A RATIONAL MIX DESIGN METHOD FOR POROUS ASPHALT MIXTURES

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1. INTRODUCTION

Porous asphalt is a type of coated macadam in which the aggregate skeleton is deliberately designed to contain, when compacted, a high air void content, usually in excess of 20%. The voids are interconnected to allow free flow of air and water through the material. The binder can be a conventional high penetration grade bitumen to which may be added synthetic fibres, or a polymer modified bitumen - which is becoming more common in current practice.

Porous asphalt is used as a wearing course on major roads, usually constructed as an approximately 50mm thick layer on an impermeable basecourse, and drains water out through the road edges into appropriately placed drainage pipes. Figure 1 shows a cross section of a typical porous asphalt pavement.

Porous asphalt descends from friction courses developed in the US in the 1950s for use on airfield runways to reduce aquaplaning. The erstwhile Property Service Agency was the first British organisation to import the technology from the US and adopt it on UK military airfields (PSA, 1979). It was later transferred to highway pavements to reduce splash and spray on high speed roads following performance monitoring in pilot-scale trials in the 1960s under the auspices of the Transport Research Laboratory (RRL, 1969).

Porous asphalt was included in the 1988 edition of BS 4987 when it used to be known as Pervious Macadam and was specified for the 10 and 20mm nominal maximum aggregate size recipes. Even though the 1993 version of BS 4987 (BSI, 1993) included both grading varieties, currently, only the 20mm nominal size porous asphalt is included in the Design Manual for Roads and Bridges (DTp, 1994) and was incorporated into the DTp Specifications for Highway Works in 1994.

Despite its inclusion in the national specifications, the use of porous asphalt on major roads in the UK remains almost non-existent. In a survey conducted by Fabb (1995), it was reported that the usage, in $M.m^2$, of porous asphalt in some European countries was as high as 20 in France, 15 in Holland, 8 in both Italy and Austria and 5 in Spain, whereas in the UK it was a mere 0.1 $M.m^2$. The main concerns that have led to such a limited use are those related to the durability of the material and its construction cost in contrast to other conventional surfacings such as Hot Rolled Asphalt. The open nature of the material renders it liable to degradation by the abrasive action of the vehicle tyres, as well as potentially accelerating the hardening/stripping of the binder due to the ingress of water and air. Added to that is the reportedly premature clogging of the voids which leads to ineffective drainage of surface water (Daines, 1992). As regards strength, traditionally porous asphalt has not been considered as a contributing layer to the overall structural integrity of the pavement. In France, Sainton (1990) reported a structural equivalency factor of 0.5 in relation to conventional dense asphalts. As a consequence of this, the overall pavement thickness will need to be enhanced to provide adequate structural support to carry the anticipated traffic volume if porous asphalt were to be used as a wearing course.

In spite of the aforementioned limitations, porous asphalt has been growing in prominence in Europe over the last decade due to the multitude of advantages it can provide. The main benefit that has contributed to the material's popularity in Europe is its noise and spray reduction characteristics. Compared to other surfacings, porous asphalt has been considered the "Rolls Royce" of noise and spray reduction (Daines, 1996). The main safety benefit of porous asphalt is that it dramatically reduces the risk of aquaplaning at high speeds, which is considered a major factor in motorway pile-ups. The reduction in aquaplaning combined with the suppression of splash and spray and the enhanced skid resistance in the wet hugely contribute to the reduction of accident risks, particularly on high speed roads with high volumes of commercial vehicles. Other benefits incurred as a result of the use of porous asphalt on major roads include reductions in fuel consumption for vehicles and in tyre wear (Fabb, 1992) and enhanced driver comfort (Lefebvre, 1993).

In the UK, porous asphalt specifications have been set by the DTp adopting the recipe approach (DTp, 1994) and is entirely based on experience gained from field trials. The only test advocated by the specifications to arrive at a Target Binder Content for porous asphalt mixtures is the Binder Drainage Test (Daines, 1992), carried out on uncompacted mix specimens. It is evident, therefore, that there is a need for a rational mix design method that addresses the critical service parameters which affect the material's performance, both in the short and long-term stages. Moreover, due to the variability of weather and traffic conditions, and the shortage of high quality aggregates to comply with the stringent specification requirements, the need for a design method based on performance criteria can be clearly seen. This paper describes the development and application of a rational design method for porous asphalt mixes that takes into account the material's overall performance requirements and failure criteria. The development of such a method is also intended to enhance the current level of knowledge and expertise in porous asphalt and enable its adoption on major road surfacing contracts in the UK at a level commensurate with that in other European countries.

2. MATERIALS

Over the last ten years there has been a noticeable shift in the DTp specifications towards a larger nominal maximum aggregate size for porous asphalt mixtures, namely from 10 to 20mm. Elsewhere in Europe 14, 12 and 10mm aggregate size mixes are employed (Fabb, 1995) with noticeable success. The main reason for the shift has been attributed to the improved acoustic durability of the larger nominal size aggregate grading and its contribution to the overall reduction in vehicle noise emissions (Abbott, 1996), as well as lasting longer before clogging of the voids occurs. Figure 2 shows the grading envelopes for the current BS 4987:1993 10 and 20mm nominal mix sizes together with the mix grading adopted in this investigation.

The aggregate used was a doleritic basalt from the Leaton quarry in Shropshire. Hydrated lime filler was added at 2% by weight of aggregates to comply with the specification requirements.

Three bitumens were used in this study, comprising a conventional 100 Pen binder, an Ethylene Vinyl Acetate (EVA) modified binder and a Styrene Butadiene Styrene (SBS) modified binder. Some of these binders' properties are given in Table 1.

