IMPROVED PERFORMANCE MIXTURE DESIGN METHODOLOGY FOR UK AIRFIELD POROUS FRICTION COURSE

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ABSTRACT

Historically, Porous Friction Course (PFC) has been successfully adopted by the Defence Estates (DE) on runways at various Ministry of Defence (MOD) airfields in the UK. Although satisfying the specialist performance criterion set in DE Specification 040, failures of the PFC surfacing have been reported during the past decade, mainly due to changes in weather, loading conditions, type and aircraft operations. This paper presents a step forward from the current mixture design to the performance related design approach, with the scope of optimising the mixture design and enhancing the PFC performance. Performance related requirements were introduced, comprising resistance to age-hardening, water induced damage and de-icing fluid, along with specific assessment methodology to determine the suitability of PFC to meet the future challenging demands. The mixture design main stages adopted aimed to enhance the current DE Specification 040 and encompassed mixture volumetrics and workability study, assessment of key surfacing characteristics, assessment of key mechanical properties, durability and mixture design optimisation. Significant mechanical properties improvement was observed for PFC containing polymer modified bitumen and hydrated lime additive. The use of hydrated lime in the polymer modified PFC led to stiffness and tensile strength improvement with respect to resistance to moisture damage and de-icing fluid. The improved performance mixture design methodology was developed based on this study and was subsequently adopted in an airfield resurfacing work in the UK.

Keywords: porous friction course, performance, durability, resistance to de-icing fluid

1. INTRODUCTION

Owing to its good resistance to cracking, reduced spray, good friction properties and good draining characteristics, the PFC has been preferred as surfacing material on the main length of MoD airfields runways and has been extensively used since the early 1960s. The service life of PFC on MoD airfields ranges from 12 to 25 years (typical service life 17 years) and the maintenance requirements are reported as minimal.

However, similar to most asphalt materials, PFC has poor resistance to fuel spillage which limits its application for areas where aircrafts stand, move slowly or routinely make tight turns. Furthermore, the high air voids content (typically around 20%) may allow water and air to penetrate which can accelerate ageing, leading to rapid hardening, reduced flexibility and ultimately to aggregate loss and fretting.

Typically, the PFC mix design incorporates high quality 2/10mm aggregate and 160/220 paving grade bitumen which results in a relatively flexible material able to inhibit reflection cracking and reduce the rate of age hardening.

Historically, the following properties were desirable for durable PFC:

- Aggregate properties: strong, durable, good affinity with bitumen;
- Aggregate skeleton: stone-to-stone contact to ensure good resistance to deformation and interconnected voids to facilitate permeability;
- Bitumen grade: soft grade bitumen to ensure flexibility and durability;
- Mixture design: PFC is recipe designed, with specified combined aggregate gradation and bitumen content; bitumen drainage and permeability tests are also specified.

Most of the failures reported on airfields developed as ravelling and loss of material and were due to the excessive shear force caused by aircraft and premature aggregate loss due to the action of mechanical sweepers. The problem was also exacerbated by the recent changes in climate conditions. Therefore, the traditional mixture design may no longer be sustainable and the transition to performance related design appears to be the optimal approach (BS EN 13108-7). As a result, there is an urgent need for optimising the mix design and enhancing the PFC performance.

In this study, the following mixture design stages were adopted, aiming to enhance the current PFC Specification [1]:

- Mixture composition (target aggregate gradation and bitumen content), including bitumen drainage test;
- Key surface characteristics, such as vertical permeability, skid resistance and texture depth and resistance to lateral shear force;
- Key mechanical properties (resistance to fretting, resistance to deformation) and durability (resistance to age-hardening of the bitumen, water and de-icing fluid);
- Mixture design optimisation.

