APPLICATION OF CANTABRIAN AND BINDER DRAINAGE TESTS IN DESIGNING OF POROUS ASPHALT BINDER CONTENT

Hardiman
Lecturer in Civil Engineering, Faculty of Engineering
Syiah Kuala University
Darussalam, Banda Aceh 23111
E-mail: hardiman_m@yahoo.com

Abstract

Traditional mix design methods which normally incorporate the Marshall test are not appropriate to design porous asphalt because of the insensitivity of the Marshall stability values to variations in binder content. It is therefore appropriate specify the design binder content (DBC) for porous asphalt rather than the optimum binder content. The design binder content incorporates an upper and a lower limit. The lower limit of the DBC can be dictated by requirements to resist disintegration while the upper limit is specified to limit binder drainage yet maintaining a porous structure that would promote permeability. This paper presents the results of a laboratory investigation to determine design binder content for porous asphalt. Three gradations were tested each made up of 10, 14 and 20 mm maximum aggregate size. Two types binder was used, conventional 60/70 pen bitumen, and styrene butadiene styrene (SBS) modified bitumen. Based on the drainage test, target binder content as the upper limit content for SBS is higher than the base bitumen 60/70. These values will be lower when the maximum aggregate size is increased. Generally, the abrasion loss decreases as the binder content increases while the curve slopes downward and becomes flatter when a certain percentage of bitumen is exceeded. It was found that design binder contents corresponding to 10, 14 and 20 mm maximum aggregate size equal 5.4%, 5.0% and 4.5% respectively for conventional binder and 5.7%, 5.2% and 4.6% for SBS binder. However, the DBC content for SBS is higher from conventional binder.

Key words: porous asphalt, binder drainage, cantabrian, design binder content

INTRODUCTION

The demands made on roads are ever increasing. Traffic volumes, tyre pressure, and loading have all increased over the last two decades. To meet the consequently more severe engineering criteria for success, road design has had to be similarly upgraded. Bituminous surfacing in Malaysia uses primarily the conventional 80/100-pen grade bitumen as a binder. Research work done by Jabatan Kerja Raya (JKR) and other research institutions overseas have shown that bitumen tends to harden while at the early stage of handling in storage, during mixing and in service.

It is not surprising that the bituminous surfacing in Malaysia failed primarily through cracking, more critically some of the bituminous surfacing suffer from surface down cracking as early as four years after laying, much earlier that their normal design life of seven to ten years. 80/100-pen grade available has a softening point of 42 –50^{O}C, and road Pavement temperature in Malaysia on the other hand ranges from 20^{O}C in the early hours of the day to as high 60^{O}C midday of hot day. Being visco-elastic material bitumen behaves as a viscous material at high temperature and consequently results in creep and permanent deformation (Mohamed and Zulakmal, 1997).

This type of bituminous surfacing which has been used a long time in Malaysia, in this report will investigate into another type of surfacing in which researchers proved its better performance under heavy traffic and high temperature. Laboratory evaluation of porous asphalt was conducted to determine bitumen content of base bitumen (60/70) and polymer modified binder.

Objectives and Scope of work

The main objective of this report is to determine the minimum and maximum range of design bitumen content.

The scope of this second report is limited on the determination of binder content for polymer modified bitumen and the conventional 60/70 bitumen, by using Cantabrian and binder drainage determination.

LITERATURE REVIEW

Bitumen

Bitumen is composed of hydrocarbon and their derivatives and is therefore soluble in organic solvent such as carbon disulphide. At ambient temperature is a viscous liquid, although at very low temperatures it is almost a solid. It displays thermoplastic behaviour, that is, it softens gradually when heated to become liquid but returns to its original state when cooled. Bitumen is black or brown in colour, non-volatile and is resistant to chemical action. Bitumen is normally derived from the distillation of crude oil. By virtue of its water proofing and adhesive properties, bitumen is extensively used as a binder in the road construction industry. Bitumen is also susceptible to time of loading. A precise definition of bitumen can be found elsewhere (BSI, 1989).

Polymer Modified Binder (PMB)

Polymer modified bitumen is a modified bitumen obtained by incorporation of thermoplastic materials, synthetic thermohardening resins, powdered rubber or elastometers in bitumen (Fritz et al., 1992).

A polymer is a very large molecule compromising hundred or thousand of atoms formed by successive linking of one or two, occasionally more types of small molecules into chain or network structures (Hall, 1985). Despite large number of products from polymer, there are relatively a few types which are suitable for bitumen modification when polymer blended with bitumen should: (1) Maintain its premium properties during a long time /temperature/stress history. (2) Be capable of being processed by conventional mixing and laying equipment. (3) Be physically and chemically stable at storage, mix and service temperature. (4) Achieve a coating viscosity at normal mix temperature. (5) Be cost effective.

