A CRITICAL APPRAISAL ON THE PERFORMANCE OF POROUS ASPHALT

Prof. A.R. Woodside, Dr W.D.H. Woodward, J.K. Baird
Highway Engineering Research Centre, School of the Built Environment,
University of Ulster.
P. Phillips
Bardon Roadstone

1. Introduction

Pervious or porous surfacing materials were initially developed in the United Kingdom in the 1950's. However, it was not until recently that Porous Asphalt, (formerly known as Pervious Macadam or Friction Course) has been used to any significant degree on British highways. This has not been the case on mainland Europe where, over the past 5 to 10 years, the use of Porous Asphalt (PA) has expanded dramatically in countries such as France, Belgium, Holland, Austria and Switzerland to name just a few (1).

Pervious Macadam was developed in the 1950's as a 10mm open textured bitumen macadam to overcome problems of aqua-planing and skidding on aircraft runways. This led to the development of the material for road pavement use. However, apparent conservatism on behalf of the Department of Transport hindered it's development for many years. Until recently all PA laid on British roads had been as trial sections. The earliest of these was recorded in May 1967 on the M40 High Wycombe by-pass in Buckinghamshire. A second was laid in September of the same year on the A452 Leamington to Stonebridge road in Warwickshire.

Throughout the 1970's and 1980's trials were undertaken throughout the country with varying levels of success. In 1984 extensive trials were undertaken on the A38 Burton by-pass in Staffordshire as a joint research project by the British Aggregates and Construction Materials Industries (BACMI), Refined Bitumen Association (RBA) and the Transport Research Laboratory (TRL) (2)(3). A wide range of aggregate gradings and binders were tried out on 15 trial sections. The long term performance of these sections ranged from very good to disastrous.

Almost 30 years after the first UK trials of Pervious Macadam, serious interest in PA has started to grow and several county councils, under the guidance of the DTp, have begun to specify PA as a wearing course material for major road projects in England such as the Blackwater Valley Relief Road for Surrey County Council.

2. Advantages and Disadvantages

PA offers safety and environmental advantages over more conventional pavement wearing course materials such as HRA. These include:

- rapid drainage of surface water
- reduction of traffic noise
- reduction of spray and the improvement of skid resistance in wet weather
- reduction of road surface glare from oncoming headlights
- improved fuel consumption due to the smooth ride qualities of the negatively textured surface
- reduction in tyre wear due to reduced rolling resistance.

However, there are some disadvantages. These include:

- reduced pavement strength. This leads to having to provide more support in the structural layers of the pavement. The reduced strength can also limit the application of the material to areas not susceptible to high stresses which could lead to aggregate fretting
- reduced pavement life in comparison with other materials due to the increased likelihood of binder oxidation caused by the voided nature of the material
- possible clogging of pores and drainage paths while under construction and also during the service life of the road
- the need for more salting during winter as snow and frost linger longer on PA
- increased construction costs due to the increased sensitivity of the material to temperature and adverse weather conditions
- increased maintenance costs incurred by many of the above factors and the fact that methods of repairing the pavement would be more complex than with other more traditional materials.

These disadvantages most probably contributed to the caution displayed by the DTp in the early stages of development. They also highlight the major problem encountered when designing PA - the necessity to achieve a balance between the two essential qualities required. These qualities are permeability and durability. The material must exhibit a degree of permeability allowing the free flow of water whilst retaining a durability that permits an acceptable pavement life. This is where laboratory assessment can help in predicting the performance of PA.

3. Aggregate and Binder Assessment

The assessment of PA in the laboratory gives an indication of how the material will perform on site. However, before trials mixes were prepared, a range of different aggregate and bitumen types were assessed to determine their physical, mechanical and rheological properties. The compatibility of aggregate and bitumen pairings was also determined using the Net Adsorption test.