2. MIXTURE COMPOSITION

The PFC mixtures under study were referenced as Mixture A (incorporating 160/220 penetration grade bitumen) and Mixture B (incorporating a proprietary PMB, bitumen slightly modified by Styrene Butadiene Styrene) respectively. For Mixture A, the study was carried out with the addition of hydrated lime filler (HL); for Mixture B, the study was carried out with and without the addition of HL. The optimum combined aggregate gradation was developed to meet the target specification envelope for the PFC mixture design [1].

One of the main risks associated with manufacturing, transporting and laying PFC is the drainage of bitumen from the aggregate, due to too low viscosity or too high bitumen content. To ensure that the optimum bitumen content is selected avoiding any drainage, the amount of bitumen and fine particles (if any) separated from the mixture following the mixing process was assessed in accordance with the Basket Method described in BS EN 12697-18.

Five number target bitumen contents were studied, starting with a minimum value of 5.2% and increasing the bitumen content by 0.3% increments by mass each time. The bitumen drainage in all cases was considered insignificant. Subsequently, a bitumen content of 5.5% was adopted for this study. This level is the minimum bitumen content specified by DE Specification 040 [1] and was adopted not only because this would be a worse case scenario in terms of mixture durability but also because this would be the bitumen content typically adopted for economical reasons.

The adopted mixture compositions for the PFC mixtures are presented in Table 1.

Table 1: Mixture Composition

Description	**Proportion (%) by Weight of Mixture**		
	Mixture A (160/220)	**Mixture B (PMB) without HL**	**Mixture B (PMB) with HL**
4/10mm	52.92	52.92	52.92
2/6.3mm	17.96	17.96	17.96
0/4mm	20.79	20.79	20.79
Limestone filler	1.42	2.84	1.42
Hydrated lime (HL)	1.42	-	1.42
Binder	5.50	5.50	5.50

The mixing process and roller compaction of slabs were carried out in accordance with BS EN 12697-33 and in-house procedures; specimens of suitable size for testing were subsequently removed from the slabs.

3. MECHANICAL PROPERTIES

3.1 Wheel Tracking

Although there are no specific requirements for deformation resistance of PFC materials, the resistance to permanent deformation of unaged and aged mixtures was assessed at 60°C, a test temperature adopted in the UK for assessment of performance related design mixtures for very heavily stressed sites requiring very high rut resistance. The laboratory accelerated ageing was carried out in accordance with Appendix A.12 of British Board of Agrément (BBA) Document SG3/08/256 [2]. The Wheel Tracking test was carried out in accordance with BS 598: Part 110, under the standard test conditions of a wheel load of magnitude 520 N, which moves backwards and forwards in simple harmonic motion at 42 passes per minute (21 cycles per minute). In this test, wheel tracking is continued until 45 minutes has elapsed, or a 15mm rut has developed, and the permanent deformation is recorded at 5 minute intervals.

Table 2: Wheel Tracking at 60°C

Mixture Ref		**Air Voids (%)**	**Rut Depth (mm)**	**Rut Rate (mm/hr)**
Mixture A (160/220)	unaged	19.2	3.0	1.0
	after ageing	20.0	1.9	0.8
Mixture B (PMB) without HL	unaged	20.5	4.3	0.5
	after ageing	18.2	2.7	1.1
***UK Requirements for very heavily stressed sites requiring very high rut resistance**			≤ 7.0	≤ 5.0

Note: *BSI PD 6691 refers; for guidance only.

The average data presented in Table 2 suggested that both PFC mixtures provide adequate resistance to permanent deformation for heavily stressed road pavements, with a reduced risk of early life rutting. The laboratory ageing procedure led to a reduction in the rut depth.

