RATIONAL CONTROL PARAMETERS FOR DETERMINATION OF DESIGN BINDER CONTENT OF POROUS ASPHALT

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ABSTRACT

Recently, porous asphalt has become popular for its noise reduction potential. Other main benefits include suppression of splash and spray, reduction of aquaplaning potential under rainy conditions and improved traffic safety. Many generations of porous asphalt have been developed. Many mechanical tests have been used to determine its design binder content. This paper presents a band chart limiting method to determine the design binder content of a porous asphalt mix. The method was tested on mixes prepared using a gradation based on the Malaysian Public Works Department specifications (Grading A) and a proposed gradation (Grading B). Two types of bitumen were used, namely a conventional binder 60/70 and modified binder PG-76. Subsequently, specimens were compacted using the Marshall compactor with 50 blows on each face. Laboratory tests carried out include permeability, Rice test for air voids, resistance to abrasion loss and binder drainage. Mix prepared using the Grading B and bitumen PG-76 exhibited the broadest range of design binder content, that is, between 3.58% to 5.82%. Mixes prepared with Grading B blended with conventional bitumen penetration grade 60/70 resulted in the highest mean design binder content.

Keywords: Porous Asphalt, Design Binder Content, Air Voids, Permeability, Abrasion Loss, Binder Drainage

1. INTRODUCTION

Governments worldwide have invested a significant amount of money to improve the road network. An innovative and adequate design is desired to improve mix performance, increase the effective service life and resistance to damages due to traffic loads and the weather. In the asphaltic mixtures, aggregates are known as a main structure of the asphalt mixture, while adequate binder contents are desired to maintain good aggregate interlocking.

The main idea of porous asphalt is to attain a large amount of continuous air voids which permits the evacuation of water from the road surfacing. Unlike dense asphalt mix design, the design binder content of porous asphalt could not be optimized based on stability and flow from the Marshall Test. The choice of design binder content should satisfy the upper and lower binder limits to produce a highly permeable mix, not susceptible to binder drainage during storage and transportation [1], as well as assures adequate resistance to disintegration, retard oxidation and moisture damage [2].

Resistance to abrasion loss via the Cantabro test is typically used to limit the lower binder content of this wearing course. The test is popular on account of its simplicity that is merely by rotating the Marshall sample in a Los Angeles steel drum without steel balls [1]. According to Kiggundu and Roberts [3], the Cantabro test was also used by the Minnesota Departments of Transportation (DOT) to determine the moisture susceptibility of asphalt mix in the Cold Water Abrasion Test that was based on the amount of abrasion loss expressed as a percentage of the original weight of the set of 50mm x 50mm compacted briquettes and whose maximum value was 25%. The specimens were first conditioned at 60^{o}C in an oven for 24 hours, then immersed in a 48.9^{o}C water bath for six days, followed by cooled to room temperature and finally cooling at 0.8^{o}C for one hour. The specimen was then tumbled at 0.8^{o}C for 1000 revolutions in 34.5 minutes.

In Europe, Ruiz [2] stated that the porous asphalt mixture design varies with the applied mechanical test. A European agreement was never reached and different procedures were adopted. In some countries, the binder drainage test, water sensitivity and particle loss test were used to determine the design binder content. Compaction of asphalt mix using the Marshall equipment is the normal approach for compaction in European countries except in France, where the gyratory compactor is applied [4].

Several agencies in the United States of America used the mix design procedure proposed by the National Center for Asphalt Technology (NCAT) in 2002 [5] and modified in 2004 [6, 7]. The common feature of these mix design procedures relied on the evaluation of volumetric properties, for example total air voids content as the main parameter to define the design binder content. An assessment of mix durability via the Cantabro test, moisture susceptibility, binder drainage, and stone-on-stone contact was also included in the mix design procedure [8]. Nevertheless, the limitation of parameters may vary depending on the road authorities or countries as shown in Table 1.