Sample	100 Pen	SBS	EVA
Cone and Plate viscosity (Poise) at			
125°C	5.4	9.0	9.6
150°C	1.9	3.9	3.8
180°C	0.6	1.6	1.4
Softening Point, $T_{R\&B}$ (°C)	47	58	54
Penetration at 25°C (dmm)	90	108	65

Table 1. Properties of the binders used in this study.

3. SPECIFICATION REQUIREMENTS AND LABORATORY TESTS

Any asphaltic mix designed to a particular method needs to comply with a set of specification requirements stipulated to control the mix's manufacture and laying operations, followed by short and long-term service performance. In the UK, porous asphalt specification requirements with respect to binder type and content have been given in Table 5.1 of HD 27/94 (DTp, 1994) in terms of traffic flow intensities in commercial vehicles (cv)/lane/day, namely ≤ 1500, 1500 - 3000 and ≥ 3000. Additionally, in order to prevent excessive binder drainage occurring during manufacture, transportation and laying, the Binder Drainage Test (Daines, 1992) has been specified to determine the Target Binder Content for any porous asphalt mix.

In addressing the critical parameters which have a significant impact on the material's performance, specifications should also preferably include criteria to deal with the following parameters:

- the resulting voids in the mix and their distribution;
- the stiffness of the material, both in dry and wet conditions;
- a measure of the material's adhesiveness and resistance to wear.

The setting of specification limits covering the above parameters is vital to ensure the success of the produced material. Good performance has been achieved in Europe with porous asphalt having an initial void content of at least 20% (Pérez Jiménez and Gordillo, 1990), and this is recommended for adoption in this work. Stiffness measurements, on cored or laboratory prepared samples, can be made using the non-destructive Repeated Load Indirect Tensile Strength Test (RLIT) at 20°C using the

Nottingham Asphalt Tester (NAT) following the procedure in Draft for Development 213 (BSI, 1993a). Therefore, stiffness limits can be set as a function of traffic intensity, in cv/lane/day, to reflect the contribution of porous asphalt to the overall structural support of the pavement. However, a soaked stiffness may be more representative of the predominant condition of porous asphalt than a dry one. Consequently, a retained stiffness upon soaking in water is recommended to complement the unsoaked stiffness specification.

The resistance to particle losses in service due to abrasion by traffic can be simulated in the laboratory using a wear test, such as the Cantabro Test shown in Figure 3. The Cantabro Test, developed in Spain (MOPU, 1986), is an abrasion and impact test conducted in the Los Angeles Rattler, without the steel ball charges, on Marshall samples with the results given as the weight loss, in percentage, after 300 drum revolutions at 30 r.p.m. It is widely used in other European countries in the design and evaluation of porous asphalt (Lefebvre, 1993). A modification to the Cantabro, called the Impact Box has been developed at Liverpool University and is also shown in Figure 3. This apparatus is operated under the same conditions as the Cantabro and initial results obtained indicated a significant similarity in the abrasion loss for porous asphalt mixes between the two instruments (Khalid and Pérez Jiménez, 1994). It follows that specification limits can be set in terms of abrasion loss in the Cantabro to safeguard against excessive disintegration during service.

A suggested set of specification criteria for the design of porous asphalt mixes using the above mentioned requirements is given in Table 2.

Property measured at 20°C	Traffic Flow (cv/lane/day)		
	≤ 1500	1500 - 3000	≻ 3000
Stiffness (MPa)	≥ 500	≥ 700	≥ 1000
Retained Stiffness (%)	≥ 70	≥ 70	≥ 70
Voids (%)	≥ 20	≥ 20	≥ 20
Cantabro Loss (%)	≺ 20	≺ 20	≺ 20

Table 2. Suggested design specifications.

With reference to the voids content criterion, it should be noted that, in themselves, the voids are nothing but a physical value that does not depict their distribution throughout the mix matrix, and as such, they are not sufficient on their own to characterise the drainability of porous asphalt. To this end, a falling-head permeability cell, shown schematically in Figure 4, has been developed at Liverpool University and used to measure the rate of flow of water through the laboratory prepared samples. The permeability test aids in ascertaining the pervious nature of the voids in the porous asphalt mix and to compare the permeabilities of new and old materials. Moreover, from a relationship developed between voids content and permeability (Khalid and Pérez Jiménez, 1994), the evolution of the voids during service can be approximated if the permeameter were to be used in-situ.

4. PROPOSED DESIGN METHOD

Notwithstanding the BS 4987 aggregate grading used in this study, any grading can be used instead to produce a porous asphalt mix provided that it satisfies the requirements suggested in the previous section.

4.1 Design Criteria

Once the aggregate grading has been decided, the design method proceeds to evaluate the Design Binder Content (DBC) for the mix. Table 3 gives an outline of the design procedure showing how the various design parameters are used to arrive at a suitable DBC.

Binder Content	Mix Property	Procedure
Maximum	Binder Run-Off	Binder Drainage Test
Maximum	Voids Content	Volumetric measurement
Maximum	Voids Structure	Falling-head permeability test
Minimum	Elastic Stiffness	RLIT
Minimum	Retained Stiffness	Soaked RLIT
Minimum	Durability/Adhesiveness	Cantabro

Table 3. Current mix design method.