Polymers can be classified into four broad categories namely plastics, elastomers, fibers and additives/Coating. Plastics can in turn be subdivided into thermoplastics and thermo sets. Among the varies types of polymer mentioned above for asphalt modification, in this Investigation Styrene-Butadiene-Styrene (SBS) copolymers have probably been the most widely used to now.

Previous Investigation for Using SBS Binder

A large number of investigations of the relationship of binder properties and mix properties have been published. Only a few examples will be presented in a summarized form. Research done by (Choyce, 1989), (Khosla and Zahran, 1989) (Gschewendt and Sekera, 1993), (Sculler and Forsten, 1993), and (Srivastava and Baumgardner, 1993) has indicated that the addition of polymers, especially SBS to bitumen improves resistance to permanent deformation of asphalt mixes. The mix resistance to stripping which is based on retained Marshall stability resistance indicates SBS modified binder has a positive effect of water resistance of asphaltic mixtures (Beecken, 1992). The improvement in binder properties with the addition of SBS was found to manifest itself in the field and from laboratory wheel tracking and repeated load tests. In another wheel tracking investigation, the average deformation rate for a 200 pen bitumen modified with 6% SBS is equivalent to that of a 50/60 pen base bitumen. SBS modified bitumen does not require modifications to existing mixing plant. Only the mixing temperature needs to be raised by 10-20 °C. They can also be laid using a conventional paver since the SBS modified mix shows a compatible workability index with other conventional mixes (Hamzah, 1996). A published state art report conducted in SHRP (Coplantz et al 1993) describes American studies of the relationship between properties of modified on pavement performance one of these studies (Reese, 1989) indicates that the addition of bitumen slows down ageing process measured by penetration, viscosity and ductility.

Design Bitumen Content (DBC)

Traditional mix design methods which normally incorporate the Marshall test are not appropriate to design porous asphalt because of the insensitivity of the Marshall Stability values to variations in binder content. It is therefore appropriate specify the design binder content (DBC) for porous asphalt rather than the optimum binder content. The design binder content incorporates an upper and a lower limit. The lower limit of the DBC can be dictated by requirements to resist disintegration while the upper limit is specified to limit binder drainage yet maintaining a porous structure that would promote permeability.

Generally, the upper limit of the DBC should be sufficiently low to prevent binder run-off and to produce more porous mixes of higher permeability. On the other hand, the binder content should be sufficiently high to retard oxidation. A number of methods have been proposed to decide upon the upper limit of binder content that the aggregate skeleton can support without binder drainage before being laid and compacted. The method involved a trade off between resistance to disintegration, thickness of bitumen film coating and mix porosity. Porous asphalt disintegrates through loss of particles. To resistance to particle loss was evaluated through the newly developed Cantabrian test. In the test, a pre-weight Marshall specimen was subjected to a 300 drum revolution, with out steel spheres, in a Los Angeles drum at well-defined temperatures of either 18 °C or 25 °C. In another Cantabrian test, the abrasion loss 18% was found at temperature 29^{o}C (Samad, 2003).

METHODOLOGY

The methodology of evaluating the new binder centers on a laboratory characterization of the porous mixes based on the results obtained from the binder drainage, and Cantabrian tests. The binder drainage test was carried on loose samples while the Cantabrian test was carried out on cylindrical Marshall sample.

Binder Drainage Test

The binder drainage test is a simulative test developed by Transport Research Laboratory (TRL), UK. Similar tests have been conducted for porous asphalt. An essential apparatus to carry out the binder drainage test is the perforated binder drainage basket. To speed up the test, a total of 5 units of such baskets were available at the Highway Engineering Laboratory of the Universiti Sains Malaysia (USM), Penang, Malaysia.

The binder drainage test involved preparing a 1.1 kg porous mix and transferring it into the perforated basket, which in turn was placed, on a pre-weighed tray in an oven at the chosen binder drainage test temperature for 3 hours, the amount of binder drained was determined at the end of test period. In preparation of mixes for the binder drainage test, the mixing temperature was kept $5^{o}C$ lower than the oven drainage temperature to ensure binder drainage took place during conditioning in the oven not during mixing in the mixer. At the end of the test, the mass of binder drained on the tray was determined. The test was repeated for a series of binder contents and the amount of material drained measured each time. Two samples were tested at each binder content. For mixtures prepared using base both binders, each of the mixing and binder drainage test temperatures were respectively 130 °C and 150 °C for base bitumen 60/70 and $175^{o}C$ and $180^{o}C$ for SBS.

