Exploring waste glass in hot-mix asphalt

South Africa faces a potential shortage of the virgin aggregates used to produce asphalt mixes. As such, manufacturers are turning to alternatives – one of which is glass.

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GIVEN THE SHORTAGE, the future availability and sustainability of virgin aggregates is a major concern. In addition to protecting non-renewable aggregate resources, the use of alternative materials can significantly reduce the high energy usage and greenhouse gas emissions associated with pavement applications.

Glass was initially implemented in asphalt pavements in the early 1960s and 1970s in the United States and Canada but there have been few investigations into the application of waste glass in the field of pavement.

The CSIR undertook a study on the potential utilisation of crushed glass as a substitute to natural aggregate in asphalt mixes to determine the performance characteristics of hot-mix asphalt produced with crushed glass material.

Research to date

Recent studies have demonstrated that optimum performance can best be achieved when 10% to 15% crushed glass is used as a fine aggregate substitute in asphalt mixes for road pavements. The major concern is the lack of absorption of bitumen by glass and the hydrophilic properties of glass that contribute to the moisture damage of glass-asphalt (GA) pavements.

An initial study conducted by the authors focused on developing a mix design for glass asphalt. The mix design results indicated that the optimum binder content of the medium continuously graded asphalt mix with crushed glass is 5.1% compared with 5.0% for a standard medium continuously graded asphalt mix that was used in this paper.

The results are analysed and compared to the SANRAL medium continuously graded asphalt (dense graded wearing course) mix with 50/70 penetration grade binder. In order to carry out a comparative study on the two mixes, the 50/70 binder used in the reference asphalt mix was used to prepare the glass asphalt mix. The aggregate grading of the glass asphalt mix was made the same as the reference mix.

Creating the right mix

Standard aggregate property tests were conducted on the individual aggregates and the crushed glass used in the mix in accordance with SANS 3001 and the American Standards for Testing and Materials (ASTM).

The grading analysis conducted on the individual aggregate fractions formed the basis for selecting the substitute material in the reference mix for the crushed glass. The goal was to use the same aggregate type from the same sources as the reference mix.

The intension was to make grading for the crushed glass mix similar to the reference mix in terms of particle size distribution. Note that during the optimisation, the granite crusher sand was partially substituted by 15% of the crushed glass. It is known that 1% to 3% of hydrated lime could act as an anti-stripping agent to reduce potential stripping problems in asphalt mixes with glass. Accordingly, to achieve the desired

TABLE 1 Properties of the 50/70 penetration grade bitumen

Property	Units	Results	Limits (minutes)	Test method
Penetration @ 25°C/100 g/5 sec	0.1 mm	66	50 - 70	ASTM D5
Softening point (ring and ball)	°C	50	46 - 56	ASTM D36
Viscosity @ 60°C	Pa.s	261	120	ASTM D4402
Viscosity @ 135°C	mPa.s	469	220 - 500	ASTM D4402
Flash point (open cup) @101.3 kPa	°C	340	230	ASTM D92
Penetration @ 25°C/100 g/5 sec	% xylene	25	30	AASHTO T102

TABLE 2 Aggregate properties and proportions for the mixes

Nominal size (mm)	Aggregate Type	Bulk Relative Density	App. Relative Density	Absorption	Fine Aggregate Angularity	Aggregate Proportions	
						Reference Mix	Glass Asphalt Mix
9.5	Andesite	2.884	2.919	0.4	N/A	21%	31%
6.7	Andesite	2.887	2.928	0.5	N/A	24%	16%
Crusher dust	Andesite	2.816	2.956	1.7	39.7	25%	18%
Crusher sand	Granite	2.628	2.676	0.7	38.3	26%	10%
Mine sand	Mine sand	2.600	2.634	0.5	48.3	3%	7%
Crushed glass	Glass	2.489	2.519	0.5	51.3	--	15%
Mineral filler	Hydrated lime	2.861	--	N/A	N/A	1%	3%

bonding effect between the crushed glass and the binder, 3% hydrated lime was chosen to replace 1% of the plant lime in the reference mix.

Preparation for testing

In preparation for testing, the binder was added to the blended aggregates and then poured into a heated mixer and the filler was added to the mixture, before being mixed for 10 minutes and then discharged back into the pans. This mixture was then placed back into the oven, set at compaction temperature for four hours to induce short-term ageing to simulate the ageing that takes place during production in an asphalt plant and transportation to site.

The loose asphalt mixes were compacted to slabs (for beam specimens) and gyratory specimens (for cylindrical specimens) to a density of between 93% and 95% of maximum theoretical relative density. The gyratory specimens were used for rutting and dynamic modulus testing, while the compacted slabs were used for fatigue testing. All the samples were compacted to the voids necessary to obtain the target design voids for testing.

Evaluation of stiffness

Dynamic modulus testing was conducted in a Universal Testing Machine (UTM-25) on three duplicate specimens for each mix. A haversine load pulse with no rest period was applied to the prepared gyratory compacted samples at five test temperatures