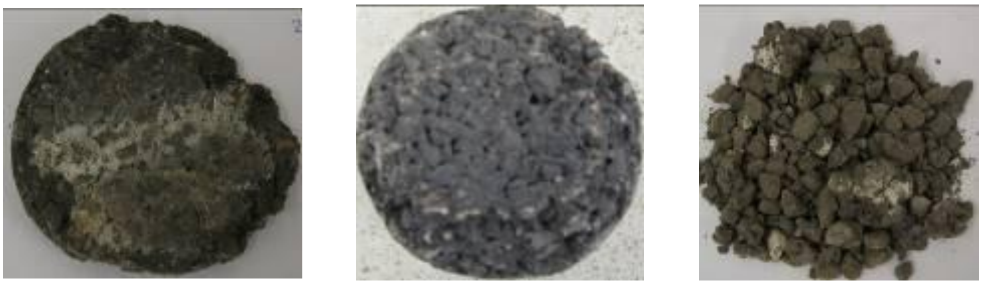
3.2 Resistance to Particle Loss (Cantabro Abrasion Test)

The Cantabro Abrasion Test was carried out in the Los Angeles abrasion machine, in accordance with EN 12697-17, to determine the loss of aggregate due to abrasion. Although the test is arguably crude and exerting severe force to the specimens, it has been widely implemented for assessment of PA type materials due to its simplicity and practicality to screen out suspected poor mixture design. The results are presented in Table 3; the benchmark adopted for the visual assessment of the sample conditions after testing is illustrated in Figure 1.

Table 3: Particle Loss

Mixture Ref		Mass Loss (%)	Extent of Damage (Visual Assessment)
Mixture A (160/220)	unaged	8.1 (7.3 – 9.4)	Low to Moderate
	after ageing	17.0 (15.5 – 18.3)	Low to Moderate
Mixture B (PMB) without HL	unaged	13.5 (12.1 – 15.4)	Low to Moderate
	after ageing	29.1 (25.7 – 33.5)	Moderate
Mixture B (PMB) with HL	unaged	19.0 (16.9 – 21.6)	Low to Moderate
	after ageing	27.6 (24.8 – 31.0)	Moderate

Note: Values in parenthesis denote range of data.



Low/Moderate Damage (35% particle loss)

Moderate Damage (50% particle loss)

High Damage (100% particle loss)

Figure 1: Benchmark for Visual Assessment of Sample Condition after Cantabro Testing

The average particle loss percentage for both Mixture B (PMB), with and without HL, was significantly higher than that found for Mixture A (160/220). All three mixtures showed an increase in the particle loss percentage after the laboratory accelerated ageing protocol, more significantly for Mixture A (160/220) and Mixture B (PMB) without HL. Overall, the particle loss recorded for all unaged samples was found to be lower than the threshold value of maximum particle mass loss of 25% specified for PA surface course in Ireland [3]. However, the repeatability of this test appears to be rather poor as reflected by the range values of particle mass loss which can vary up to 5% (unaged samples) or 8% (aged samples). These results also suggest that, for the samples subjected to this test, no improvement in the performance of the PA using PMB and/or HL was observed.

3.3 Stiffness

The Indirect Tensile Stiffness Modulus (ITSM) was assessed in the Nottingham Asphalt Tester (NAT), at various temperatures, 5 ± 2 microns target deformation and 124 ± 4 milliseconds rise time, in order to assess the stiffness, durability (resistance to age-hardening and de-icing fluid) and the temperature susceptibility of the materials. The test was carried out on samples in three conditions:

- unaged;
- after conditioning in de-icing fluid: soaking test procedure was carried out broadly in accordance with BS EN 12697-41 . In this case, the de-icing fluid was used in 100% concentration (i.e. as received);
- after ageing: laboratory accelerated ageing procedure **[2].**

The temperature susceptibility was assessed for Mixture A and Mixture B without HL in aged condition (by carrying out the test at -18°C, 5°C and 25°C), whilst the effects of the conditioning and ageing procedures were evaluated for all three mixes, by carrying out the ITSM at 25°C. The results are presented in Table 4 and Figure 2.