The drained binder was partly composed of filler. To compensate this, the actual drained binder is computed from equation (1).

$$R = 100 \times B\,[1-D/(B+F)]/(1100 + B) \quad (1)$$

with:

D = The mass of mass and filler drained (g)

B = The initial mass of binder in the mix (g)

F = The initial mass of filler in the mix (g)

Cantabrian Test

Porous asphalt disintegrates through loss of particles. The resistance to particle loss was evaluated by the Cantabrian test. The simulative test method adopted followed closely the procedure developed in Spain (Jimenez and Perez 1990). The test was carried out on Marshall samples.

To assess resistance to disintegration, one Marshall specimen was placed inside a Los Angeles drum that was normally used for testing abrasion of aggregates. Each specimen was subjected to 300 drum rotations without steel balls. The mass of the specimen after test was determined. Two specimens were tested per bitumen content. During the Cantabrian test, the average room temperature was measured.

The resistance to disintegration was expressed as a percentage of mass loss in relation to its initial mass as defined in equation (2). The percentage of abrasion loss expresses the resistance to disintegration.

$$AL = \frac{m_i - m_f}{m_i} \times 100 \quad (2)$$

with:
AL = Abrasion loss (%)
m_i = Initial mass of specimen (g)
m_f = Final mass of specimen (g)

Preparation of Marshall Samples

Aggregates and fillers were batched in metal containers to produce one specimen weighing approximately 1.1 kg. The batched aggregates were placed in a thermostatically controlled oven at the desired mixing temperature for a period of at least 4 hours. The adopted mixing and compaction temperatures for a given binder type is shown in Table 1.

Bitumen, which arrived in bulk, was subjected to no more than two cycles of heating. Sufficient quantity of bitumen during one laboratory session was placed in the oven at the required mixing temperature until it fully liquefied for mixing with the aggregates.

A 100-mm inner diameter steel mould and base plate were used in conjunction with the Marshall hammer. Both steel moulds and their corresponding base plates were placed in the oven together with the aggregates.

An electrically heated paddle mixer was used to blend the aggregates and bitumen. The mixer was first calibrated and then set to the required mixing temperature. Mixing of dry aggregates was accomplished for 1 minute. Then the correct amount of binder was poured onto the dry mixed aggregate and wet mixing continued for a further 1 minute. The amount of bitumen required was calculated as a percentage of the total mix. The mixer was transferred into the heated mould and partially compacted by means of 15 tamping. Full compaction was accomplished using the Marshall hammer once the mix temperature dropped to the desired compaction temperature shown in Table 1. Each specimen was subjected to 50 blows per face corresponding to the normal compaction level. Specimens were left overnight to cool prior to extrusion. Specimen weight and geometry were noted. Specimen volumetric properties will be based on its geometry. The specimens were then ready for the Cantabrian Test.

Table 1 Mixing and Compaction Temperatures for Cantabrian

Binder Type	Mixing Temperature (°C)	Compaction Temperature (°C)
Base 60/70	140	130
SBS	180	165

Design binder content criteria

The binder content of porous asphalt could not be optimized as in the Marshall method of mix design for dense mixes. This is due to the insensitivity of the Marshall stability with variations in binder content. Besides, the binder content could not be optimized from the relationship between mix density versus binder content.

The choice of design binder content for porous mix is to satisfy the following criteria:

(1) A minimum binder content to assure resistance against particle losses resulting from trafficking.

(2) A maximum binder content to avoid drainage or runoff.

In other words, the lower and upper limits of the DBC are respectively determined from the Cantabrian and binder drainage tests.

TEST RESULTS AND DETERMINATION OF DESIGN BINDER CONTENT

Binder drainage test result

The binder run off data, presented as a graphical plot between retained binder content, corrected for filler content, versus mixed binder content for mixes prepared using base bitumen 60/70 for each maximum aggregate sizes are shown in Figure 1, 2 and 3, for SBS are shown in Figure 4, 5, and 6. The retained binder content and mixed binder contents are equal up to the point where drainage just begins. The maximum mixed binder content is the binder content at which the retained binder peaked to a maximum value. The mixed binder content M is assumed to coincide with a 0.3% drainage. The target binder content is equivalent to (M-0.3)%. Target binder content for mixtures made of base bitumen 60/70 and SBS are shown in Table 2 in appendix. Based on the drainage test, target binder content as the upper limit content for SBS is higher than the base bitumen 60/70. These values will be lower when the maximum aggregate size is increased.