As mentioned earlier, the Binder Drainage Test (BDT) is the only component in the present method that is conducted on uncompacted mix specimens made at various binder contents. These mixes are heated in an oven at the maximum mixing temperature (at which the binder's viscosity is 0.5 Pa.s) for three hours after which the drained binder is weighed and the retained binder is calculated. Figure 5 shows the BDT results for the three mixes, from which the Target Binder Contents (TBC) have been determined as 4.3% for the 100 Pen mix and 4.5% for the modified mixes as there was no detected drainage of the binders, for which the latter value is suggested by the specifications as the maximum recommended. These TBC values should be used in conjunction with the relevant mixes to prevent the occurrence of excessive binder drainage prior to compaction.

Marshall samples are then manufactured at various binder contents for each mix and compacted in the Marshall moulds giving 50 blows per side for each sample. The volumetric properties are determined by weighing the samples in air and then in water with the use of an industrial cling film. These samples are then subjected to a series of non-destructive tests starting with the RLIT in the dry, upon which the samples are soaked overnight in water at 20°C before being tested for their retained stiffness moduli. Subsequent to the soaked RLIT tests, the samples are fitted into the permeability cell for the determination of the rate of flow of water through each sample. The only destructive part of the testing regime is the Cantabro abrasion loss test using the Impact Box, to which the samples are introduced at the final stage.

Figure 6 shows the design parameters plotted against binder content for the three porous asphalt mixes.

4.2 Design Binder Content Determination

A "Range" approach is adopted to arrive at the DBC, in which the ranges of binder contents at which the proposed specification criteria are satisfied are overlapped and the mid-point is identified and taken as the DBC for the mix. Figure 7 shows the range method applied to the three porous asphalt mixes from which a DBC of 4.5% can be deduced for the EVA mix which is adjudged to be suitable for the heavy traffic flow category (> 3000 cv/lane/day) according to the suggested criteria in the previous section. Similarly, for the 100 Pen mix a DBC of 4.0% is recommended and is suitable for the 1500 - 3000 cv/lane/day category. It is interesting to note that the SBS mix fails to meet the minimum stiffness requirement for the lowest traffic intensity, and as such it does not comply with the proposed design criteria. This by no means suggests that, when laid, the mix will not offer any strength. Nonetheless, if the DBC were to be chosen without including the stiffness requirement, then a value of 4.3% can be recommended. It follows that such a mix may be used in circumstances where no structural contribution is expected from the porous asphalt mix and where only the environmental and safety benefits are sought.

4.3 Advantages of the proposed design method

The proposed design method is a much needed tool for the design of porous asphalt mixes in the UK that will help in providing assurances of the suitability of the material for the anticipated service conditions. This, in turn, will help enhance the current level of confidence in and knowledge of the material, which may well lead to increased usage. The design method has a wide range of advantages which can be summarised as follows:

- The method adopts a "Range" approach in arriving at the DBC, thus obviating the need for identifying well-defined peaks in the plots between the parameter and binder content, which is used in the BS 598 "Averaging" approach. Difficulties can arise with plateau-like curves in which no single binder content value can be taken as optimum.
- The process of choosing the DBC is directly related to the relevant specification criteria, in contrast to the BS 598 procedure in which the DBC choice is carried out independently with the corresponding parameters checked against the specifications for compliance.
- The design method uses performance-related criteria which address the material's likely distress modes in service thus discarding the archaic "Recipe" approach and falls in line with modern design techniques.
- The method offers flexibility in the choice of the DBC by identifying a range of binder contents which satisfy the specifications. This enables the engineer to take into account economic factors as well as local weather and traffic conditions in selecting the DBC.
- The method adopts non-destructive testing techniques (except for the Cantabro) to evaluate the required properties, thereby avoiding duplication of sample manufacture and lessening sources of variability.

5. PERFORMANCE RANKING OF MIXES

Figures 8 and 9 show the influence of temperature on the stiffness moduli and abrasion loss results obtained for the various porous asphalt mixes adopted in this study. Included with these results is a mix in which synthetic fibres are added to the 100 Pen binder at 0.3% by weight of total mix. Also included, for comparison, are individual results obtained from a previous study (Khalid and Pérez Jiménez, 1994) on the BS 4987 10mm porous asphalt and a 12mm Spanish mix whose voids contents ranged between 17 and 19%. The stiffness results indicate that the EVA mix is superior to the conventional mix and shows a good retained stiffness behaviour over the temperature range covered. The SBS mix, on the other hand, gives the lowest moduli of all the mixes studied. The use of fibres does not seem to add any strength to the 100 Pen binder at any temperature. Not unexpectedly, the 10mm mix (with both 100 and 200 Pen binders) and the Spanish mix achieve higher stiffness values at 20°C than the 20mm mix variety.

As regards abrasion loss, the EVA mix again gives a better resistance than the SBS and 100 Pen mixes. The role of the fibres is inconclusive, and thus more work is required to ascertain the conditions under which they may contribute to performance enhancement of the conventional mix. The smaller nominal size mixes exhibit very similar resistance to abrasion loss to that of the conventional 20mm mix.

6. CONCLUSIONS

A useful method for the design of porous asphalt has been developed. This method uses a "Range" approach to arrive at the Design Binder Content and employs important performance criteria as design parameters.

The role of polymers in modifying the properties of porous asphalt mixes has been investigated. It has been found that some modifiers, such as the EVA used in this study, help improve the overall performance of the material compared to the conventional 100 Pen mix. Others, such as the SBS binder used herein, however, do not seem to enhance the performance criteria. However, the SBS binder was shown to improve binder drainage characteristics of the mix. It is thus concluded that caution must be exercised in choosing the type and level of polymer to incorporate into the porous asphalt binder to optimise performance in return for the additional investment.

