptible to stripping. The design air void content, VTM, was 4.0 percent. Density and air void determinations on specimens were made in accordance with ASTM D 2726 and D 3203, respectively.[9]

### *Stripping Test*

The TSR stripping test was performed according to AASHTO T283-89, which includes a freeze cycle.[10] One exception to the test method was that the specimens were compacted to 7.5 percent air voids (VTM) instead of the specified 7.0 percent. This void content of 7.5 percent is the target air void content specified in a similar Virginia test method, which does not use the freeze cycle. Eight cylindrical specimens were made and divided into two subsets having approximately equal densities (voids). One set was tested dry and the second set was preconditioned by saturating with water, freezing, and placing in a water bath at 60$^{o}$C. The ratio of the indirect tensile strength of the conditioned set to the indirect tensile strength of the dry set, which is the tensile strength ratio (TSR), was used to predict stripping susceptibility. The Virginia Department of Transportation normally specifies a minimum value of 0.85; however, 0.90 was specified for glasphalt field test sections in order to ascertain superior stripping resistance.

## Materials

The mix design gradations and asphalt contents are listed in Table 2. The sources and amounts of component materials are listed in Table 3 and Table 4. The glass cullet, which was obtained from Metro Recycling, had a 9.5 mm top size. An attempt was made to maintain constant natural sand content along with a constant gradation to prevent those factors from influencing the stripping results.

**Table 2. Glasphalt Mix Designs - Percent passing**

| Sieve, mm | Mix 1 - S. L. Williamson Co. Least stripping susceptible | | | | Mix 2 - MEGA Contractors Most stripping susceptible | | | |
|---|---|---|---|---|---|---|---|---|
| 19.0 | 100 | | | | 100 | | | |
| 12.5 | 100 | | | | 98 | | | |
| 9.5 | 93 | | | | 87 | | | |
| 4.75 | 60 | | | | 62 | | | |
| 2.36 | 42 | | | | 45 | | | |
| 1.18 | 28 | | | | 32 | | | |
| 0.60 | 20 | | | | 22 | | | |
| 0.30 | 14 | | | | 12 | | | |
| 0.15 | 9.0 | | | | 7.5 | | | |
| 0.075 | 5.5 | | | | 5.5 | | | |
| | | | | | | | | |
| Percent Glass | 0 | 5 | 12 | 20 | 0 | 5 | 12 | 20 |
| Percent AC | 4.75 | 5.0 | 4.9 | 4.8 | 5.7 | 5.7 | 6.0 | 5.9 |

**Table 3. Sources and Percentages of Materials for Mix 1**

| Material | Source | Percentage | | | |
|---|---|---|---|---|---|
| #8's | Luckstone, Shadwell, Va. | 50 | 47 | 42 | 38 |
| #10's | Luckstone, Shadwell, Va. | 20 | 23 | 21 | 16 |
| Mfg sand | Luckstone, Shadwell, Va. | 15 | 15 | 15 | 15 |
| Nat sand | Luckstone, Shadwell, Va. | 15 | 10 | 10 | 10 |
| Glass | Metro Recycling, Fairfax, Va. | 0 | 5 | 12 | 20 |

**Table 4. Sources and Percentages of Materials for Mix 2**

| Material | Source | Percentage | | | |
|---|---|---|---|---|---|
| #8's | Luckstone, Rockville, Va. | 62 | 61 | 58 | 55 |
| #10's | Luckstone, Rockville, Va. | 23 | 19 | 15 | 10 |
| Nat sand | Luckstone, Rockville, Va. | 15 | 15 | 15 | 15 |
| Glass | Metro Recycling, Fairfax, Va. | 0 | 5 | 12 | 20 |

## TEST RESULTS

Stripping test results are presented separately for the two mixes.

### Mix 1

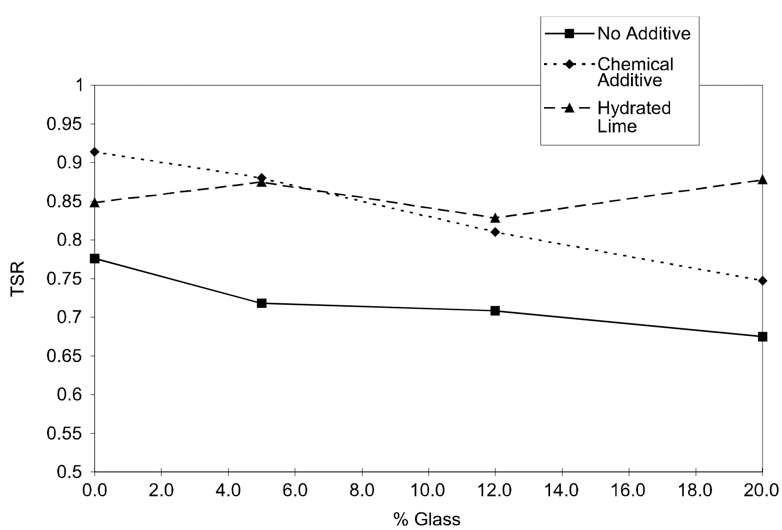
Table 5 lists the individual test results for Mix 1. An earlier study indicated that typical within-lab standard deviation for TSR was approximately 0.035.[11] Therefore, the acceptable range for two test results should be within (2.8)(0.035) = 0.10.[12] According to this criterion, all of the duplicate test results appear to be within this range and therefore are reasonable.