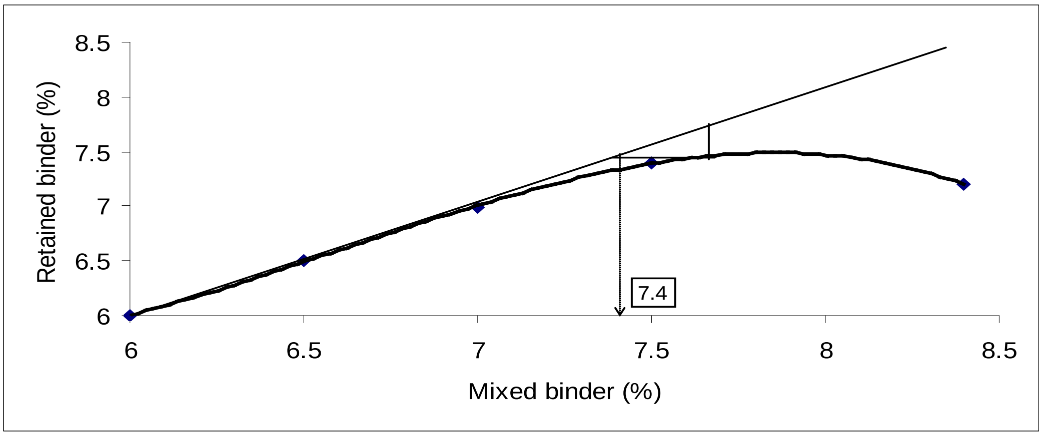

Figure 1 The Result of Drainage Test for Conventional Binder (Agg. Max. 10 mm)

Table 2 Target Binder Content for Base Bitumen 60/70 and SBS

Maximum Aggregate Size (mm)	Target Binder Content (%)	
	Base Bitumen 60/70	SBS
10	7.4	8.2
14	6.8	7.4
20	5.9	6.2

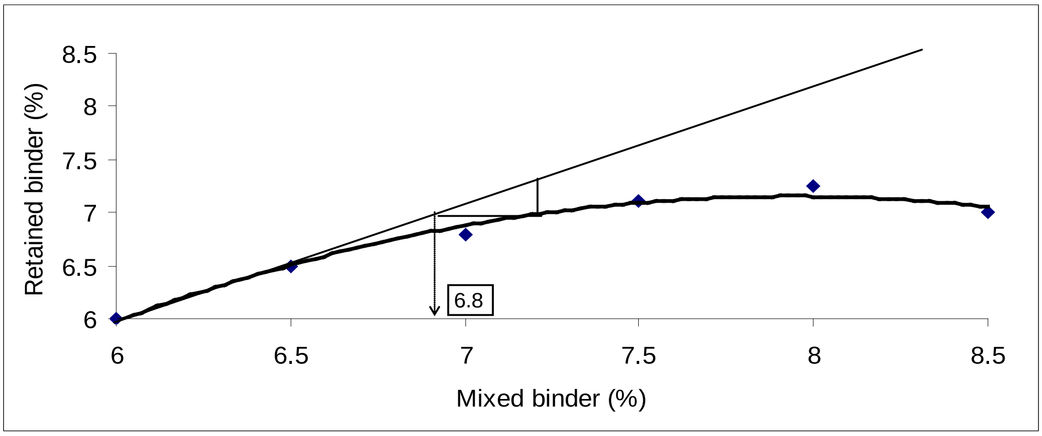

Figure 2 The Result of Drainage Test for Conventional Binder (Agg. Max. 14 mm)