Finally, from the limited results obtained on the 10mm BS 4987 mix and the 12mm Spanish mix, it has been shown that the smaller nominal size mixes have a great potential for giving good performance. Work should thus be carried out to optimise their design and use in the UK to complement the 20mm mix currently adopted by the specifications.

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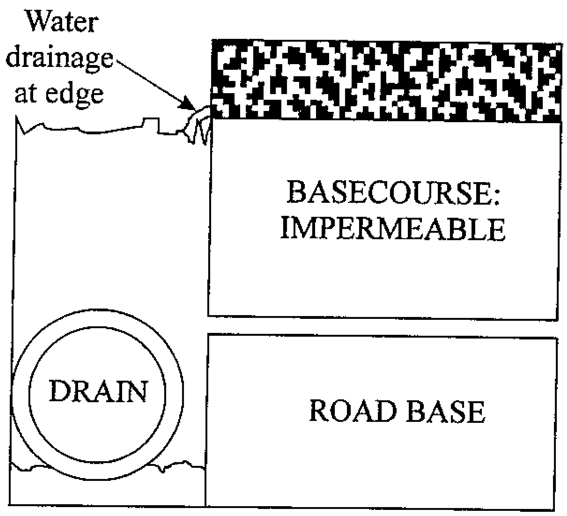

Figure 1. Section through a typical porous asphalt pavement showing its function.

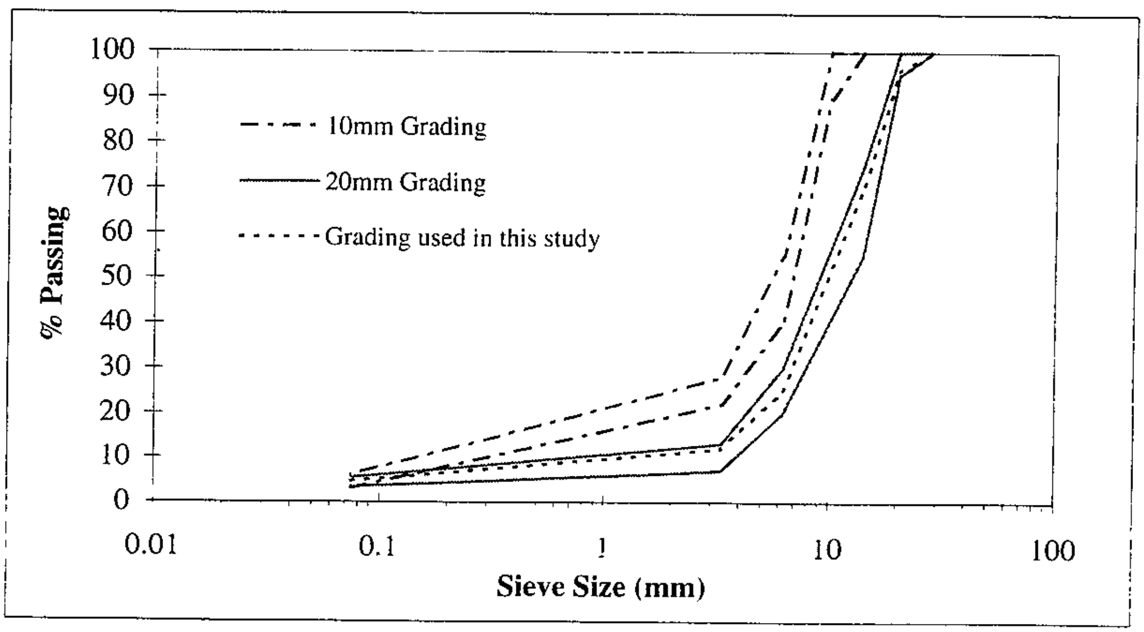

Figure 2. Grading envelopes.

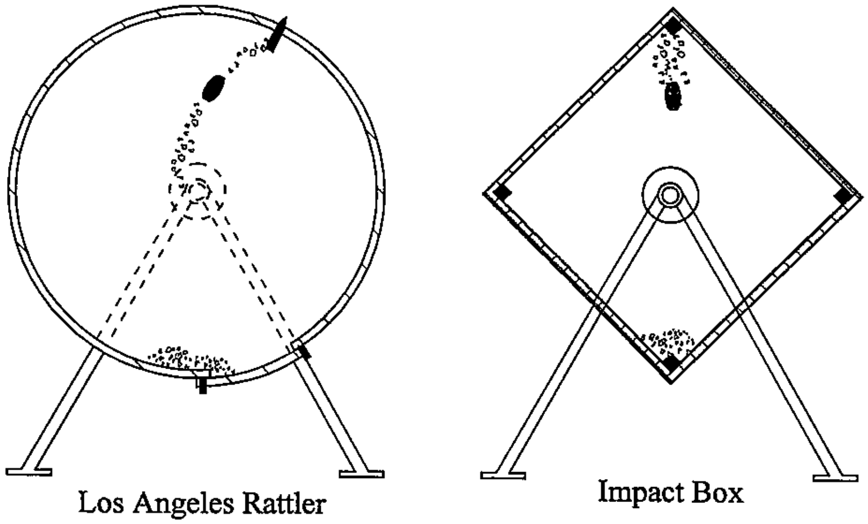

Figure 3. Equipment used for abrasion loss determination in the Cantabro test.

