DESIGN AND PROPERTIES OF HOT MIXTURE POROUS ASPHALT FOR SEMI-FLEXIBLE PAVEMENT APPLICATIONS

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Abstract
Semi-flexible pavement consists of selected porous asphalt mixture filled with cementitious slurry. This new type of pavement has prospects to be designed as a high deformation resistant pavement (Setyawan et al, 2001). Porous asphalt, as the skeleton of the composite has been de-signed to have a porosity of 30% by selected the aggregates gradation, type of bitumen, bitumen content and fibre content. This investigation concerned with the design and properties of porous asphalt to be used as the skeleton for grouted macadam. The ranges of mixtures were evalu-ated by using different type of bitumen, bitumen content, filler addition and aggregate gradation. This investigation concluded that porous as-phalt manufactured by using specified gradation utilising 50-pen bitu-men is appropriate to be used as skeleton for grouted macadam.

Keywords:
cellulose filler, grouted macadam, polymer modified, porous asphalt, semi-flexible pavement.

LITERATURE REVIEW

Even though this type of pavement has already been constructed in 1960's, there is a lack of guidance available for designing the porous asphalt for semi-flexible pavement. The first recommendations for porous asphalt skeleton gradations were presented in the report of *Salviacim* process evaluation conducted at WES for the U.S. Army (Rone 1976, Anderton 2000). The recommended gradation resulted in a porous asphalt skeleton with air voids content in the range of 15% to 25%, which is generally 10% less than the air voids recommended for current gradations. The lower air voids was believed to be the major reason for test section failures since the cementitious grouts failed to fully penetrate the porous asphalt skeleton.

Further guidance was authored by Roffe in two marketing publications for Jean Lafebvre Enterprises (Roffe 1989a & Roffe 1989b), which offered general description of the *Salviacim* process. These publications contained fundamental mix design guidance, such as recommended open graded aggregate gradations for asphalt mixtures and grout formulations, but offered limited information on thickness design and engineering properties. The guidance recommended the use of even more open aggregate grading, resulting in air void contents in the range of 25% to 35%.

POROUS ASPHALT MIXTURE DESIGN AND PROPERTIES

The design of aggregate gradations

The porous asphalt aggregate gradations used in this investigation were based on a non-standard UK gradation adopted in Blackwater Valley Route project (Child 1998). The original gradation used in this investigation was gradation A, whilst the modified gradations B and C were investigated to assess the effects of increasing the proportion of finer aggregate fractions on the properties of the mixture. The porous asphalt gradations are presented in Table 1 and in Figure 1.

Compared to gradation A, gradation B contained 3% more of aggregate size B (10-6mm), 7% more of aggregate size D (4.75-2.36mm) whilst omitting aggregates size A (14-10mm) and maintaining the proportion of aggregate size C (6.3-4.75mm).

Table 1. Aggregate sizes and gradations.

Bin designation	*Size (mm)*	*Gradation A %*	*Gradation B %*	*Gradation C %*
A	14-10	10	0	0
B	10-6	52	55	45
C	6.3-4.75	30	30	30
D	4.75-2.36	3	10	20
E	2.36-0.075	2	2	2
F	<0.075	3	3	3

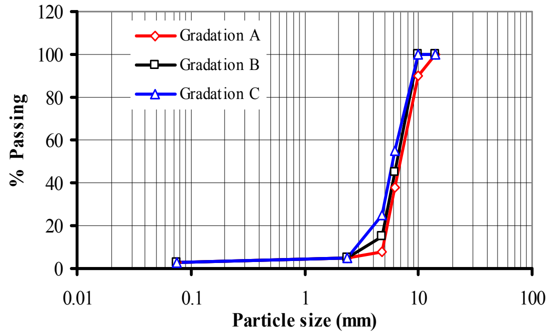

Figure 1. Porous asphalt aggregate gradations.

Gradation C utilised an even finer gradation. Compared to gradation A, it incorporated 7 % less of aggregate size B (10-6mm), 17% more aggregate size D (4.75-2.36mm) whilst omitting aggregate size A (14-10mm).

Three types of porous asphalt mixtures were produced utilising gradations A, B and C and their mix compositions are shown in Table 2.

Table 2. Initial porous asphalt mix compositions.

Mixture Code	Type of bitumen	Gradation	Bitumen Content
7SBSAL5	7%SBS	A	5%
7SBSBL5	7%SBS	B	5%
7SBSCL5	7%SBS	C	5%

The compacted mixtures were then characterised according their volumetric properties and water permeability. The results, are presented in Table 3, each value in the table was an average result from four test specimens.

Table 3. Properties of porous asphalts made with different aggregates gradations.

Specimens code	Density (g/cm^3)	Specific Gravity	Porosity (%)	Water Permeability 10^{-3} (m/s)
7SBSAL5	1.83	2.46	25.57	1.34
7SBSBL5	1.85	2.46	24.85	1.11
7SBSCL5	1.87	2.46	23.78	0.94

The essential characteristics of the porous asphalts selected were porosity and water permeability. Mixture porosity is related to water permeability but it is not the only controlling factor. The pore size and hence interconnectivity of these voids is what dictates the magnitude of hydraulic conductivity. A larger value of water permeability would imply a mix that is easier to impregnate with cementitious grout.