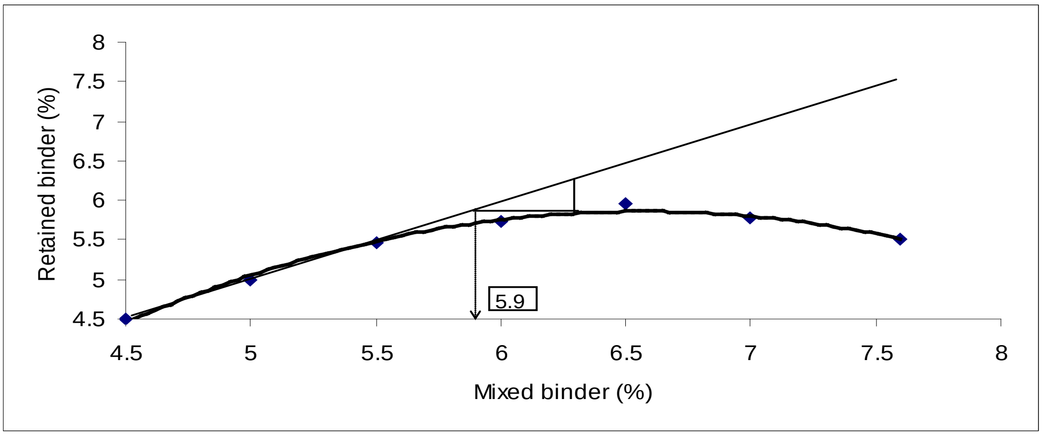

Figure 3 The Result of Drainage Test for Conventional Binder (Agg. Max. 20 mm)

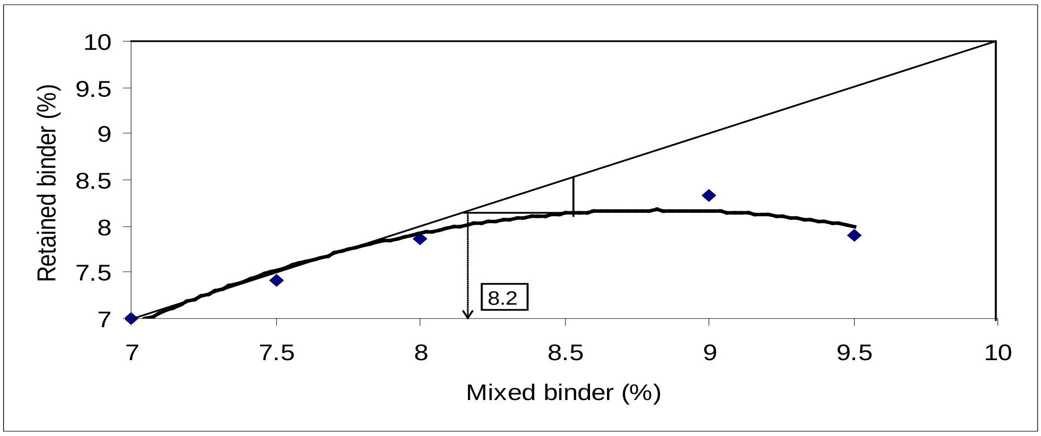

Figure 4 The Result of Drainage Test for SBS Binder (Agg. Max. 10 mm)

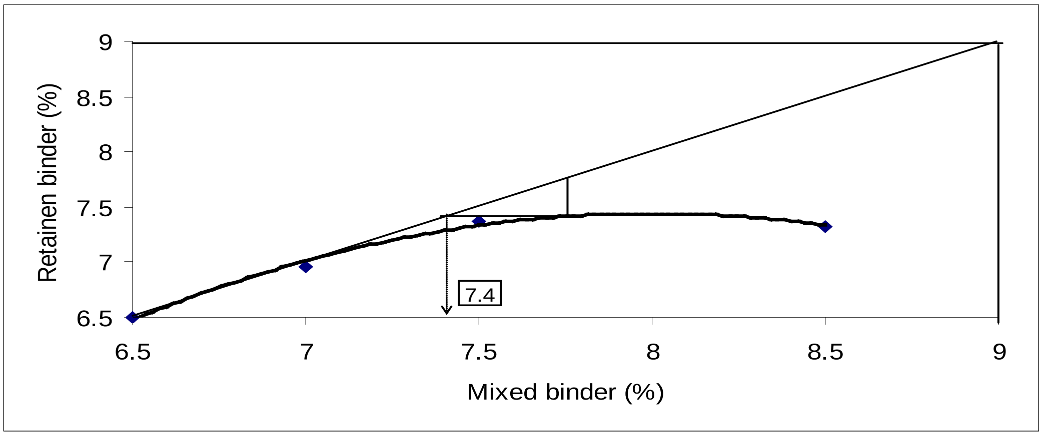

Figure 5 The Result of Drainage Test for SBS Binder (Agg. Max. 14 mm)