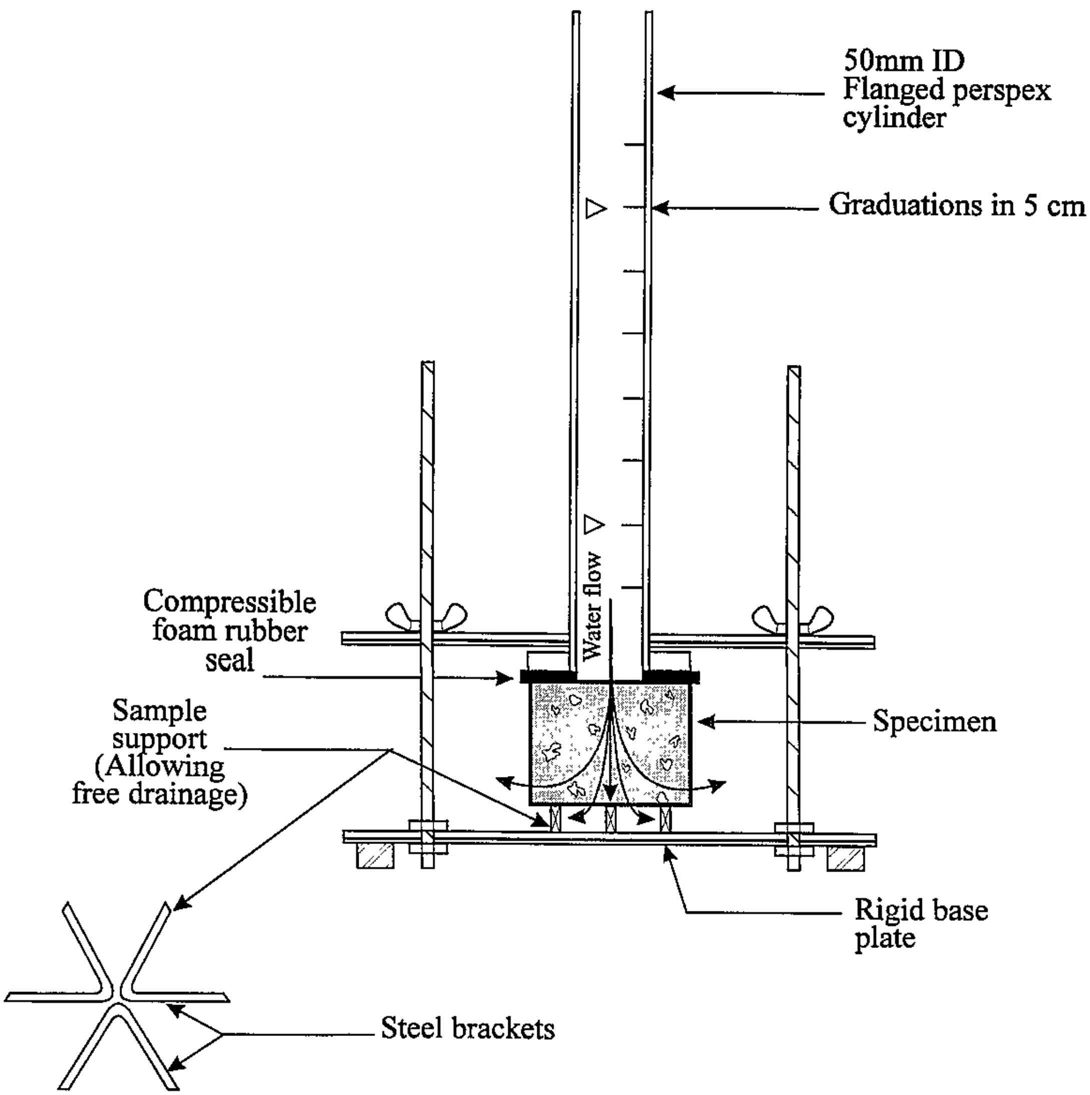

Figure 4. Porous asphalt permeability apparatus

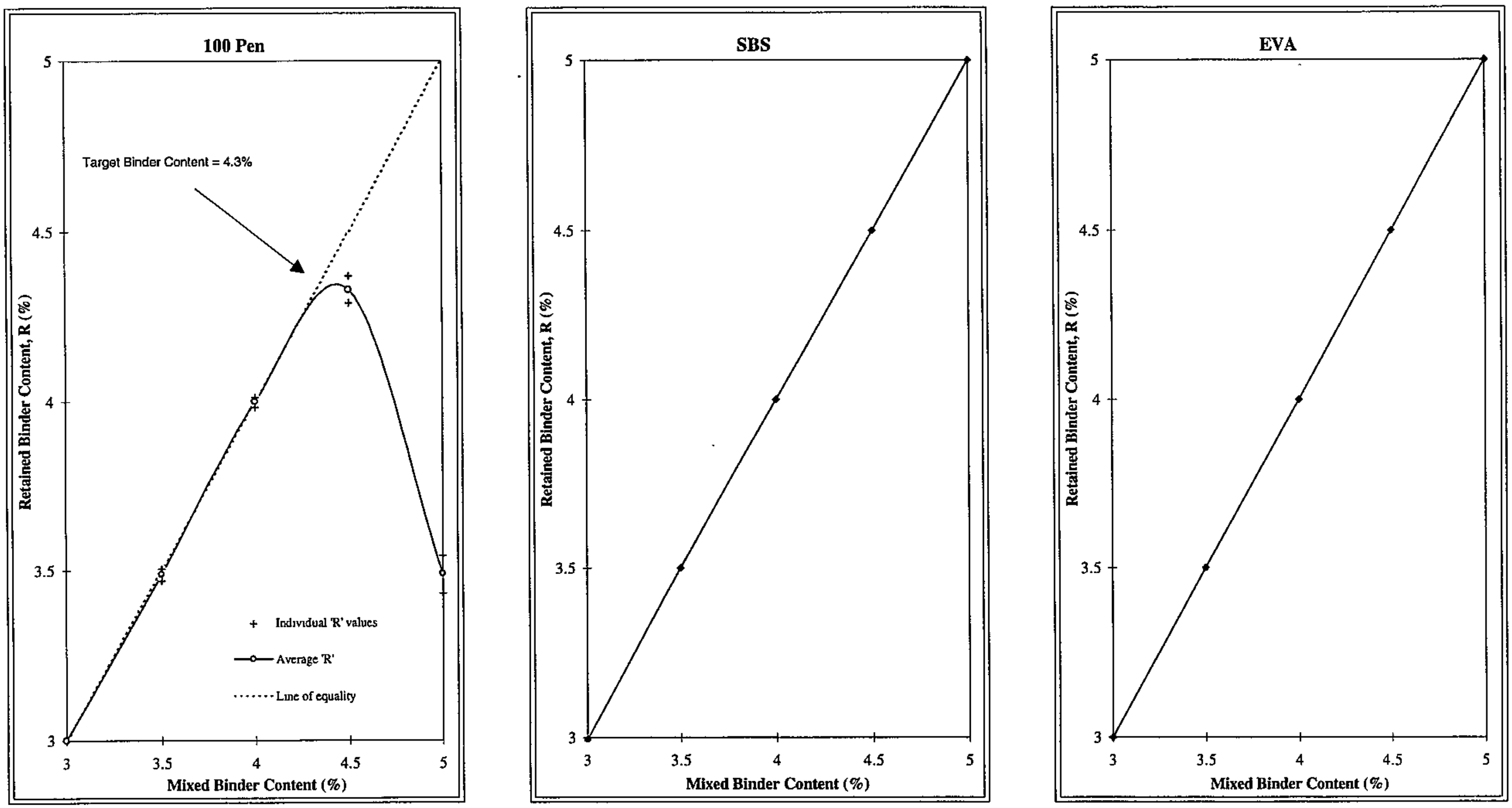