3.1 Aggregate

Aggregate for PA must be of good quality and conform to a high specification. Crushed rock is used as coarse aggregate with crushed rock fines, natural sand or a mixture of both used as fine aggregate. Any aggregate considered for use in PA undergoes rigorous testing in the laboratory to ensure that all criteria specified for a particular design are met. The tests carried out include:

Aggregate Impact (AIV)	(BS 812: Part 112)
Aggregate Crushing (ACV)	(BS 812: Part 110)
Ten Percent Fines (TFV)	(BS 812: Part 111)
Polished Stone Value (PSV)	(BS 812: Part 114)
Aggregate Abrasion (AAV)	(BS 812: Part 113)
Magnesium Sulphate Soundness (MSSV)	(BS 812: Part 121)
Water Adsorption (WA)	(BS 812: Part 107)
Flakiness Index (FI)	(BS 812: Part 105.1)
Micro Deval (MDE)	(CEN)

The main properties required of a coarse aggregate for use in PA are laid out in the Highways Authority Design Manual for Roads and Bridges Volume 7 Section 1 Part ** Porous Asphalt Surfacing Course (4). Listed in Appendix A, these are:

PSV - as specified in design
TFV - not less than 180kN
AAV - maximum 12
FI - maximum 20

These requirements help distinguish between suitable and unsuitable aggregates for PA. Although PSV and AAV are of equal importance regarding long-term pavement life, PSV is often seen as the main property requirement of the aggregate. Sometimes a number of different rocks may be considered for use and show similar qualities, all of which meet specification. A further way of distinguishing between aggregates is then needed. At UUJ this is carried out using the SHRP Net Adsorption Test (5) which is described in paragraph 3.3.

Aggregate grading and shape are also important factors as these can affect both porosity and durability. In general terms, a coarse graded mix will show good porosity but may not have sufficient interlock between the aggregate particles to give adequate durability. Alternatively, a fine graded mix will not drain as well but will be more durable.

3.2 Binder

Various types of binder are used in PA. These cover a range of penetration grade bitumens and modified binders. The use of a particular binder is generally dependent on the site conditions and traffic densities that will be experienced by the pavement.

The durability of PA is improved using soft binders i.e. 100 and 200 pen grade. Trials on the A38 indicated that 200 pen bitumen provided an acceptable service life before excessive hardening of the binder film occurred. However, closing up of the material could occur under heavy traffic. This reduced the permeability. It was found that 100 pen bitumen gave more resistance to closing up and was more suitable to slightly heavier traffic loads. Modified bitumen provided better durability under heavy traffic conditions. Turning traffic in hot weather has led to fretting of the surfacing due to low viscosity and higher temperature susceptibility of the residual bitumens.

Modifiers are used to increase the viscosity of the bitumen. This promotes a thicker binder film on the aggregate which helps to hold the material together more effectively. The increased thickness of the film also helps to reduce the effects of oxidation of the binder. Modifiers commonly used include natural and synthetic rubber, polymers and fibres. As well as maximizing durability, additives such as rubber also give flexibility where needed. Modifiers also change the rheological properties of the binder which can lead to improved behavior at extremes of temperature i.e. greater viscosity at high temperatures to resist fretting and greater elasticity at lower temperatures to resist embrittlement.

Binder content is also an important consideration. The content should be as high as possible to aid durability but not so high as to clog voids in the mix or cause problems such as binder drainage when produced for actual pavement laying. Insufficient binder content leads to reduced durability due to the thinner coating of the aggregate being more prone to hardening.

To aid making the choice of a particular binder, the SHRP Net Adsorption Test is used(as mentioned in paragraph 3.1).

3.3 The Net Adsorption Test

The Net Adsorption Test (NET) was devised by the Strategic Highways Research Programme (SHRP) in the USA. The test gives an indication of the adhesive bond between various aggregates and a particular binder. The NET test is very beneficial when used in the design of PA as different aggregate and binder combinations can be assessed to ascertain the pairing exhibiting the best overall adhesive qualities.

The test consists of crushing samples of aggregate to produce a 50g continuously graded 5mm to dust test sample. A solution of toluene and bitumen is prepared and added to the test samples. After six hours the concentration of the bitumen remaining in solution is determined using a spectrophotometer to give the percentage initial adsorption of the aggregate. Water is then added to the solution and the aggregate/bitumen resistance to stripping is obtained by the determining the increase, if any, in concentration of bitumen in solution. This result gives the percentage net adsorption - an indication of aggregate/binder adhesion in the presence of moisture.