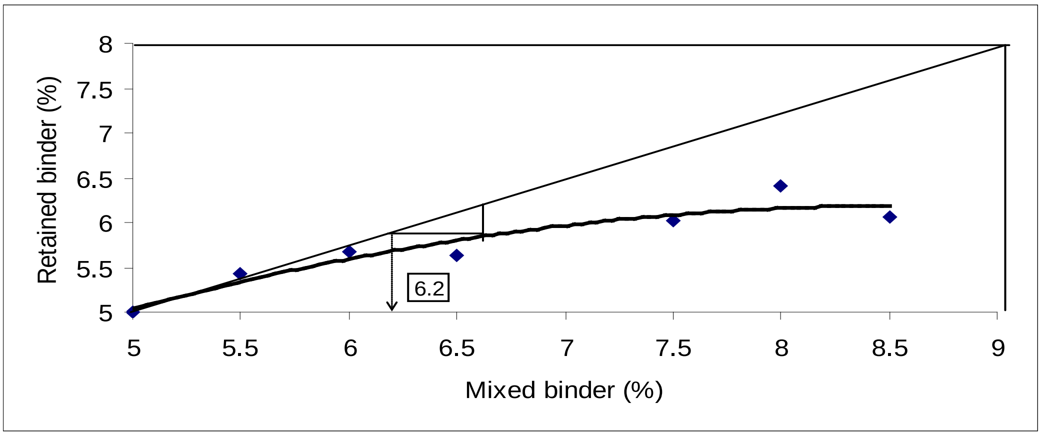

Figure 6 The Result of Drainage Test for SBS Binder (Agg. Max. 20 mm)

Cantabrian Test Result

The relationship between abrasion loss versus binder contents for mixtures using base bitumen 60/70 for each maximum aggregate sizes are shown in Figures 7, 8 and 9, for SBS are shown in Figures 10, 11 and 12. Generally, the abrasion loss decreases as the binder content increases while the curve slopes downward and becomes flatter when a certain percentage of bitumen is exceeded. Based on this graphs can be determined the lowest limit content for SBS and base bitumen 60/70 as shown in Table 3.

Table 3 The Lowest Limit Content for Base Bitumen 60/70 and SBS

Maximum Aggregate Size (mm)	The Lowest Limit Content (%)	
	Base Bitumen 60/70	SBS
10	3.4	3.2
14	3.3	3.0
20	3.2	3.0

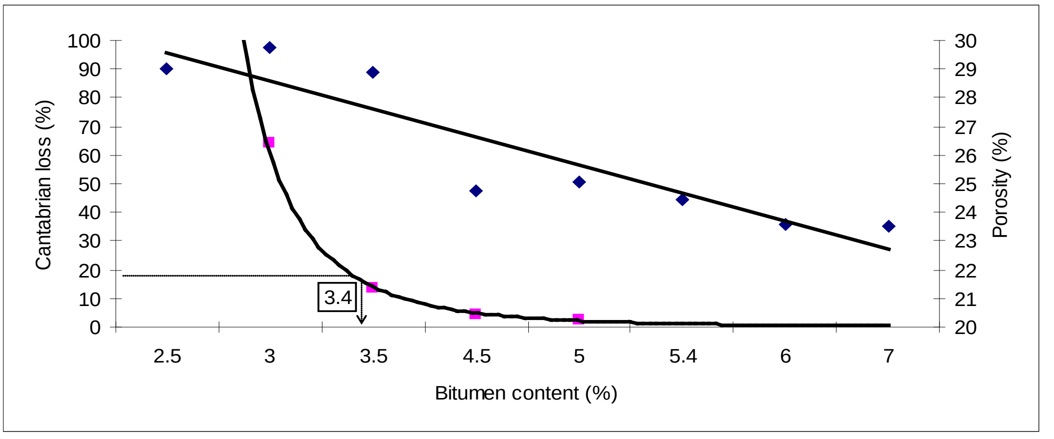

Figure 7 The Result of Cantabrian Test for Conventional Binder (Agg. Max. 10 mm)

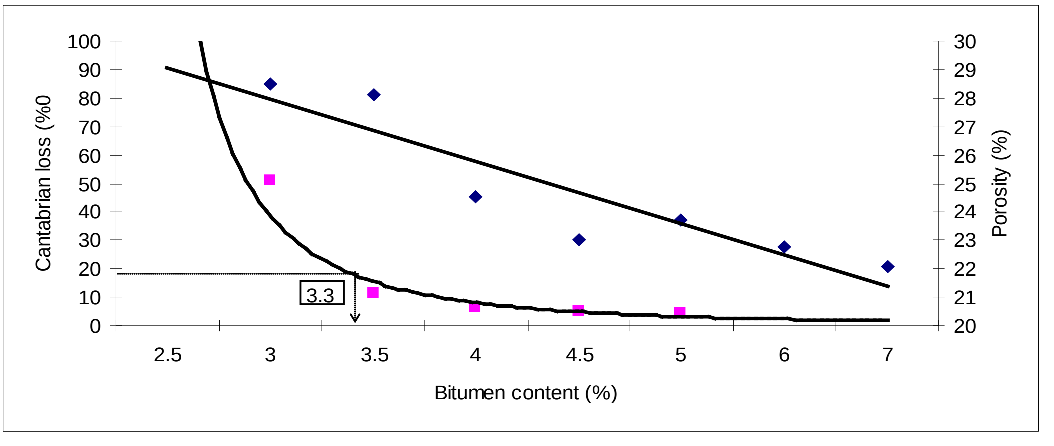

Figure 8 The Result of Cantabrian Test for Conventional Binder (Agg. Max. 14 mm)