Figure 5. Binder Drainage Test Results.

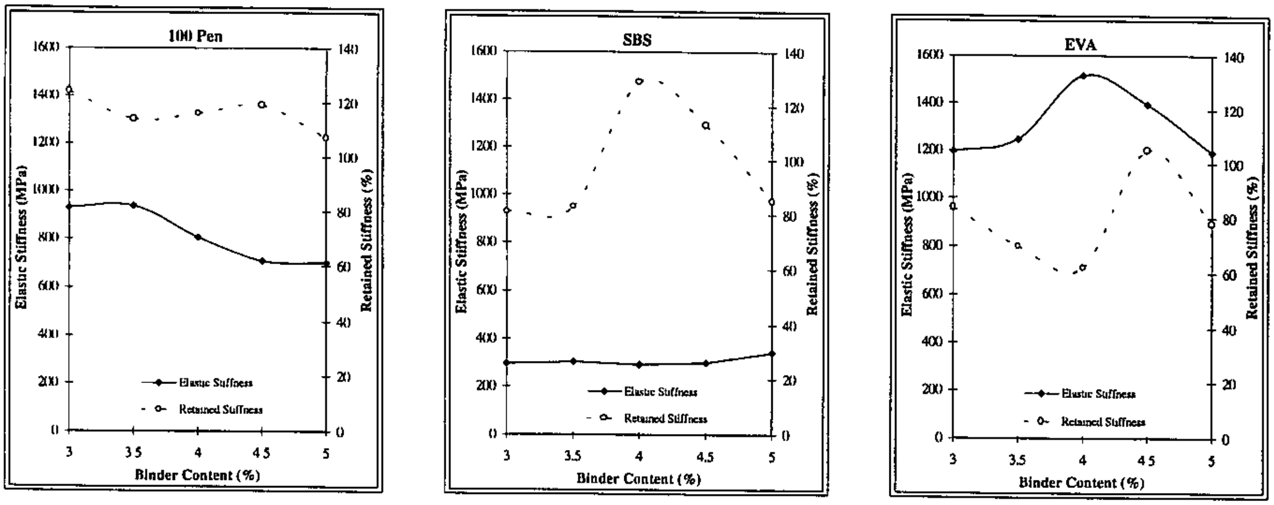

Figure 6a. Elastic Stiffness before and after soaking.