Table 4: Stiffness (ITSM)

Mixture Ref		Stiffness (MPa) @		
		-18°C	5°C	25°C
Mixture A (160/220)	unaged	-	-	190 (140 – 330)
	after conditioning in de-icing fluid	-	-	sample disintegrated
	after ageing	19740 (16620 – 23110)	4440 (3920 – 5160)	500 (250 – 800)
Mixture B (PMB) without HL	unaged	-	-	1490 (1230 – 1900)
	after conditioning in de-icing fluid	-	-	1400 (940 – 1870)
	after ageing	23530 (19650 – 25990)	9300 (8530 – 9810)	1520 (1450 – 1620)
Mixture B (PMB) with HL	unaged	-	-	1250 (1080 – 1370)
	after conditioning in de-icing fluid	-	-	1680 (1310 – 2000)

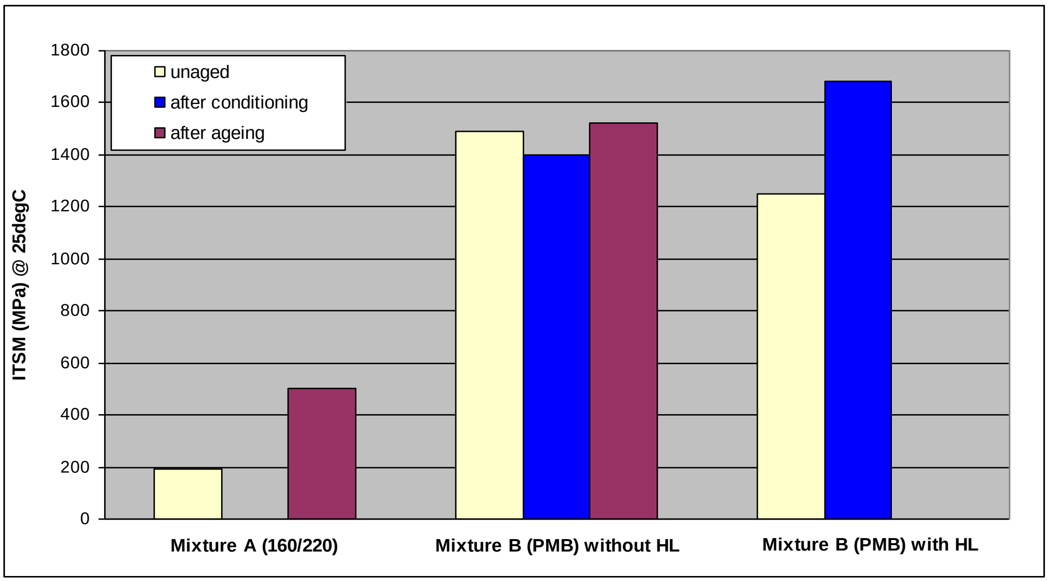


Figure 2: Susceptibility of ITSM @ 25°C to Conditioning in De-icing Fluid and Ageing

The data presented in Table 4 and Figure 2 shows that the stiffness of Mixture A (160/220) at 25°C was significantly lower than that of Mixture B, with and without HL respectively. Also, Mixture A was found to be more temperature susceptible than Mixture B (PMB) without HL.

The stiffness data suggests that Mixture B was less sensitive (more resistant) to ageing than Mixture A, highlighting the benefits in using PMB (reduction of stiffness sensitivity to temperature changes and age-hardening). It is of course true that the penetration of the bitumen in Mixture A (160/220) is higher than that in Mixture B (PMB) and therefore greater change with age would be expected with the former.

The conditioning in de-icing fluid did not incur any significant changes in stiffness for Mixture B (PMB) without HL, whilst an average stiffness increase of around 35% was noted for Mixture B (PMB) with HL. Mixture A (160/220) samples disintegrated during the conditioning period. The use of HL in Mixture B improved the mixture resistance to de-icing fluid. This indicates a potential benefit from using both HL and a PMB.

3.4 Indirect Tensile Strength

The Indirect Tensile Strength Test (ITST) was carried out in accordance with Section 10.2 of AASHTO T283, on samples in three conditions: unaged, after ageing, after conditioning (as described in Section 3.3). Temperature susceptibility in aged condition and the effects of ageing and conditioning in de-icing fluid were also assessed. The results are presented in Table 5 and Figure 3.