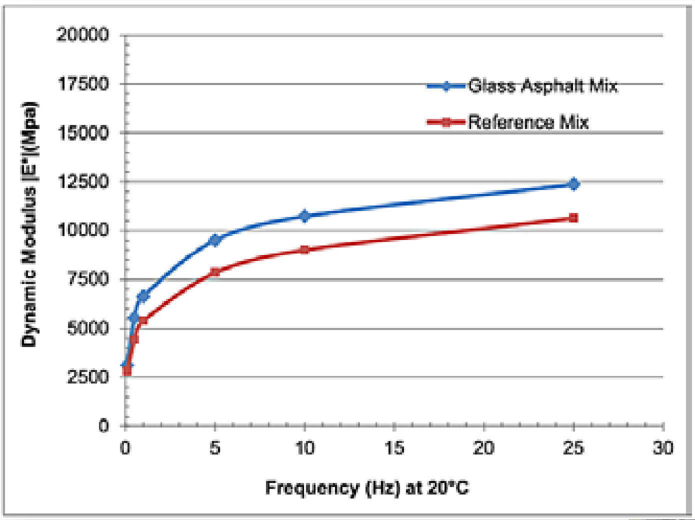

FIGURE 1 Dynamic modulus results for mixes at 10 Hz and 20°C

of -5, 5, 20, 40, and 55°C, and six loading frequencies of 25, 10, 5, 1, 0.5, and 0.1 Hz. A total of 30 tests were conducted on each mix to complete a full factorial dynamic modulus test matrix.

The specimen's vertical deformation was determined by averaging the readings of three axial linear variable displacement transducers. The axial stresses and the corresponding axial strains recorded for the last 10 load cycles for each test are normally used to compute the dynamic modulus of the sample.

Figure 1 compares the results of the two mixes at 10 Hz and 20°C. It is believed that these two conditions best simulate field pavement conditions. At these conditions, the dynamic modulus of the GA mix increase by 25% from the reference mix.

The GA mix contains 3% hydrated lime which acts as an anti-stripping agent, resulting in stronger cohesion between the aggregates and glass particles with the bitumen. Furthermore, the higher angularity of the glass particles, in comparison with the conventional aggregates, plays an important role in the increased dynamic modulus behaviour of the GA mix. It is suspected that the higher internal friction – due to the increased angularity of the glass particles – increases the interlock between the particles, which contributes to the increased dynamic modulus of the GA mix. It can be further observed that at temperatures of 20°C and 40°C, the stiffness of the GA was marginally higher than the reference mix, whereas the stiffness was comparable at temperatures of -5°C and 55°C.

Permanent deformation

Permanent deformation of the mixes was evaluated using the flow number test. The asphalt mixture performance tester (AMPT) test procedure stipulated in AASHTO TP79 was used to determine and compare the flow number of the mixes for the glass-asphalt mix and the reference mix. Three duplicate specimens per mix were tested at the temperature of 50°C – two deviatoric stress levels of 483 kPa and 276 kPa, and one confining pressure of 69 kPa – using a repeated compressive haversine loading (one cycle with 0.1 s loading time and 0.9 s resting time). During testing, cumulative permanent axial deformations

IPC Servopac Gyratory Compactor for sample preparation

TABLE 3 Design aggregates for the mixes

Sieve size (mm)	Equivalent SANS 3001-AG1 sieve sizes	Design grading (% passing)		Grading specification	
		Reference mix	Glass asphalt	Min (%)	Max (%)
19	20	100	100	100	100
13.2	14	100	100	100	100
9.5	10	97	97	82	100
6.7	7.1	75	75	66	87
4.75	5	59	59	54	75
2.36	2	42	42	35	50
1.18	1	30	29	27	42
0.6	0.6	21	21	18	32
0.3	0.3	14	15	11	23
0.15	0.15	9	9	7	16
0.075	0.075	5.8	6.0	4	10

were measured and used to calculate the flow number.

The results indicate that the GA mix has a higher flow number than the reference mix, implying that it has a lower susceptibility to rutting in comparison with the reference mix at 276 kPa and 483 kPa at the test temperature of 50°C.

The crushed glass used in this mix has a higher fine aggregate angularity (51.3%) than the natural fine aggregates. Accordingly, it is expected that the crushed glass would have higher internal friction as a result of the increased angularity. This will, in turn, increase the interlock between the particles and contribute to the increased resistance to permanent deformation of the GA mix.

Evaluation of fatigue performance

The four-point beam fatigue test is recommended in South Africa to evaluate fatigue cracking in the laboratory. Fatigue tests were conducted on beam specimens under controlled strain loading conditions at three strain amplitude levels of 200, 400 and 600 macrostrains at a frequency of 10 Hz and a temperature of 20°C to compare fatigue life of the two mixes. The test was run to 50% reduction in stiffness, which is defined as the failure criteria. Three duplicate specimens of each mix were tested under a continuous sinusoidal load at the design voids and design binder content.

The two mixes were found to have similar resistance to fatigue cracking at the higher strain levels. However, at low strain levels, there are relatively large differences in terms of the fatigue life of the two mixes. At a test temperature of 20°C and a frequency of 10 Hz, the fatigue life of the GA mix reduces by 50% at 200 microstrains when compared to the reference mix. This is expected, as the stiffness of the GA mix was higher than the reference mix by about 25%. For instance, this percentage increase in the stiffness of the GA mix results in the fatigue life being reduced by almost half at strain levels less than 300 microstrains.

Conclusions

Based on the results presented in this study, the following conclusions are made:

1. There is potential to substitute depleting natural aggregates with crushed glass in asphalt mixes. This is based on the finding that asphalt mixes with crushed glass could outperform a conventional dense-graded mix in terms of rutting and has comparable fatigue resistance at low strains.
2. The higher stiffness behaviour exhibited by the glass mix at 20°C and 40°C confirms that this mix is more likely to provide better resistance to permanent deformation than most conventional medium continuously graded asphalt mixes.

It is important to note that these conclusions pertain only to the crushed glass evaluated in this study and the specified design aggregate grading used, and cannot be transferred to any other crushed glass from different source. Moreover, these conclusions are based only on the properties of the mixes as determined in the laboratory. 3S

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