A high percentage initial and high percentage net adsorption would indicate good adhesion between a particular aggregate and bitumen source and vice-versa. As the long term life of a pavement is as important as its initial behavior, combinations of aggregate and binder exhibiting a good percentage net adsorption are most desirable. Such combinations would indicate a favorable pavement life.

4. Permeability and Durability

4.1 Assessing Permeability

The ability of PA to drain surface water is normally assessed using the Relative Hydraulic Conductivity test (RHC). This is carried out using a radial flow falling head permeameter to determine the time taken for two litres of water, under known head conditions, to dissipate through an annular area of surfacing. The reciprocal of the corrected outflow time is used to calculate the RHC of the material. This test is normally carried out on site and would be difficult to carry out in the laboratory. To overcome this, at UUJ, a simple yet effective test has been developed to assess the drainage characteristics of laboratory samples of PA. The test is known as the Saturated Head Permeameter (SHP).

4.1.1 The SHP Test

The apparatus for this test consists of a length of plastic piping with a rubber seal at one end. Attached to the pipe is a thin clear plastic tube which acts as a manometer with a centimetre/millimetre scale. A Marshall mould is placed inside the rubber seal and the device supported using a tripod and retort stand. Water is poured into the pipe until full and the time recorded for the water level to fall 300mm. From this the rate of flow can be worked out in litres per second. As the time taken decreases, the rate of flow through the material increases, therefore indicating an increase in permeability and vice versa. Although this method of testing only measures downward flow of water through the PA and not the lateral movement that would occur in reality, the test has given good indications of how quickly the material will drain.

4.2 Assessing Durability

One of the most frequent causes of failure in open textured mixes like PA is disintegration due to the abrasive action of traffic. This mainly occurs in mixes which lack adequate cohesion. This is one of the most fundamental properties that has to be considered when designing PA. However, as it is difficult to evaluate, it has not been incorporated into any particular design method.

Tests previously used to assess cohesiveness were the Hveem Cohesiometer and the Indirect Traction Test. However, results obtained from these tests by Calzada and Perez served only to show their lack of validity (6). The tests are empirical and were developed to characterize other types of mix and were shown to be unsuitable for open mixes. This lead to the development of the Cantabrian Test of Abrasion Loss by Calzada and Perez at the Civil Engineering School of the University of Cantabria in Spain.

4.2.1 The Cantabrian Test of Abrasion Loss

The Cantabrian Test of Abrasion Loss allows adequate assessment of the cohesiveness of porous mixes and their resistance to disintegration. The test consists of making a Marshall mould of a particular mix grading. This is weighed and placed in a Los Angeles machine and subjected to 50 revolutions in the LA drum. The sample is removed, weighed and process repeated every 50 revolutions up to a total of 500. The percentage mass retained and the percentage mass lost to abrasion can be calculated and examined over this period of time. At 300 revolutions the cohesiveness and durability is assessed. The test is therefore useful in assessing and comparing the durability of mixes with different binder contents and gradings.

5. Assessing two Porous Asphalts

Samples of 10mm and 14mm PA were made in the laboratory using a gritstone coarse aggregate, crushed rock fines and hydrated lime filler. The binder used was BP PA100 Olexobit polymer modified bitumen with binder contents ranging from 4.0% to 5.5%. Three samples were made for each binder content. The gradings of the two mixes are shown in table 1.

BS Sieve size (mm)	10mm PA (% passing)	Actual (% passing)	14mm PA (% passing)	Actual (% (passing)
20	-	-	100	100
14	100	100	95-100	96
10	85-100	95	55-75	64
6.3	30-60	36	-	-
5	-	-	15-23	17
3.35	15-25	19	-	-
2.36	-	-	10-18	13
0.075	2-6	3	4-5.5	5

Table 1 10mm and 14mm PA aggregate gradings

5.1 Void Content

Void contents for all the samples were assessed using the bulk volume and actual volume of each sample. The bulk volumes were calculated using the actual physical dimensions of each sample i.e. diameter and height. The samples were weighed in air and water and the difference in weights gave the actual volume of the material using Archimedes principle. The void contents were calculated using the equation below:

$$\% \text{ Voids} = 100\,[1-(\text{Actual Volume}/\text{Bulk Volume})]$$

As shown in table 2, the average void content for the 10mm PA and 14mm PA samples differed even though the same target void content of 25% was chosen for both mixes. The average 10mm results ranged from 16.9% to 20.8% whereas the average 14mm results ranged from 22.1% to 24.9%.