Table 5: Indirect Tensile Strength (ITS)

Mixture Ref		ITS (GPa) x 10^{-4} @		
		-18°C	**5°C**	**25°C**
Mixture A (160/220)	unaged	-	-	1.35 (1.12 – 1.84)
	after conditioning in de-icing fluid	-	-	sample disintegrated
	after ageing	16.1 (15.3 – 17.6)	13.0 (12.9 – 13.2)	1.75 (1.63 – 1.80)
Mixture B (PMB) without HL	unaged	-	-	6.77 (6.43 – 6.97)
	after conditioning in de-icing fluid	-	-	7.95 (5.30 – 10.8)
	after ageing	17.5 (15.3 – 19.3)	19.9 (18.3 – 21.3)	7.61 (6.86 – 8.21)
Mixture B (PMB) with HL	unaged	-	-	7.90 (7.34 – 8.41)
	after conditioning in de-icing fluid	-	-	7.99 (7.40 – 9.06)

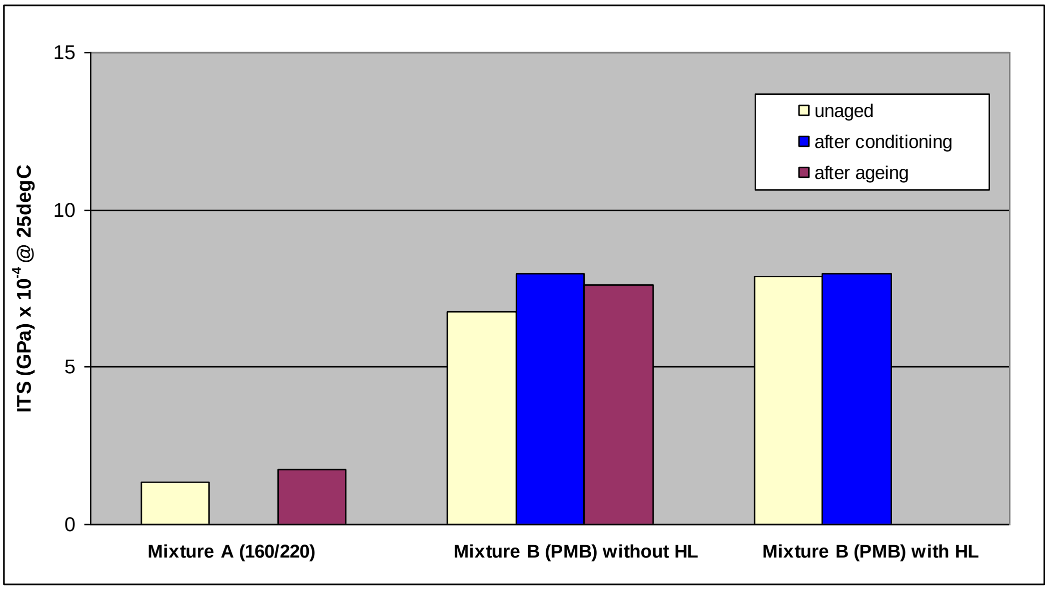


Figure 3: Susceptibility of ITS @ 25°C to Conditioning in De-icing Fluid and Ageing

The data presented in Table 5 and Figure 3 show that the ITS at 25°C for both of the Mixture B (PMB) mixtures was comparable and significantly better that that of Mixture A (160/220). Higher tensile strength is desirable to resist lateral stresses induced by an aircraft. For comparison, a B747 aircraft may induce horizontal shear stress of up to 5 x 10^{-4} GPa [4]; an excessive horizontal shear stress induced by an aircraft may break the cohesive bond within the surfacing material, leading to material loss (fretting). In this case, Mixture A (160/220) is unlikely to withstand horizontal shear stress exerted by a heavy aircraft and PMB (such as that used in Mixture B) is required to improve the ITS.