Country or Centre	Design Properties				
	Permeability	Air voids (%)	Binder Drainage (%)	Abrasion loss (%)	ITSR
NCAT (USA)	>0.116 cm/s[4]	>18[4]	<0.3[4]	<20 at 25^{o}C[4]	Min ITS Ratio 80%[4]
TxDOT (USA)	NA	18-22[4]	<0.2[4]	<20 at 25^{o}C[4]	NA
Denmark (DRI)	0.15-0.50cm/s[4]	>26[4]	NA	NA	NA
Netherlands	NA	>20[4]	NA	NA	NA
Australia	NA	TypeI (>20) [4] TypeII(20-25) [4]	<0.3[4]	Type I (<25) [4] Type II (<20) [4]	NA
Belgium	NA	> 21[4] 16-18[9]	NA	<20 at 18^{o}C[4]	NA
Switzerland	NA	18 – 22[4]	NA	NA	ITS Ratio 70-80%[4]
British	0.12/s-0.40/s[4]	>20[9]	NA	NA	NA
Spain	NA	>20[4,9]	NA	<25 at 25^{o}C[4,9]	NA
Italy	NA	18-23[4,9]	NA	<25 at 20^{o}C[4,9]	NA
South Africa	NA	>22[4]	NA	<25 at 25^{o}C[4]	NA
Georgia	NA	10-20[9]	<0.3[9]	NA	NA
Other (Khalid and Perez)	>0.029 cm/s[4]	>16[4]	<0.3[4]	<25 at 20^{o}C[4]	NA

NA = Data Not Available

Table 1: Limitation of Some Properties in Design Binder Content

Generally, various laboratory tests are involved in classic and modern mix design methods. Due to the lack of correlation between laboratory test and real field situation to simulate the action of traffic to test the resistance to raveling, a number of alternative laboratory tests were introduced to evaluate porous asphalt mix design and performance such as Cyclic Tensile Test (CTT), Wheel Fretting Test (WFT), California Abrasion Test (CAT), Immersion Wheel Tracking and Rotating Surface Abrasion Test (RSAT) [1]. However, there are only a few countries that used this alternative test due to the lack of equipment availability.

In this study, four control parameters were selected to ascertain the design binder content of both gradations, which is coefficient of permeability, air voids, abrasion loss and binder drainage as shown in Figure 1. Laboratory works were initiated to produce reliable design binder contents for porous asphalt designed to Malaysian and proposed gradations.

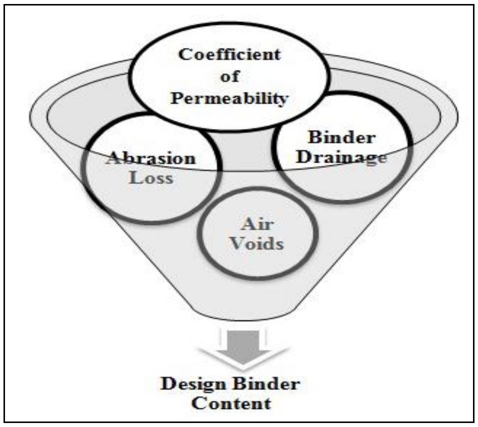

Figure 1: Controlled Parameter For Design Binder Content

2. MATERIALS AND METHODS

2.1 Material properties

Granite aggregate used in this study is the typical of aggregate type used for the road construction in Malaysia. Two types of asphalt binders were used, conventional bitumen 60/70 penetration grade and modified bitumen PG-76. Two types of fillers were employed, namely ordinary Portland cement (OPC) and hydrated lime, the former was incorporated in mixes prepared to the Malaysian gradation. The basic properties of the materials used are shown in Table 2.

Material	**Properties**	**Coarse**	**Fine**
Aggregate	Bulk Specific Gravity (g/cm^3)	2.633	2.714
	Apparent Specific Gravity (g/cm^3)	2.679	2.771
	Water Absorption (%)	0.661	0.758
	Abrasion loss (%)	23.59	-
	Aggregate Crushing Value (%)	21.51	-
	Polished Stone Value	51.80	-
	Flakiness Index (%)	21.80	-
	Elongation Index (%)	38.56	-
		60/70	**PG-76**
Bitumen	Specific Gravity (g/cm^3)	1.030	1.055
	Penetration at 25°C (dmm)	63	45

	Softening Point (°C)	49	64
	Ductility at 25°C (cm)	> 100	88.8

Table 2: Basic Properties of Materials

2.2 Gradation

Two types of gradations were employed, a gradation based on the Malaysian Public Works Department (PWD) specifications [18] (Grading A) and a proposed gradation (Grading B). The gradations are shown in Figure 2. Specimens were designated based on their gradations and binder type as shown in Table 3 for ease of reference.