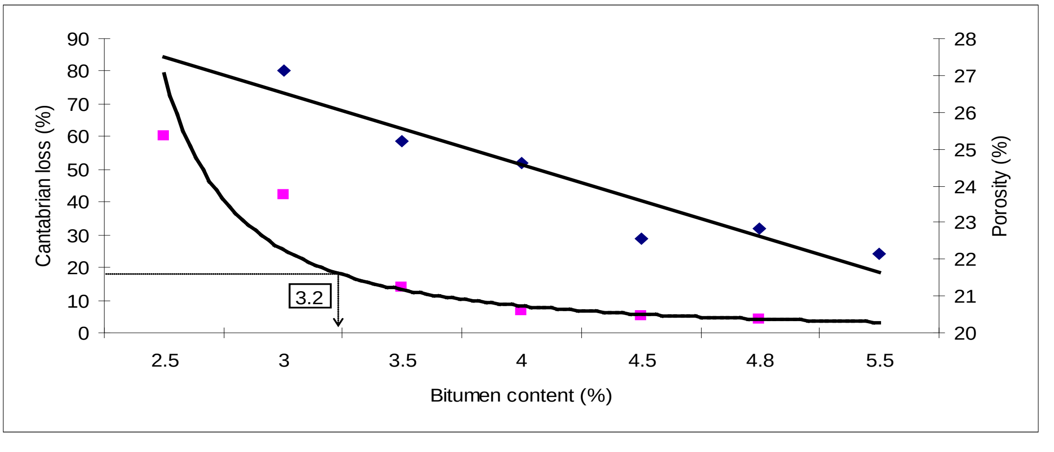

Figure 9 The Result of Cantabrian Test for Conventional Binder (Agg. Max. 20 mm)

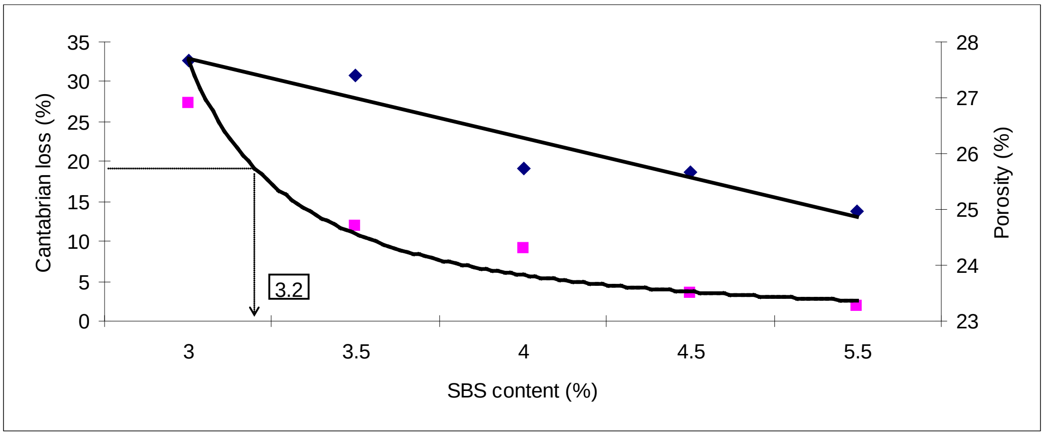

Figure 10 The Result of Cantabrian Test for SBS Binder (Agg. Max. 10 mm)