At lower temperature range (-18°C to 5°C), no significant ITS changes were observed for the aged Mixture A and Mixture B without HL materials; however, both mixes exhibited a significant drop in tensile strength at temperature range of 5°C to 25°C. Aged Mixture B showed higher ITS throughout the entire temperature range and the values remained above 5×10^{-4} GPa, demonstrating the benefit of using PMB to reduce the sensitivity to temperature changes. The failure modes of both mixtures were relatively similar, i.e. clear tensile break at -18°C (samples in elastic condition) and combination between clear tensile break and deformation at 5°C and 25°C (samples in visco-elastic condition). After the ageing process, there was a small increase in the ITS values, which is typical for asphalt.

After conditioning in de-icing fluid, Mixture A samples disintegrated during the conditioning period whilst the two Mixture B materials exhibited a slight increase in ITS values. This demonstrates the benefit of using PMB to improve the resistance to de-icing fluid.

3.5 Low Temperature Performance

A summary of the laboratory aged materials performance at low temperature (-18^{o}C) is reproduced in Table 6.

Table 6: Low Temperature Performance

Mixture Ref		Test @ -18^{o}C		
		ITS (GPa) x 10^{-4}	**ITVD (mm)**	**ITSM (MPa)**
Mixture A (160/220)	after ageing	16.1 (15.3 – 17.6)	1.5 (1.4 – 1.7)	19740 (16620 – 23110)
Mixture B (PMB) without HL	after ageing	17.5 (15.3 – 19.3)	2.2 (1.1 – 3.3)	23530 (19650 – 25990)

ITVD is an indirect tensile vertical deformation at the point of sample failure. This parameter has been considered to provide an indication of low temperature 'ductility'; a higher ITVD value might be regarded as being less brittle than, and preferable to, a smaller value. Table 6 data suggest that the use of PMB contributed to a slight improvement in stiffness, indirect tensile strength and low temperature ductility the PFC samples.

3.6 Resistance to Moisture Induced Damage (Freeze-Thaw Cycles)

The resistance of the PFC materials to moisture induced damage was assessed in accordance with AASHTO T283 test procedure. The test protocol requires two sets of specimens ('dry' and 'wet' sub-sets) with similar mixture type and volumetrics; the retained indirect tensile strength is calculated based upon the ratio of the mean indirect tensile strength of the 'wet' sub-set to that of the 'dry' sub-set. The moisture conditioning was carried out by subjecting the 'wet' sub-sets to vacuum saturation followed by a freeze-thaw and other temperature conditioning cycles, specifically, for one cycle: a minimum of 16 hours at -18 ± 3^oC, 24 ± 1hours at 60 ± 1^oC and a minimum of 2 hours at 25 ± 1^oC. The 'dry' sub-sets were tested after conditioning at 25 ± 1^oC for a minimum of 2 hours. The results are presented in Table 7.

Table 7: Retained Indirect Tensile Strength

Mixture Ref	Resistance to Moisture Damage		
	Set	**Indirect Tensile Strength (kPa)**	**RITS (%)**
Mixture A (160/220)	Dry	114	39
	Wet	44	
Mixture B (PMB) without HL	Dry	677	40
	Wet	269	
Mixture B (PMB) with HL	Dry	790	78
	Wet	618	

Mixture A (160/220) exhibited significantly lower tensile strength when compared with Mixture B (PMB) materials. Furthermore, the addition of HL has clearly improved the indirect tensile strength of Mixture B (PMB), in both 'dry' and 'wet' conditions, respectively. According to the Federal Aviation administration (FAA) Advisory Circular (AC) 150/5370 [5], airfield asphalt surfacing materials with RITS of 75 or greater could be deemed as not-prone to stripping. The RITS values indicate that Mixture A (160/220) would be considered to have poor resistance to moisture induced damage, whilst Mixture B (PMB) with HL showed a significantly better RITS value. Overall, the results indicate the benefit of using both PMB and HL to improve RITS value.