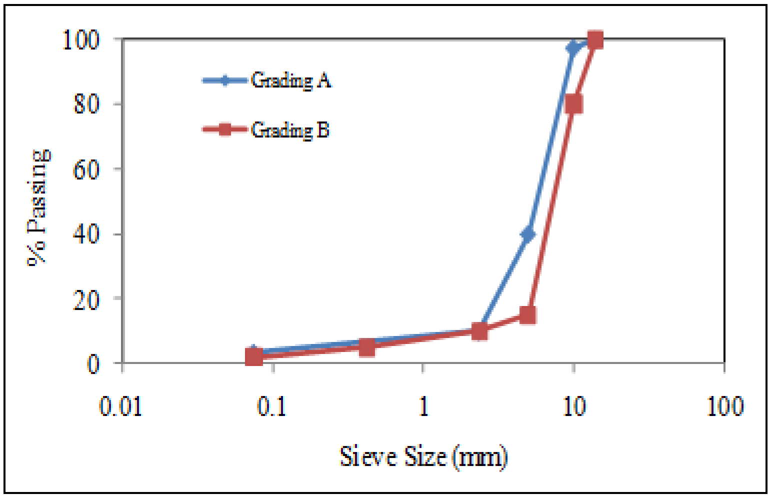

Figure 2: Aggregate Grading

Gradation Type	Binder Type	Mix Designation
Grading A	60/70	A6
	PG-76	AP
Grading B	60/70	B6
	PG-76	BP

Table 3: Specimen Designation

2.3 Test Methods

2.3.1 Cantabro Test

The Cantabro test was used to determine the resistance to abrasion loss. Few literatures suggested limiting values of abrasion loss when samples were tested at certain temperatures. A study in Southern Italy recommended the maximum permitted abrasion loss value for freshly compacted specimens tested at 18, 20, 25^{o}C, respectively equal to 30, 25, and 20% [10]. Studies by Khalid and Perez [11] and Huber [12] recommended a maximum weight loss of 25% is allowed at test temperature 20^{o}C, while Watson et al [7] had suggested a maximum weight loss of 20% is allowed when tested at 25^{o}C.

Figure 3 presents the relationship between permitted abrasion values at various temperatures. In the laboratory where the Cantabro test was carried out, the ambient temperature was 30^{o}C. According to Hamzah et al [13] the permitting abrasion loss values at 30°C was 16%. This value was adopted as the limiting abrasion loss value and corresponds to the lower limit of the design binder content. Specimens were tested for abrasion loss at binder content ranging from 3.0% to 4.5% in 0.5% increments.

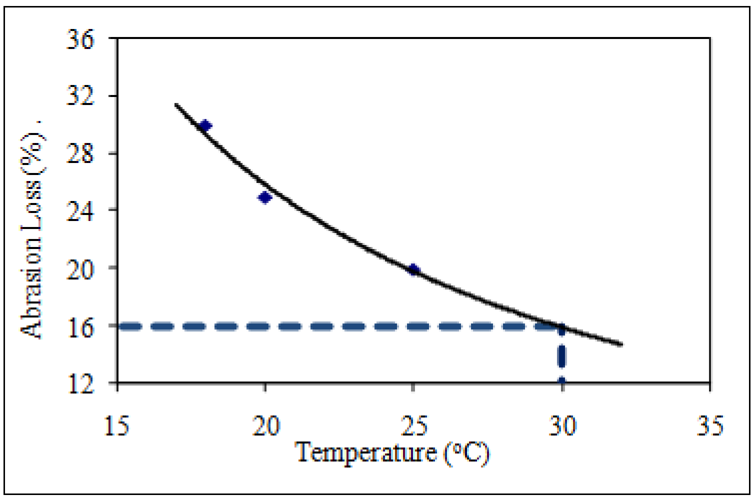

Figure 3: Permitting Abrasion Loss Value [13]

2.3.2 Binder Drainage Test

The binder drainage test was performed to determine the target binder content of the mixtures, making the binder content adequate to cover the whole surface of the aggregates without excessive binder drainage during production, transportation and construction [14]. The test was developed at the British Transport Research Laboratory (TRL) which involved preparing 1.1kg mix and transferring it into perforated metal basket with 3mm diameter holes. The mixing unit was pre-heated inside an oven at the test temperature for at least one hour prior to the test. The drainage baskets containing the mix were hung freely over the tray in the oven at pre-selected test temperature as shown in Table 4. After three hours, the drainage basket and tray were removed from the oven and the mass of tray was recorded after it has sufficiently cooled.