From the results in Table 3, it could be seen that the porous asphalt gradations B and C have about 1% and 3% lower porosities respectively compared to gradation A.

However gradation A has approximately 30% and 60% higher permeability value compared to gradations B and C respectively. For the remainder of the investigation, gradation A was thus adopted as the primary gradation for designing porous asphalt skeletons.

The selection of optimum bitumen contents and bitumen types

Theoretically, when designing hot mix porous asphalts, the optimum bitumen content can be calculated using an empirical equation based on previously determined aggregate properties (Roffee 1989) as follows:

$OBC = 3.25\ (\alpha)\ \Sigma^{0.2}$……………………..[1]

$\alpha = 2.65/SG_{agg}$

$\Sigma = 0.21C + 5.4S + 7.2s + 135f$

where: OBC = optimum bitumen content, SG_{agg} = apparent specific gravity of aggregate blend, Σ = specific surface area, C = percentage of material retained on 4.75mm sieve,

S = percentage of material passing 4.75mm sieve and retained on 600μm sieve,

s = percentage of material passing 600μm sieve and retained on 75μm sieve,

f = percentage of material passing 75μm sieve.

Substituting the appropriate gradation and properties of the selected aggregates, the Optimum Bitumen Content (OBC) was calculated as 4.2% by mass of the combined aggregates. For practical considerations, the three bitumen contents selected for the remainder of the investigation were 4.0%, 4.5% and 5.0%.

Three bitumen types were also incorporated in producing porous asphalt skeletons; 100 pen straight run bitumen, 50pen straight run bitumen and 7% SBS (Styrene butadiene Styrene) Modified bitumen. The proposed mix designs are presented in Table 4.

Table 4. Porous asphalt mixture compositions.

Mixture code	Bitumen types	Aggregates types	Gradation	Bitumen content
100AL4	100 pen	Limestone	A	4.0%
100AL4.5	100 pen	Limestone	A	4.5%
100AL5	100 pen	Limestone	A	5.0%
50AL4	50 pen	Limestone	A	4.0%
50AL4.5	50 pen	Limestone	A	4.5%
50AL5	50 pen	Limestone	A	5.0%
7SBSAL4	7% SBS	Limestone	A	4.0%
7SBSAL4.5	7% SBS	Limestone	A	4.5%
7SBSAL5	7% SBS	Limestone	A	5.0%

The mixtures were characterised according their volumetric properties and water permeability, the results are presented in Table 5.

Table 5. Properties of porous asphalt skeletons at different bitumen types and contents.

Mixture Code	Density (g/cm^3)	Specific Gravity	Porosity (%)	Water Permeability 10^{-3} (m/s)
100AL4	1.81	2.50	27.74	1.55
100AL4.5	1.80	2.48	27.51	1.48
100AL5	1.79	2.46	27.45	1.45
50AL4	1.82	2.51	27.44	1.57
50AL4.5	1.82	2.49	26.99	1.25
50AL5	1.83	2.47	25.94	1.22
7SBSAL4	1.82	2.50	27.20	1.61
7SBSAL4.5	1.82	2.48	26.53	1.47
7SBSAL5	1.83	2.46	25.57	1.34

The result clearly shows that for all types of porous asphalt mixtures, increasing the bitumen content had resulted in a reduction in the measured porosity and hence water permeability. It was also observed that at bitumen contents higher than 4%, binder drainage was evident for all the bitumen types used. For the remainder of this investigation, 4% bitumen content was selected as the optimum bitumen content (OBC) for producing porous asphalt skeletons.

The addition of loose cellulose fibres into the hot-mix porous asphalt mixes was also investigated. Two types of specimens were produced incorporating 50pen. and 100pen. bitumen as presented in Table 6. The fibres are added to allow the use of more bitumen, whilst reducing the risk of binder drainage during hot mix storage and transportation (Woodside et al 1997a).

The volumetric properties and water permeability of all the porous asphalt types investigated at optimum bitumen content are presented in Table 7 and the mechanical properties are presented in Table 8.

The average bulk densities of the compacted porous asphalt specimens, manufactured with different binders reflected no significant differences as shown in Table 7. The porosity of the compacted samples is also shown in Table 7 and the range of porosity values were all within the expected range of 27 to 30%.

Table 6. Porous asphalt mixtures to evaluate the effect of additional cellulose fibre.

Mix Code	Type of bitumen	Gradation	Aggregates Type	Bitumen Content	% Fibre
100AL4f	100pen	A	Limestone	5%	0.3
50AL4f	50pen	A	Limestone	4.36%	0.3

Table 7. Properties of porous asphalt at optimum bitumen content.