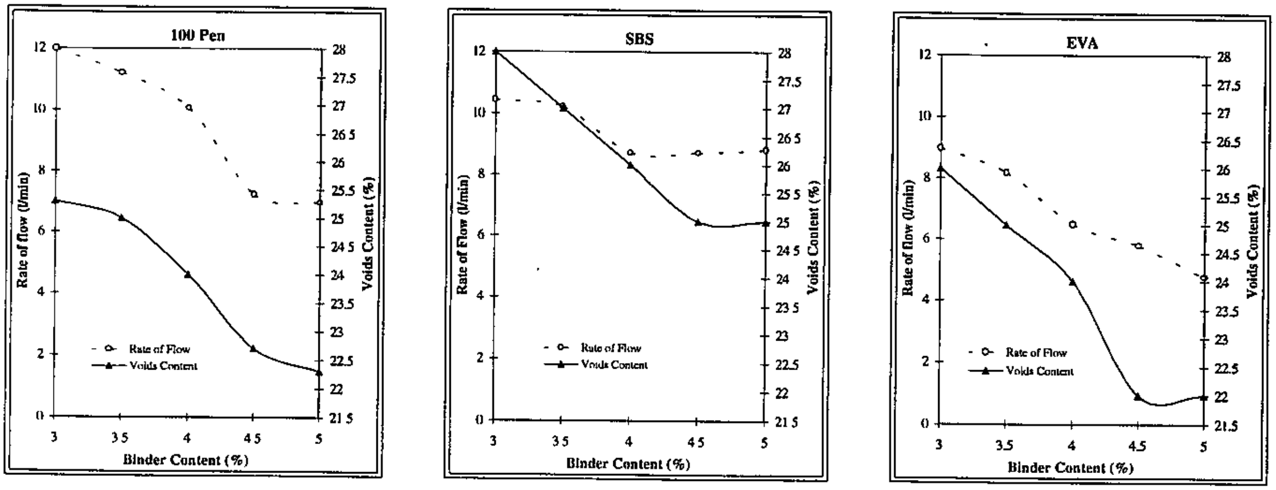

Figure 6b. Permeability and Voids Content.

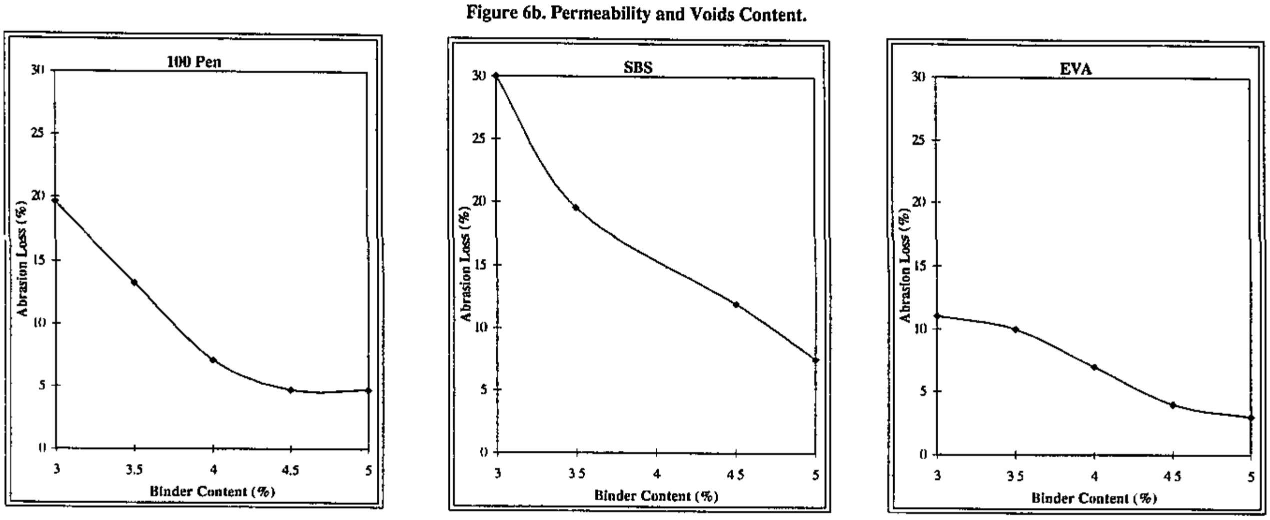

Figure 6c. Abrasion Loss.

Figure 6. Design parameters for the three porous asphalt mixes.

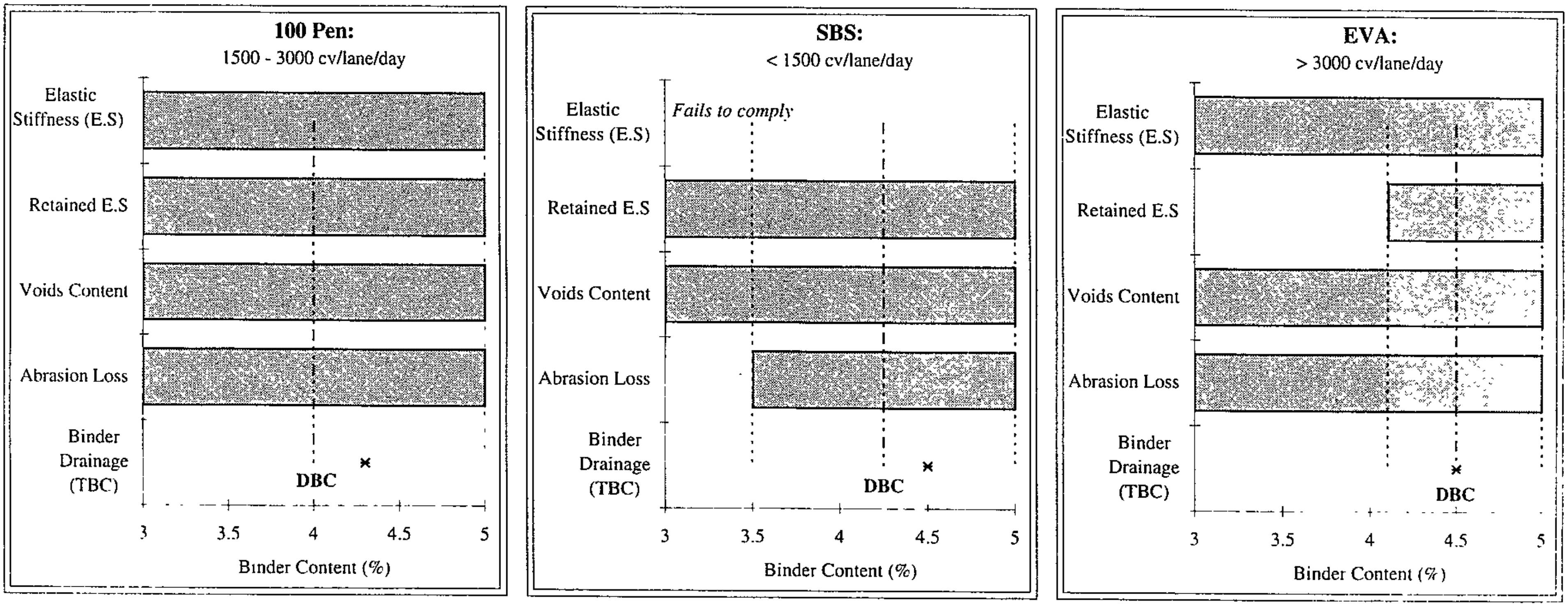

Figure 7. The "Range" method used to determine the DBC for the three porous asphalt mixes.