4. CONCLUSIONS

Significant mechanical properties improvement can be achieved when using PMB and/or HL additive. The best performance was obtained when both PMB and HL were used in the PFC. Also, the use of HL additive in the PFC (PMB) enhanced the stiffness and tensile strength values specifically with respect to resistance to moisture damage (freeze thaw cycles) and de-icing fluid.

Figure 4 presents a proposed mixture design methodology, which is based upon the current study findings.

Further work incorporating wider range of PFC materials (e.g. PFC with different PMBs and/or adhesion promoting agents) and field trials are recommended, to enable verification whether the proposed threshold values are practical and achievable in practice.

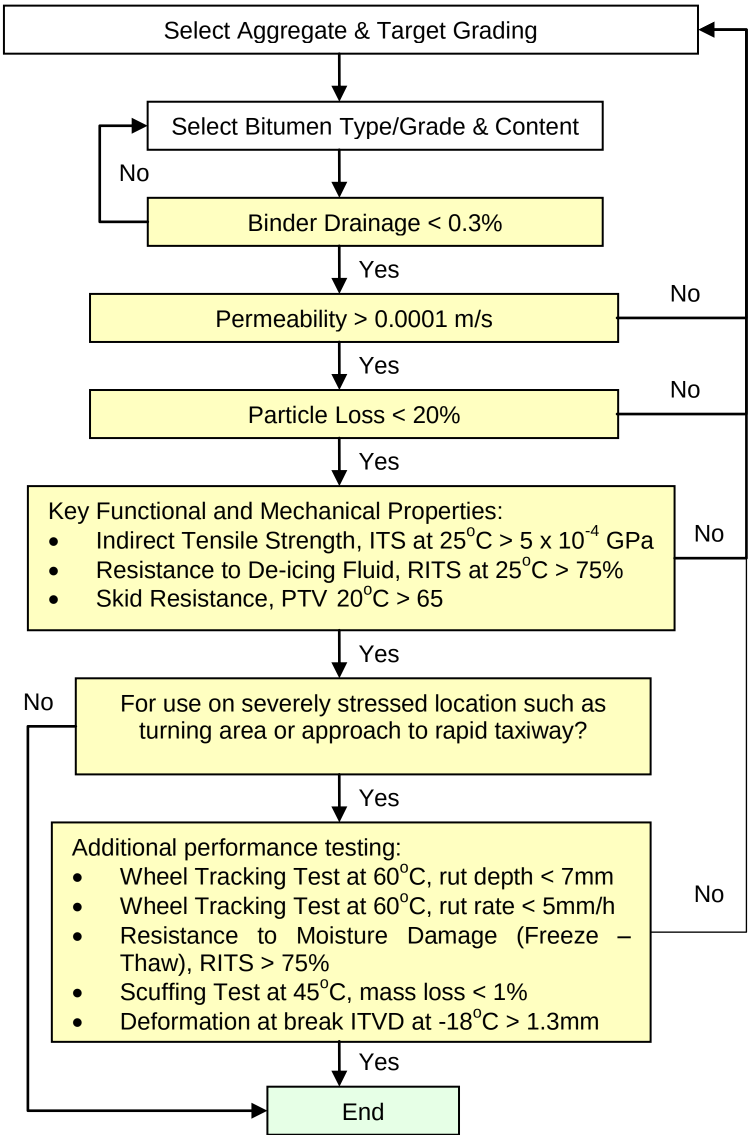


Figure 4: Proposed Methodology for Mixture Design

Note 1: The Particle Loss (Cantabro Abrasion Test) is regarded by some authorities as too severe, with relatively poor repeatability. However, it has been included in the above methodology due to its simplicity and practicality to screen out suspected poor mixture design.

Note 2: A comprehensive surface characteristics study including permeability, skid resistance by Pendulum Test, texture depth and resistance to lateral shear force was carried out and the findings were presented in Asphalt Professional No 47, February 2011 [6].

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