**Table 5. Individual TSR Test Results for Mix 1**

| Percent Glass | No Additive | | Chemical Additive | | Hydrated Lime | |
|---|---|---|---|---|---|---|
| | Test #1 | Test #2 | Test #1 | Test #2 | Test #1 | Test #2 |
| 0 | 0.73 | 0.82 | 0.90 | 0.93 | 0.86 | 0.83 |
| 5 | 0.70 | 0.73 | 0.88 | 0.88 | 0.85 | 0.90 |
| 12 | 0.74 | 0.67 | 0.84 | 0.78 | 0.82 | 0.84 |
| 20 | 0.70 | 0.65 | 0.75 | 0.75 | 0.88 | 0.88 |

When viewed in graphical form, it is seen that in the mix with no additive and the mix with chemical additive, the average TSR results generally declined as the percentage of glass was increased (see Figure 1).

**Figure 1. Average TRS Results of Mix 1**



The mix with hydrated lime indicated no significant change as the percentage of glass was increased. Figure 2 shows the effect of the amount of glass on the average dry strength. The average dry strength decreased at 5 percent glass and then remained constant as the amount of glass was increased up to 20 percent. The average wet strength showed a gradual decrease as the amount of glass was increased up to 12 percent. However, the strength of the mix with hydrated lime appeared to increase at 20 percent glass, whereas the mixes with no additive and chemical additive continued the downward trend (see Figure 3).

**Figure 2. Average Dry Strengths of Mix 1**

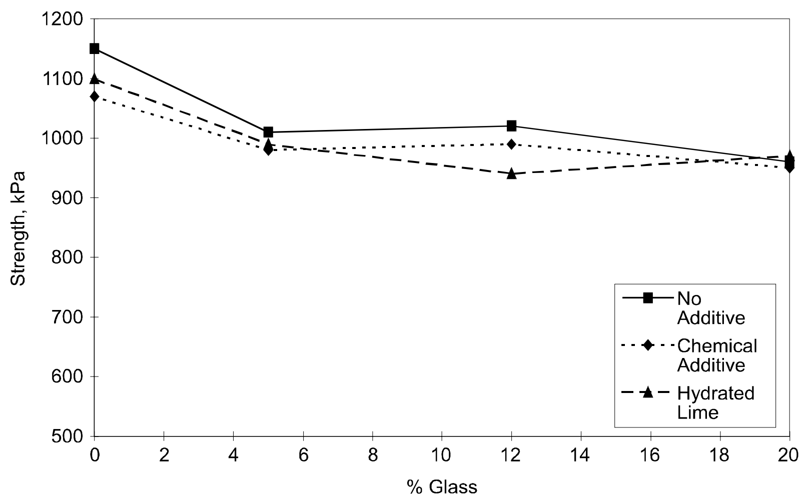
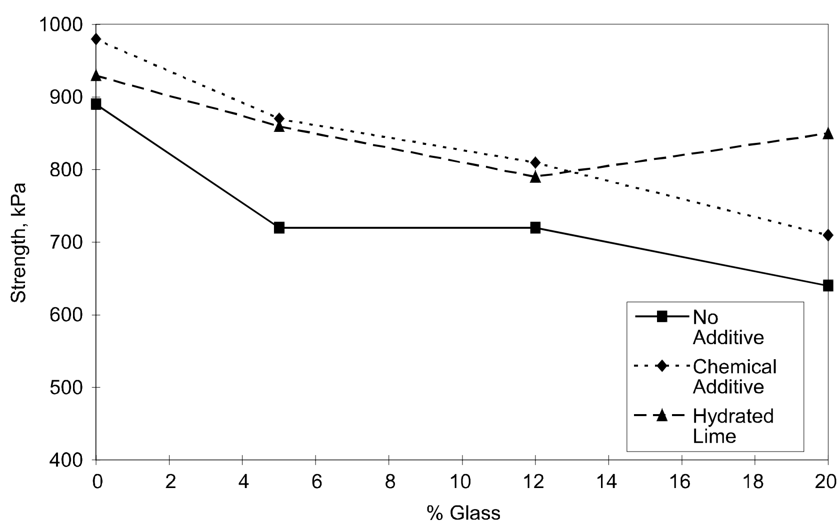



**Figure 3. Average Wet Strengths of Mix 1**




The t-test with an alpha risk of 0.05 indicated that the difference between the average wet strengths of the mix with hydrated lime and the average wet strengths of the mix with chemical additive was significant only at 20 percent glass content. The reason for the divergence of wet strengths at the high percentage of glass is unknown. The difference between average wet strengths of the mixes with no additive and chemical additive was also significant.