The material that drained onto the tray was a combination of bitumen and filler. The percentage of drained binder was calculated from Equation (1).

$$BD(\%) = \frac{100 \times B\left(\frac{D}{B+F}\right)}{1100 + B} \qquad \text{Equation (1)}$$

Where:

BD = Drained binder (%)
D = The Mass of Binder and Filler Drained (gm)
B = The Mass of Binder in The Mix (gm)
F = The mass of filler in the mix (gm)

Binder Type	Temperature (°C)	
	Mixing	Binder Drainage Test
Modified Bitumen PG-76	170	180
Conventional Bitumen 60/70	155	165

Table 4: Mixing and Binder Drainage Test Temperatures

2.3.3 Permeability Test

The purpose of the permeability test is to evaluate the drainage capacity of the sample. A permeameter based on the falling head principal was used to quantify the coefficient of permeability by creating a hydraulic gradient across the specimen to measure the water flow over a period of time.

The confined specimen in the Marshall mould was fixed on the rubber padding attached to the perspex plate and the screws were fastened to avoid any leakage. The orifice of the tube was sealed using a rubber bung. When the water reached a stable state, the rubber bung was pulled out and the time taken for the water to flow from one designated point to the other was noted. The time recorded was taken as the coefficient of permeability using Equation (2).

$$k = 2.3\frac{aL}{At}\log_{10}\left(\frac{h1}{h2}\right) \qquad \text{Equation (2)}$$

Where:

k = Coefficient of permeability (cm/s)
A = Cross section area of specimen (cm^2)
a = Cross section area of standpipe (cm^2)
L = Height of specimen (cm)
t = Time taken for water in the standpipe to fall from h_1 to h_2(s)

$h1$ = Head at the beginning of time measurement (cm)

$h2$ = Head at the end of time measurement (cm)

2.3.4 Determination of Air Voids

Mix air voids was evaluated based on the bulk specific gravity of compacted mix and the theoretical maximum density of the loose mix. The bulk specific gravity of compacted mix (G_{mb}) was determined using the Specimen Geometry Method (SGM) by measuring diameter, thickness and the mass of the specimen in air [15]. The G_{mb} was calculated from Equation (3).

$$G_{mb} = 4M_a / \pi d^2 h \qquad \text{Equation (3)}$$

Where:

M_a = Mass of specimen in air (g)

d = Diameter of specimen (mm)

h = Height of specimen (mm)

Furthermore, the theoretical maximum density (G_{mm}) of the loose mix was ascertained according to ASTM D2041 procedures [16]. The air voids (V_a) in the compacted specimen was then calculated by using Equation (4).

$$V_a = 100x\,(1 - (G_{mb}/G_{mm})) \qquad \text{Equation (4)}$$

3. RESULTS AND DISCUSSION

3.1 Abrasion Loss

The abrasion loss of porous asphalt decreases as the binder content increases as reflected in Figure 4. Generally, the values differ with the type of gradation and the binder type used. The B6 mix exhibits the highest abrasion loss and followed by A6, BP, and AP mixes. Mixes prepared with Grading A results in greater resistance to abrasion loss for the mixes prepared with 60/70 binder; however the abrasion loss of both mixes are almost similar when prepared with PG-76 bitumen.

The solid horizontal line represents the permitting abrasion loss value (16%) at Malaysian ambient temperature, 30°C. The corresponding binder contents, and which is also the minimum limit of the design binder content for mixes A6, AP, B6 and BP are 3.67%, 3.60%, 4.10% and 3.58%, respectively.