	10mm PA			14mm PA		
% Binder	Ave SHP (l/s)	Ave % Mass @ 300 revs	Ave % Voids	Ave SHP (l/s)	Ave % Mass @ 300 revs	Ave % Voids
4.0	0.28	31.7	20.8	0.45	34.1	24.8
4.5	0.28	33.8	19.7	0.50	33.6	24.9
4.8	0.29	56.9	18.9	0.45	70.6	24.7
5.0	0.28	39.5	18.2	0.43	85.2	22.1
5.5	0.27	43.3	16.9	0.44	38.6	23.8

Table 2 Summary of 10mm PA and 14mm PA test results

All the samples were mixed and compacted at 130°C and 90°C respectively. It is therefore the variation in coarse aggregate size that accounts for the difference in void content. The authors believe it is the finer grading of the 10mm PA that accounts for the lower void content. This occurs as the 10mm grading is more closely packed than the 14mm PA. The % binder content had more of an effect on the void content of the 10mm mix than the 14mm PA mix as shown in figure 1. This further supports the author's belief that the voids in the 10mm PA mix are smaller and more easily clogged up with excess binder than those in the 14mm PA mix.

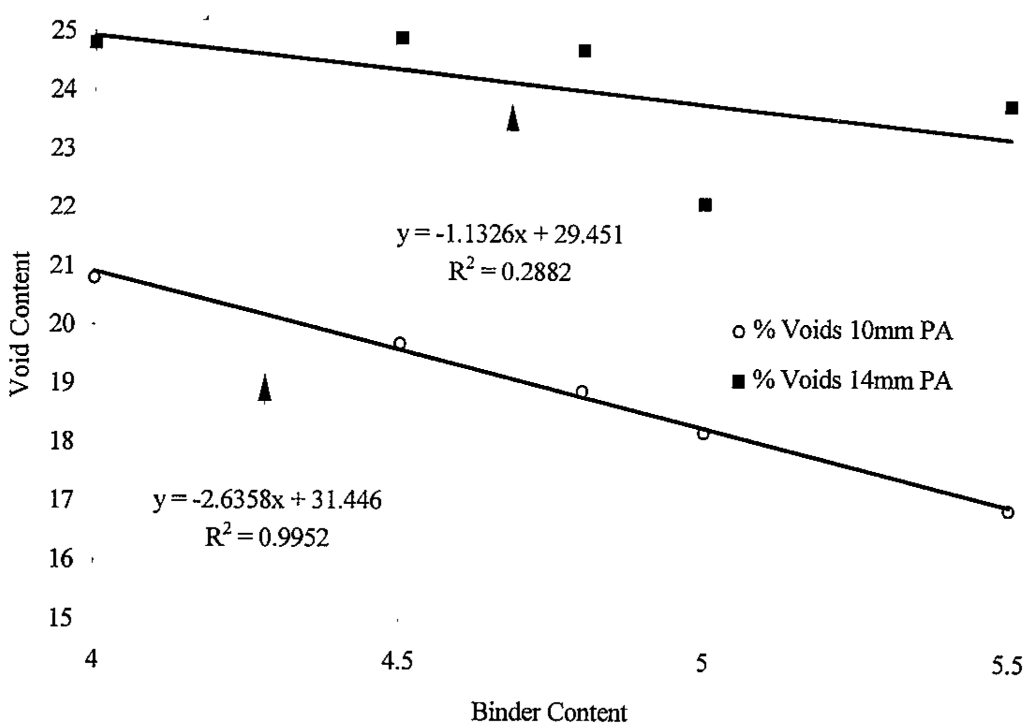

Figure 1 Relationship between void and binder content for the two mixes

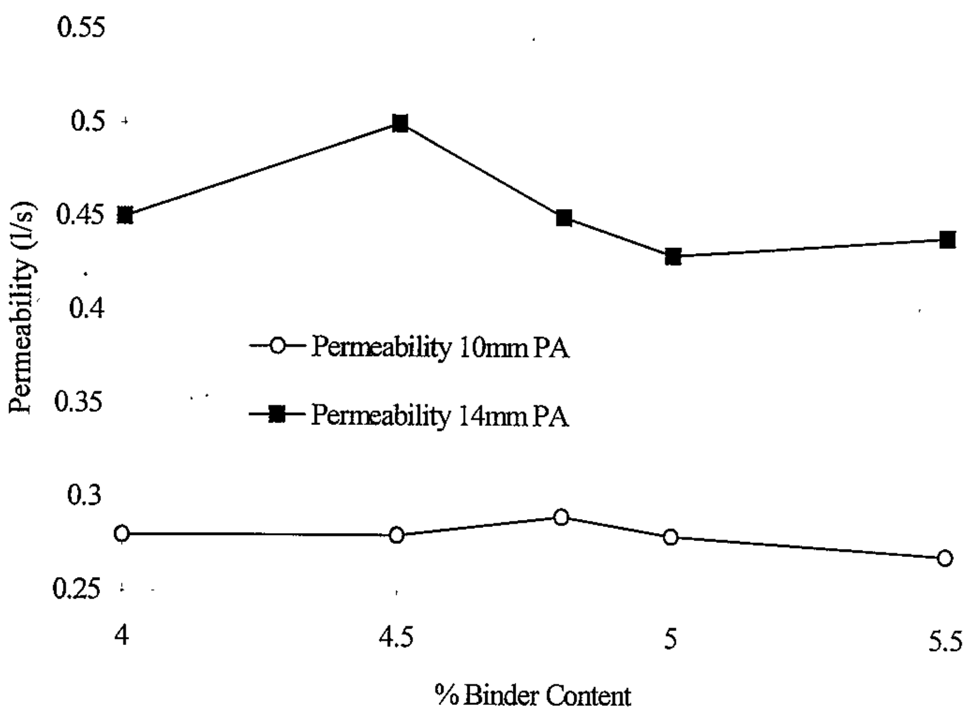

Figure 2 Variation of permeability with increasing binder content

5.2 Permeability