## Mix 2

Table 6 lists the individual stripping results for Mix 2 and Figures 4-6 show trends for TSR, dry strength, and wet strength. One set of tests, the mix with 12 percent glass containing chemical additive, was suspected of having a faulty value because the range of the duplicate tests is large. Both tests were used to plot the results and the plot appears reasonable. The other tests also appear to be reasonable.

**Table 6. Individual TSR Test Results for Mix 2**

| Percent Glass | No Additive | | Chemical Additive | | Hydrated Lime | |
|---|---|---|---|---|---|---|
| | Test #1 | Test #2 | Test #1 | Test #2 | Test #1 | Test #2 |
| 0 | 0.67 | 0.78 | 0.87 | 0.84 | 0.83 | 0.93 |
| 5 | 0.79 | 0.73 | 0.84 | 0.93 | 0.85 | 0.86 |
| 12 | 0.75 | 0.67 | 0.75 | 0.96 | 0.88 | 0.80 |
| 20 | 0.72 | 0.71 | 0.84 | 0.77 | 0.85 | 0.88 |

**Figure 4. Average TSR Results of Mix 2**

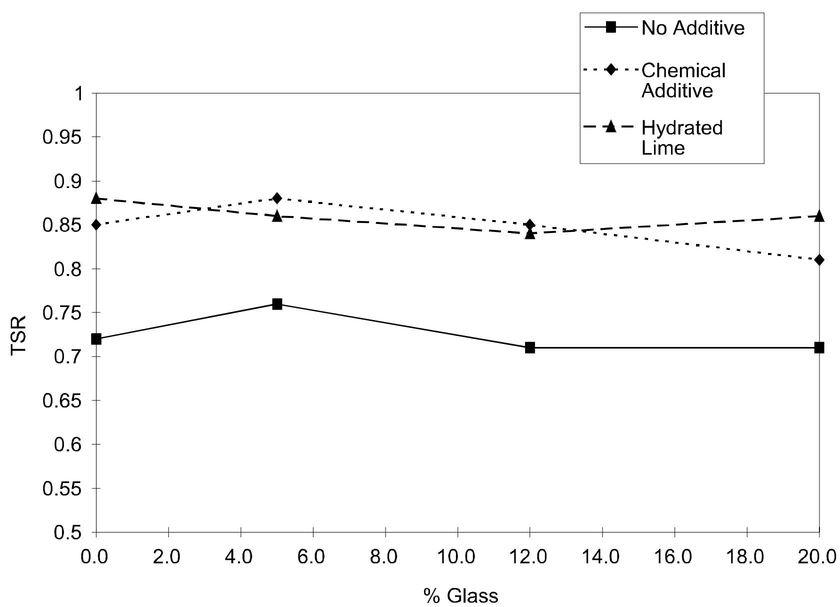


**Figure 5. Average Dry Strengths of Mix 2**

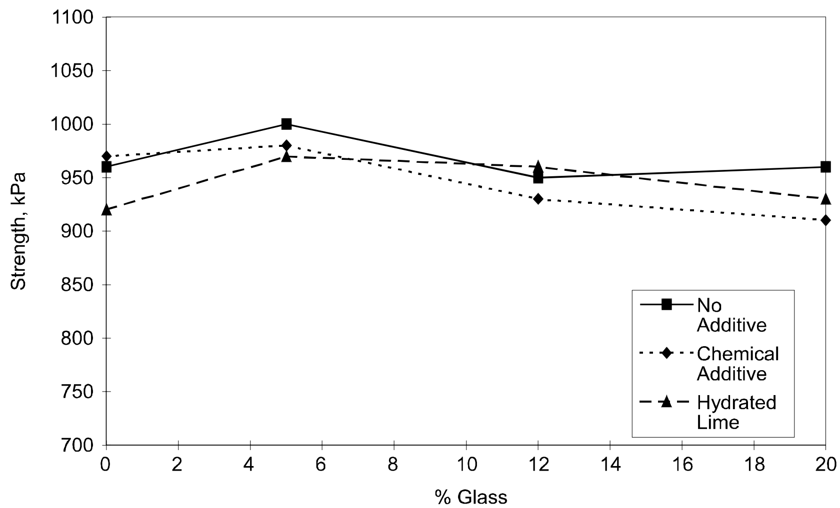
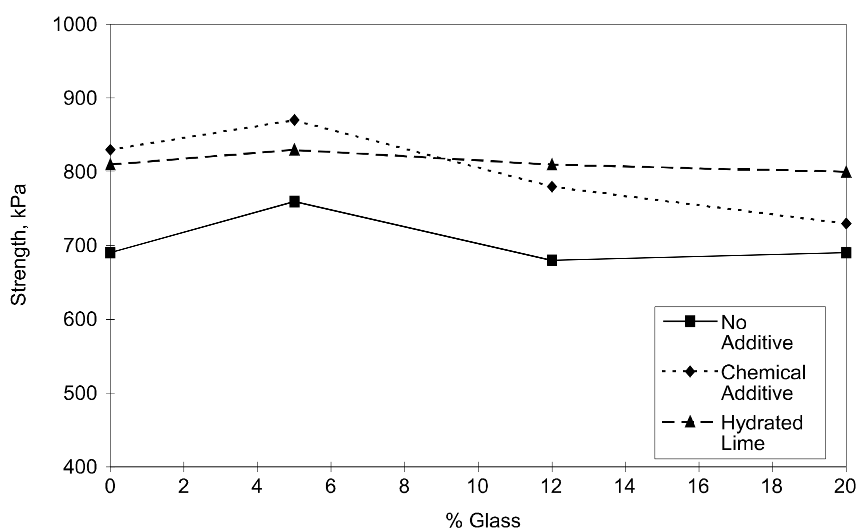



**Figure 6. Average Wet Strengths of Mix 2**




The mixes with both chemical and lime additives produced average TSRs that were approximately 0.15 higher than that of the mix with no additive at all concentrations of glass. The mix with hydrated lime showed the least change of TSR as the concentration of glass changed, which also occurred with Mix 1. This result indicates that the hydrated lime could be more consistent in maintaining a certain level of stripping resistance. Although there were no detectable differences between the average wet strengths of the two mixes with additives at 5 and 12 percent glass, there was a significant difference at 20 percent glass. The average wet tensile strength of the mix with hydrated lime was significantly higher than that of both the mix with no additive and the mix with chemical additive.

## DISCUSSION

The results of this study only apply to the specific gradation of glass and type of mixes that were used. Other gradations of glass or types of mixes may produce different results.

Although previous preliminary stripping tests indicated that Mix 2 was more susceptible to stripping than Mix 1, there was no practical difference between the TSRs of the untreated mixes tested in this study. Both mixes with no additive produced TSRs in the 0.7 to 0.8 range. It was anticipated that additives would raise the TSR, which did occur. Both mixes containing no glass but with additives produced TSRs of approximately 0.85 or above.