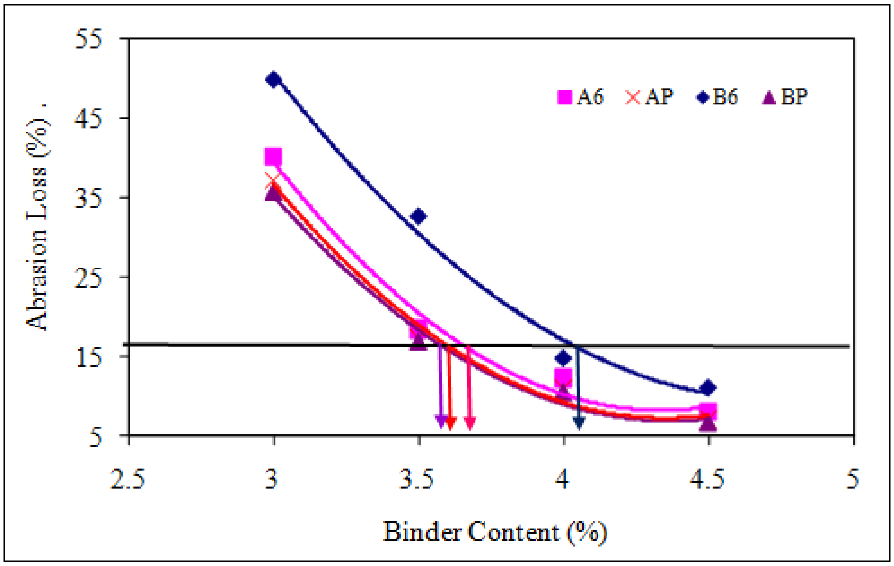

Figure 4: Relationship of Abrasion Loss versus Percentage of Binder Content

3.2 Binder Drainage

The relationship between binder content and percentage of binder drained is shown in Figure 5. The results indicate that the binder drainage increases as the binder content increases. The target binder content is taken as the value that corresponds to the maximum drained binder allowed, which is 0.3% of the total mix as illustrated in Figure 5. For mix B6 and A6 prepared with conventional binders, the respective limiting binder contents are 5.87% and 6.80%. By using modified binder PG-76, the limiting binder content increases by approximately 2%.

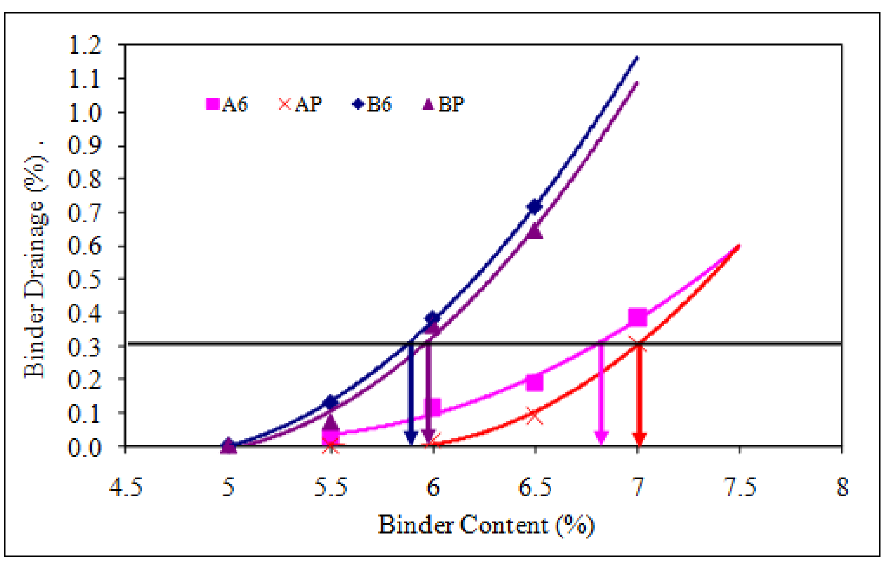

Figure 5: Relationship of Binder Drainage versus Percentage of Binder Content

3.3 Air Voids

Within the range of binder contents tested, the linear relationship between air voids and binder contents for all mixes tested is shown in Figure 6. A noticeable reduction in mix air voids is very apparent as the binder content increases. Additional bitumen in the mixture filled up the spaces between the aggregates and the rest remain as air voids.

The PWD specification [18] recommends mix air voids not less than 18%. The binder contents corresponding to this limiting air voids for B6, A6, BP and AP mixes are equal to 5.80%, 4.62%, 7.10% and 4.60%, respectively.