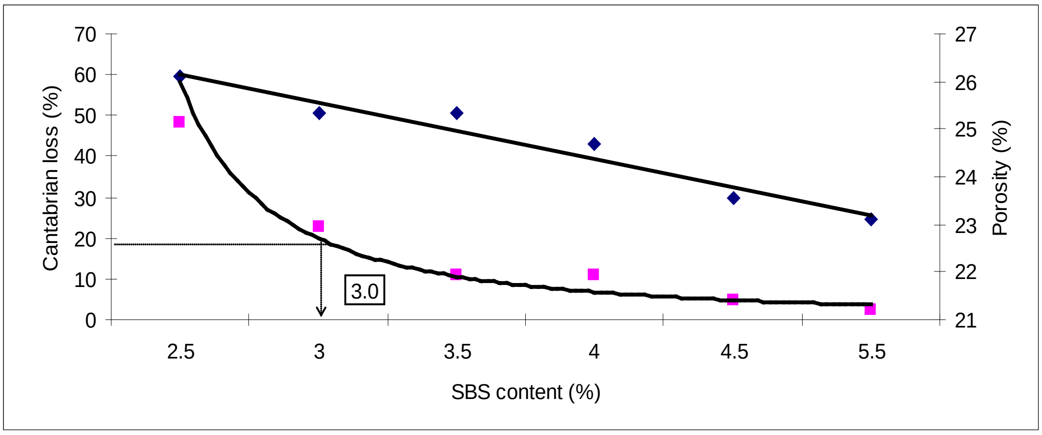

Figure 11 The Result of Cantabrian Test for SBS Binder (Agg. Max. 14 mm)

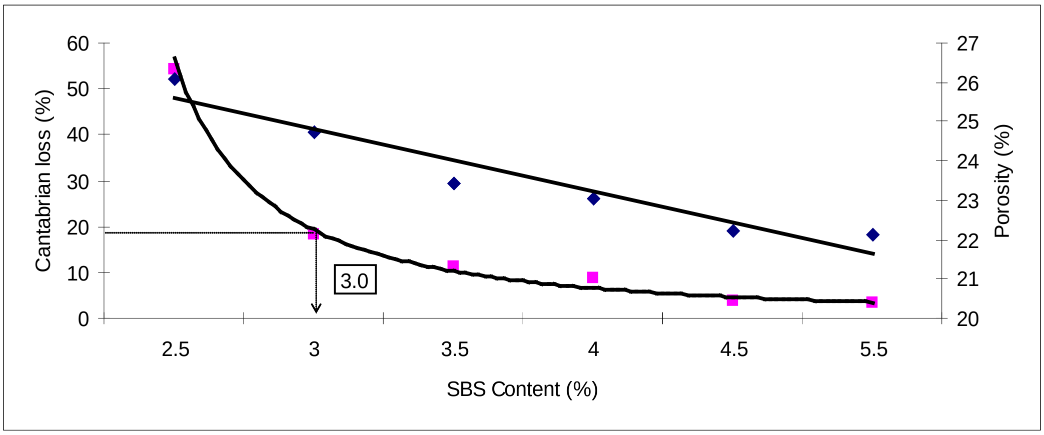

Figure 12 The Result of Cantabrian Test for SBS Binder (Agg. Max. 20 mm)

The original Cantabrian tests conducted in Spain was carried out at a well-defined temperature of either 18°C or 25°C. The suggested maximum permitted abrasion loss is below 35% and generally lower than 30% if the test was carried out at 18°C (Jimenez and Gordillo 1990) or below 25% and generally lower than 20% if the test was carried out at 25°C (Jimenez and Perez 1990). The typical laboratory temperature at the time the test was done was about 29°C. Earlier studies by (Samat 2003) were made to study the relationship between abrasion loss and temperature. At 29°C, the acceptable abrasion loss is 18%. With these criteria, the respective binder contents for base bitumen and SBS as shown in Table 3. These values will be lower when the maximum aggregate size is increased.

Design Binder Content (DBC)

In general, the Cantabrian test established the minimum binder content requirement while the binder drainage test establishes the upper limit of the DBC. Conventionally, the design binder content (DBC) lies between the maximum and minimum values described above are summarized in Table 4, in which designs binder contents corresponding to 10, 14 and 20 mm maximum aggregate size equal 5.4%, 5.0% and 4.5% respectively for conventional binder and 5.7%, 5.2% and 4.6% for SBS binder. However, the DBC content for SBS is higher from conventional binder.

Table 4 Design Binder Content for Base Bitumen 60/70 and SBS

Maximum Aggregate Size (mm)	Base Bitumen 60/70 content (%)			SBS (%)		
	Min.	Max.	DBC	Min.	Max.	DBC
10	3.4	7.4	5.4	3.2	8.2	5.7
14	3.3	6.8	5.0	3.0	7.4	5.2
20	3.2	5.9	4.5	3.0	6.2	4.6

CONCLUSIONS

The increasing of maximum aggregate sizes 10, 14 and 20 mm in porous asphalt will decrease minimum binder content, maximum binder content and design binder content for base bitumen and SBS.

The upper limit and design binder content for SBS is always higher than base bitumen 60/70, except for minimum binder content.

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