The permeability results from the 14mm PA samples were much better than those from the 10mm PA samples. This was expected due to the higher void content of the 14mm PA mixes. The SHP results did not vary widely over the range of binder contents for both mixes. The 10mm PA results ranged from 0.27l/s to 0.29l/s and the 14mm PA results ranged from 0.43l/s to 0.50l/s. Generally, permeability would be expected to decrease as binder content increased but there was no obvious effect exhibited by the binder content on the permeability of both sets of mixes as can be seen from figure 2. There were peaks in the permeability of both mixes with the most permeable 10mm mix at 4.8% binder and the most permeable 14mm mix at 4.5% binder.

5.3 Durability

Based on the Cantabrian results, the durability of the 10mm PA mix was found to peak at 4.8% binder with 56.9% mass retained at 300 revolutions. The 14mm PA mix peaked at 5.0% binder with 85.2% mass retained. The results can be seen in figure 3. There was an optimum binder content for both mixes, either side of which durability was compromised by lack of binder to help hold the mix together or by excess binder which started to reduce the aggregate interlock by acting as a lubricant. It can also be seen that binder content had a greater effect on the durability of the 14mm PA mix. There was a large improvement in durability by increasing the binder content by just 0.3% from 4.5% to 4.8% and again from 4.8% to 5.0%.