Mix Code	Density (g/cm^3)	Specific Gravity	Porosity (%)	Water Permeability 10^{-3} (m/s)
100AL4	1.81	2.50	27.74	1.55
50AL4	1.82	2.51	27.44	1.57
7SBSAL4	1.80	2.50	27.20	1.61
100AL4f	1.80	2.49	27.68	1.44
50AL4f	1.81	2.49	27.11	1.52

Table 8. Mechanical properties of porous asphalt mixtures at optimum bitumen contents.

Mix Code	ITSM (MPa)	ITS (kPa)	Unconfined Comp. Strength (kPa)	Cantabro loss (%)
100AL4	548.68	125.26	760.64	34.3
50AL4	953.71	259.65	1691.59	18.7
7SBSAL4	331.44	155.82	906.56	10.1
100AL4f	926.37	138.78	840.96	67.2
50AL4f	1063.42	267.70	1687.64	41.7

In this investigation, water permeability was the most important property since it indicated the ease and extent to which the cementitious grout can penetrate the interconnected voids of the porous asphalt skeleton. All the porous asphalt skeletons showed quite similar water permeability in the range of 1.44×10^{-3} m/s to 1.61×10^{-3} m/s. The usual range of porous asphalt permeability values is between 0.5×10^{-3} m/s to 3.5×10^{-3} m/s (CEN 1998). The permeability values obtained from this investigation were close to the mid-point of the range. Incorporation of cellulose fibres into the 100-pen and 50-pen porous asphalts slightly lowered the mixture permeability.

The results of modulus and strength properties as shown in Table 8 indicate that the type of binder used in a porous asphalt mixture has a significant influence on its properties. The 50-pen fibre reinforced bituminous mixture gave the highest values of tensile strength as well as stiffness modulus followed by the straight run 50-pen bituminous mixture. The SBS modified bituminous mixture exhibited the lowest stiffness value.

The results of the Cantabro test as shown in Table 8 indicated that 7% SBS Polymer modified porous asphalt, with its enhanced elastic properties, provided excellent resistance to disintegration with an average abrasion loss value of 10.1% followed by 50-pen porous asphalt with average abrasion loss value of 18.7%. The 100pen mixture produced unacceptably high values of disintegration. Therefore a 100pen mixture may not be suitable for trafficking prior to filling with the cementitious grout. The lower abrasion loss value of SBS modified bituminous mix could be attributed to the improved cohesion in the compacted mixture. In another investigation, the use of 7% SBS modified binder reduced the abrasion loss of porous asphalts by approximately half compared to the straight run bitumen (Zoorob et al 1999).

The results in this investigation showed that the introduction of loose cellulose fibres lowered the abrasion resistance capabilities of 100-pen and 50-pen mixtures. The reason for this increase in Cantabro loss was not clear. One possibility is that the fibres absorbed some of the binder thus reducing the binder film thickness, although this was anticipated in the mix design and was offset to some extent by the increased bitumen content of the fibre mixtures as shown in Table 6. It is also possible that the fibre modified binders were less workable at the same mixing and compaction temperatures. This would have generated mixtures with greater, and thus weaker binder film thicknesses at the aggregate to aggregate contact points. Research conducted at Ulster University to investigate the effect of fibre types as modifiers in Stone Mastic Asphalts concluded that the addition of loose fibres lowered the ability of the mixtures to withstand the Cantabro test and may have resulted in durability problems (Woodside et al 1997b).

The recommended maximum allowable value of abrasion loss is 20% (Khalid & Perez-Jimenez 1996), therefore, in this investigation 7% SBS modified mix and 50-pen mix could be classified as mixtures suitable for porous asphalt surfacings. For the remainder of the investigation only 50-pen bituminous mixture was selected as skeleton for semi-flexible, grouted macadam. Figure 1 shows the hot mix hot laid porous asphalt ready for grouting process during the full scale trial after 24 hours of compaction.

Figure 2. Cementitious slurry grouting on the hot mix hot laid porous asphalt.

CONCLUSION

1. Selecting the porous asphalt gradation was mainly controlled by the need to provide adequate porosity and void interconnectivity to facilitate rapid impregnation with highly flowable cementitious grouts. The use of finer aggregate gradations indicated slightly lower porosities but accompanied by much lower water permeability. It was clear that mixture porosity is related to water permeability but was not the only controlling factor. The pore size and hence the interconnectivity of these voids dictated the magnitude of hydraulic conductivity.
2. The mechanical properties of the porous asphalt skeleton were crucial factors during the process of selecting the optimum bitumen content and bitumen type. It was decided early on the investigation that the porous asphalt skeleton should be designed to withstand limited site traffic as would be expected during the construction phase. The optimum bitumen content and bitumen type for the porous asphalt skeleton were thus selected based on a range of mix performance parameters including: hydraulic conductivity, indirect tensile strength, indirect tensile stiffness modulus, unconfined compressive strength and resistance to abrasion tests. A 14mm maximum aggregate size porous asphalt skeleton was finally adopted which having a design aggregate gradation with 4% bitumen content using a 50-pen grade straight run bitumen.

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