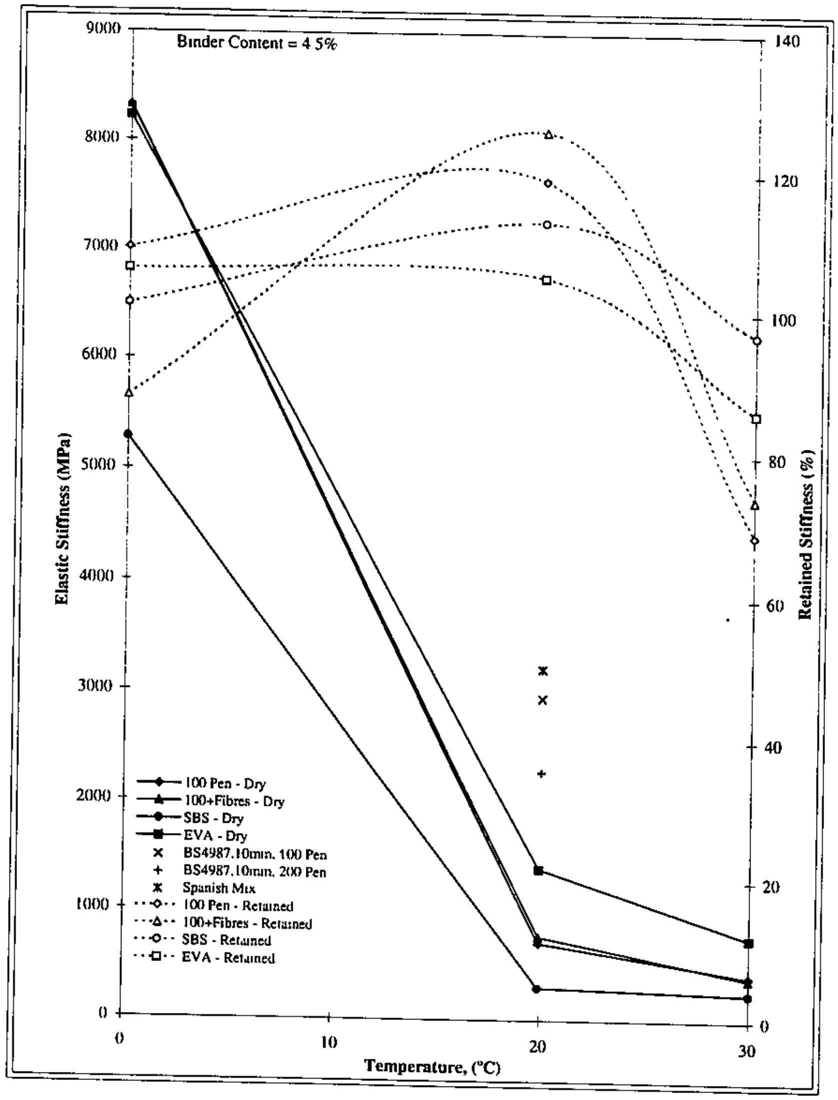

Figure 8. **Influence of temperature on dry and retained stiffness moduli of various porous asphalt mixes.**

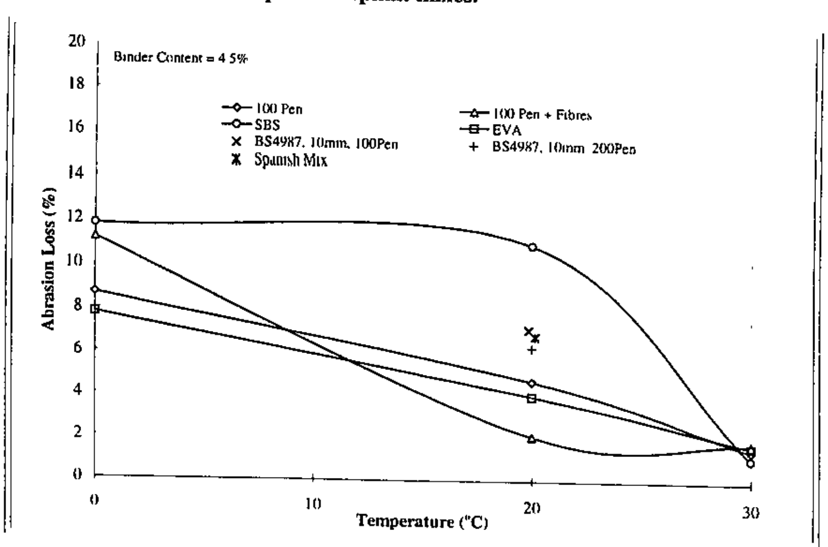

Figure 9. **Influence of temperature on abrasion loss in the Cantabro for various porous asphalt mixes.**