If 0.85 is considered acceptable, then Mix 2 with chemical additive and 20 percent glass failed. Also, Mix 1 with chemical additive was borderline at high percentages of glass. It appears that mixes containing 10-15 percent glass would be capable of meeting the TSR criterion with the types of additives used in this laboratory study.

The true effect of glass can be observed from the results of the TSR tests on the mixes with no additives. Mix 1 showed a slight decrease of TSR as the percentage of glass was increased. However, Mix 2 did not exhibit the same downward trend. Probably, glass contributed more to strength development in Mix 1 than to the strength development in Mix 2.

At 20 percent glass, the average wet strength of the Mix containing chemical additive was significantly lower than the average wet strength of the mix with hydrated lime for Mix 1 and Mix 2. At the lower glass contents, the average wet strengths of the mixes were not different. It would be preferable to be able to use any type of additives with glasphalt; therefore using less than 20 percent glass seems to meet this goal.

## CONCLUSIONS

The conclusion in this study was based on the assumption that the TSR test is a reliable predictor of field stripping. Because of the extremely smooth surface of glass particles, the author expected the addition of glass to have a more profound effect on stripping than was observed with the two mixes tested. The TSR test did not indicate a significant negative effect when adding up to 12 percent glass. At 20 percent glass, there was a significant difference between the effect of chemical and hydrated lime additives. It appears that the accepted level of 15 percent allowable glass is generally correct and should be used for the coarse type of aggregate used in this study. The maximum allowable percentage may be different for other types of mixes and particularly for other gradations of glass.

## RECOMMENDATION

Based upon the results of the TSR stripping test as a performance indicator, it is recommended that the standard specifying a maximum allowable glass content of 15 percent in asphalt concrete be continued.

## ACKNOWLEDGEMENTS

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