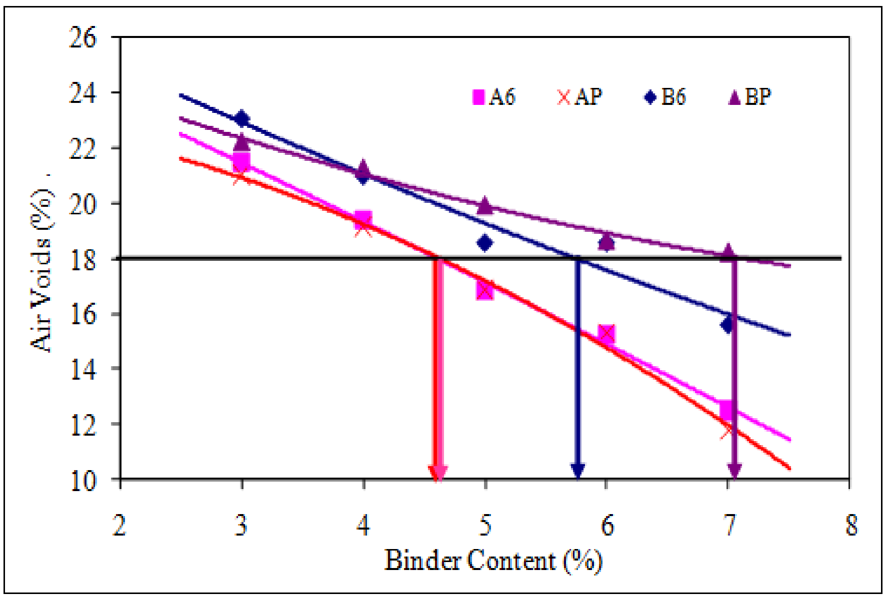

Figure 6: Relationship of Air Voids versus Percentage of Binder Content

3.4 Coefficient of Permeability

Drainage capacity is an important property of open mixes. Excessive binder may disrupt the continuity of air voids and resulted in reduced permeability. From the overall results shown in Figure 7, B6 and BP mixes exhibit higher coefficient of permeability compared to mixes prepared with Grading A. This may be due to higher air voids continuity that exists in the mixes. Mallick et al [17] recommended coefficient of permeability not less than 0.116cm/s to ensure a good drainage system. From Figure 7, the limiting binder contents to satisfy permeability requirements for mix A6, B6, AP and BP are 4.84%, 6.70%, 4.82% and 7.40%, respectively.

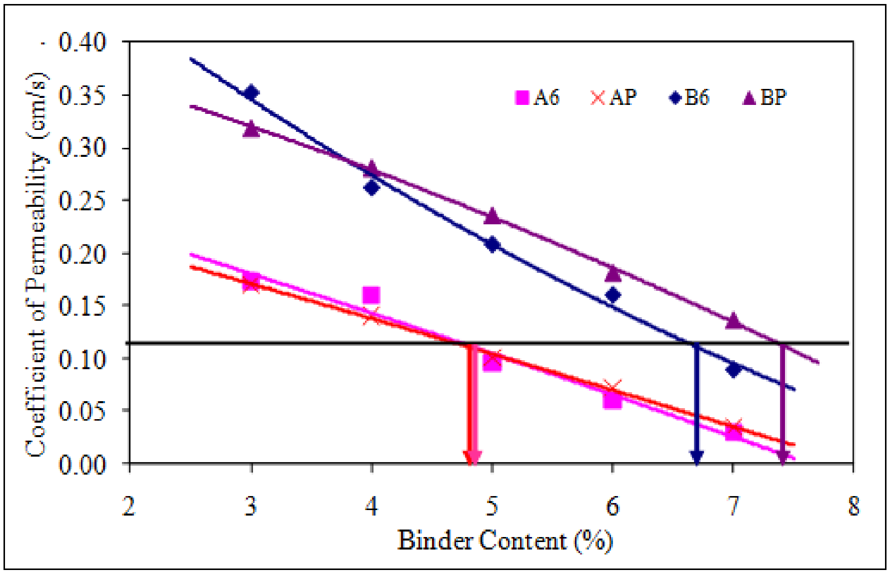

Figure 7: Relationship of Coefficient of Permeability versus Percentage of Binder Content

3.5 Summary of Design Binder Content Limits

Figure 8 illustrates the band charts of the limits of binder content for all mixes. Each mix exhibits different binder content limits due to differences in aggregate gradation and bitumen type. The design binder content is taken as all criteria that overlap each other at certain limit of binder content. Table 5 summarises the design binder contents obtained from this study. The highest mean binder content (4.95%) is recorded by mix B6, followed by BP, A6 and AP mixes, corresponding to binder contents 4.70%, 4.15% and 4.10%, respectively.