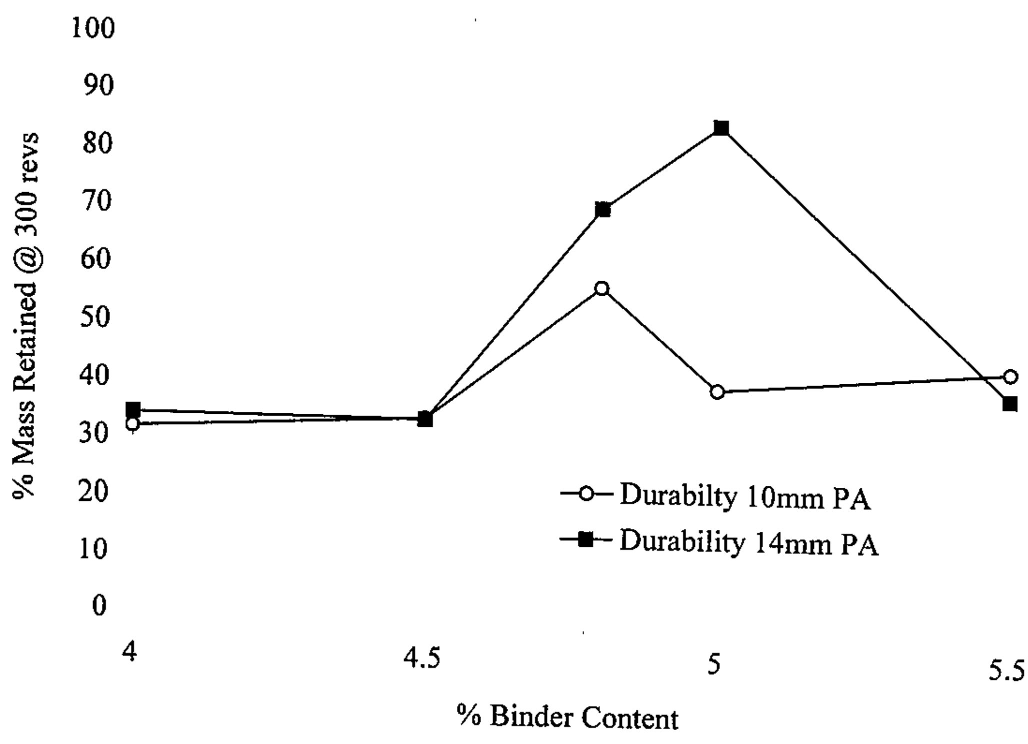

Figure 3 Variation of durability with increasing binder content

6. Choosing the most suitable mix

After laboratory testing for permeability and durability, the authors' were able to predict their likely behavior in situ. A compromise must be made between permeability and durability as the most durable PA will not necessarily offer the best drainage and the most porous material will not exhibit the best durability. This decision is also based on the particular application for which the material is being considered.

From the above results, the optimum results for the 10mm PA mix were obtained using 4.8% binder. It exhibited the best permeability and durability and also had a relatively good void content. The optimum results for the 14mm PA mix were also obtained using 4.8% binder. Although this particular 14mm PA mix did not show the best results for each individual property tested, it had sufficiently good results to make it the best all round mix.

As previously mentioned, the significance and interpretation of the different test results is at the discretion of the designer and dependent on the use for which the material is being developed. The testing described in this paper was carried out on two mixes of different gradings but using the same binder source. The testing regime allows mixes with different combinations of aggregate, binder and grading to be assessed and is a useful tool for indicating how the material will perform on site.

7. Conclusion

From the procedures listed, the laboratory assessment of the performance of PA can be seen to be a useful way of predicting how the material will perform on site. Testing in the laboratory reduces the risk of laying inadequate material and by doing so, reduces maintenance costs that may eventually arise. Laboratory testing also indicates the optimum performance with respect to permeability and durability for all types of PA.

8. References

1. FABB, T.R.J.(1993). The case for the use of Porous Asphalt in the UK. Institute of Asphalt Technology Yearbook 1993, pp46-59.

2. DAINES, M.E.(1986). Pervious Macadam: Trials on Trunk Road A38 Burton Bypass, 1984. Department of Transport TRRL Research Report 57. Transport and Road Research Laboratory, Crowthorne.

3. DAINES, M.E.(1992). Trials of Porous Asphalt and Rolled Asphalt on the A38 at Burton. Department of Transport TRRL Research Report 323. Transport and Road Research Laboratory, Crowthorne.

4. Highways Authority (1992). Draft Design Manual for Roads and Bridges Volume 7 Section 1 Part ** HA 50/92: Porous Asphalt Surfacing Course. Department of Transport.

5. RUSSELL, T.E.I.(1995). Evaluating the Net Adsorption Test. First Postgraduate Research Conference Proceedings. Faculty of Engineering, University of Ulster. 8th November 1995.

6. PEREZ-JIMENEZ, F.E. and CALZADA, M.A.(1989). Application of the Cantabrian test to open cold mix design. 4th Eurobitume Symposium, Madrid, pp 386-390.