Mix Designation	Lower Limit	Upper Limit	Mean Design Binder Content
A6	3.67	4.62	4.15
AP	3.60	4.60	4.10
B6	4.10	5.80	4.95
BP	3.58	5.82	4.70

Table 5: Summary of Design Binder Content

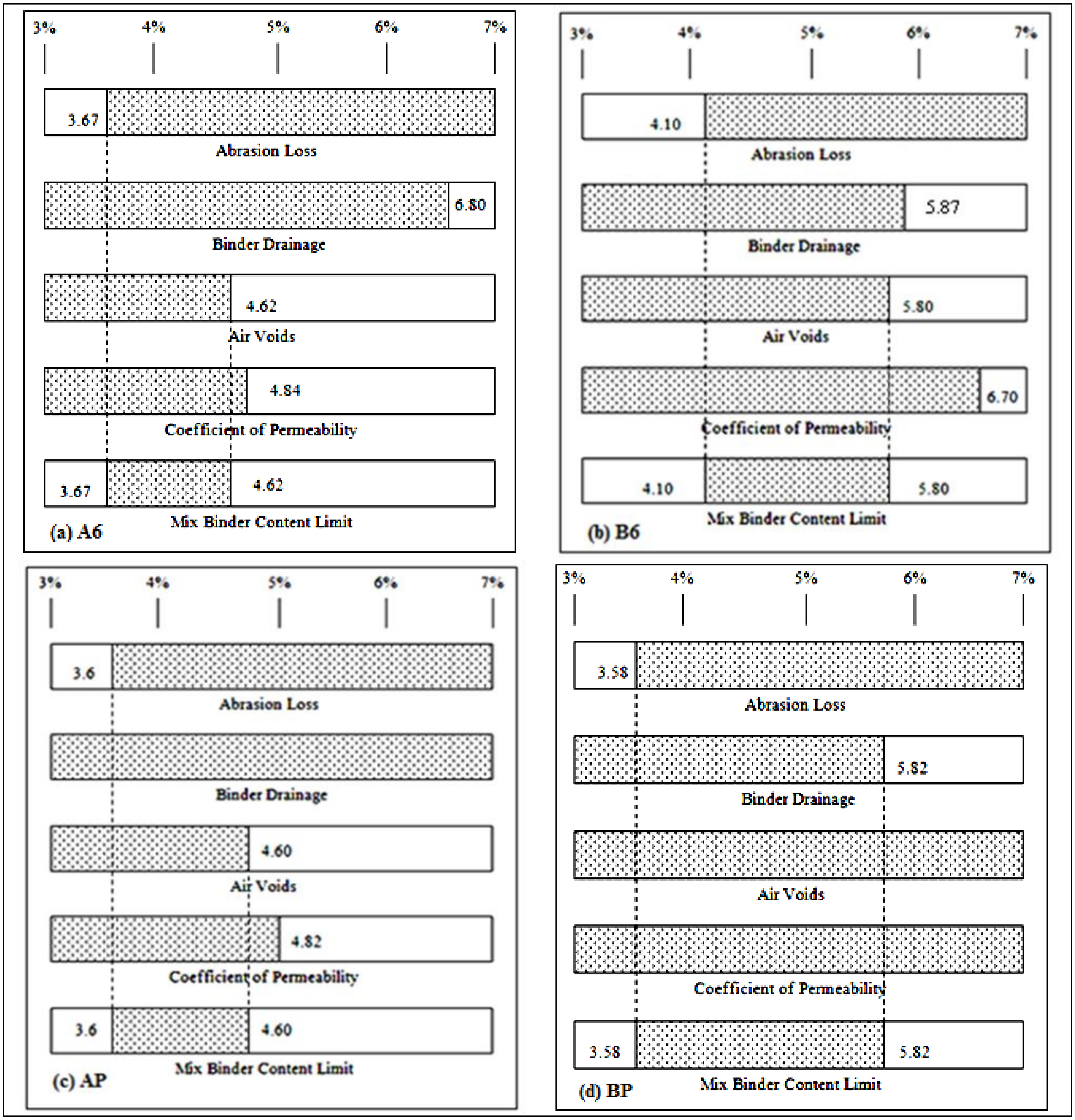

Figure 8: limitation of design binder content

4. CONCLUSION

A method to select the design binder content has been proposed based on the abrasion loss from the Cantabro test, air voids, permeability, and binder drainage test results. Adequate binder content is essential to ensure good mix performance. Mix with higher air voids content, good drainage capacity, less susceptible to binder drain down and higher durability are crucial in promising effective drainage system and longer service life. Use of modified binder enables addition of higher binder content without excessive drainage due to its higher stiffness. This is expected to prolong mix service life due to thicker bitumen film thickness coating aggregate particles.

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