ASPHALT MIX DESIGN AND CONSTRUCTION: A SELECTION OF POSSIBLE PITFALLS

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ABSTRACT

Every year large volumes of asphalt are paved on roads, streets, airports and other pavements in southern Africa. The requirements in terms of performance of some of these asphalt pavements are high due to severe environmental or loading conditions. Failures in asphalt layers occurs regularly on asphalt projects in southern Africa. Most of these failures in asphalt pavements can be attributed to some problem during the mix design, manufacturing or paving operation.

The paper describes lessons learnt from asphalt failures and problems experienced during the last few years on a number of projects in southern Africa. It provides a look at various asphalt mix design and construction factors, as experienced on actual projects, that may result in problems or defects that leads to various distress types, including deformation, stripping, high permeability and premature cracking. Examples from actual projects are presented.

The paper concludes with the factors that repeatedly results in problems with asphalt mixes and that should be kept in mind during the design, manufacturing and paving of asphalt mixes.

Keywords: Asphalt mix design, Permeability, Surface texture, Asphalt failures, Stripping, Permanent deformation, Quality control, Bitumen, Marshall mix design

1. INTRODUCTION

A large portion of surfaced roads in South Africa have asphalt as part of their pavement structure. These surfacings, and to some extent base layers, are used in a large variety of traffic loading and environmental conditions. The aggregates, fillers and bitumens used in asphalt mixes vary to a large extent and with the availability of good quality natural materials becoming less, the challenges in providing good quality asphalt mixes are increasing.

This paper takes a look at some of the common problems recently experienced in asphalt mix production and construction. Since the paper is based on failures rather than successes, few answers are provided on the number of questions that usually arises from asphalt failures and the aim is to create awareness on some possible pitfalls. The paper briefly reviews the background of asphalt mix design in South Africa and continues to discuss a few typical problems commonly encountered in South Africa recently. The paper emphasises the important role of asphalt permeability and other important aspects, but focus on aspects that are not addressed in the Interim guidelines for the design of hot mix asphalt in South Africa (HMA, 2001). A few case studies from recent projects are also included and evaluated.

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None of the results published in this paper were obtained from a research point of view and all data were collected from actual construction projects around Southern Africa.

2. BACKGROUND OF ASPHALT MIX DESIGN IN SOUTH AFRICA

The use of hot-mix asphalt in South Africa dates back to the 1920's when the larger cities felt the need for more durable surfacing materials to pave their increasingly heavily trafficked streets. The use of asphalt has steadily increased since then and today the performance required from asphalt surfacings and bases are increasingly demanding. In 1978 the first draft Technical Recommendations for Highways on asphalt mix design (TRH8) was published and in 1987 it was revised (CSRA, 1987). This document provided guidelines on the selection and design of hot-mix asphalt surfacing layers and was centred on the Marshall design method. In 2001 the Interim guidelines for the design of hot mix asphalt in South Africa (HMA, 2001) was published and it included the latest international technology available.

Despite the availability of these manuals, as well as procedures produced by the Superpave project in the United States, premature failures of asphalt pavements still occur in South Africa. With experienced pavement engineers becoming more scarce in South Africa, young practitioners need access to information in order to gain experience on why asphalt layers still fail occasionally despite passing all (or most of) the laboratory tests during the design process.

3. TYPICAL PROBLEMS COMMONLY ENCOUNTERED ON ASPHALT PAVEMENT IN SOUTH AFRICA

In 1971 Charles Freeme (1971) identified cracking as the "cancer" of South African Roads. Cracking of asphalt layers was a major problem at that stage and he continued to develop transfer functions for the structural design of asphalt pavements against fatigue cracking. Although fatigue cracking in asphalt could still be regarded as a possible failure mechanism, modern asphalt mixes, with the addition off modifiers, are inherently more flexible and could take more strain than the mixes of the early 1970's. This has resulted that cracking is not the major problem on asphalt pavements any more, although instances of premature severe cracking has been recorded recently.

Because of the complexity of asphalt mixes, failure may occur as a result of a large variety of failure mechanisms. These mechanisms may be of structural or functional nature, but all will result in a condition where the asphalt layer will no longer be able to meet its designed purpose.

Typical failure mechanisms currently experienced includes:

- Permanent deformation
- Cracking
- Loss of surface texture (smoothing)
- Loss of surface aggregate
- Stripping
- Disintegration of the layer
- Bleeding and flushing

In most cases the failure of an asphalt layer cannot be ascribed to only one of the above failure mechanisms and is often due to a combination of a few of these. Proper mix design should prevent the occurrence of the above to happen prematurely, however, a few of the failure mechanisms listed above are dependant on the permeability of the layer. Currently there are few guidelines available on the permeability of asphalt mixes. The intent of the paper is not to discuss all the failure mechanisms mentioned, but rather to present a few significant causes for these failures.

3.1 Permeability

Permeability can be defined as the ability of a medium to allow the flow of a liquid or gas through it. Asphalt layers in the United States and in Europe are usually thick (more than 60 mm) and because of the thickness of the layer, the total layer is inherently less permeable, provided it is not a porous asphalt layer. South African pavements usually have a 40 mm asphalt surfacing layer on top of a granular base layer. Pre-coated chips are usually rolled into these surfacing layer to improve the surface texture and therefore the skid resistance. The performance of granular base layers are highly dependant on the moisture regime in these layers and granular layers tend to fail quickly when the moisture content of these layers become too high. An important feature of any “thin” asphalt surfacing layer would be to prevent the ingress of water into the granular base layers. The same argument is valid when overlaying and existing asphalt layer which, due to its age, could be permeable and trap water within itself. A permeable overlay would allow water to enter into the asphalt layer and high pore pressures could develop under the effect of traffic which could lead to stripping in the old asphalt.

Figure 1 presents a comparison between different Marshall compaction levels in the laboratory and air permeability on a medium continuously graded asphalt surfacing. Marshall briquettes were prepared at 45, 75 and 95 blows per side. The figure clearly indicates the decrease in permeability with increase in compaction level, but most of the values are still below the accepted maximum value of 1 x 10^{-8}cm^2. Note the difference in spread of permeability between lower compaction levels and higher compaction levels. The air permeability tests were done according to TRH8 appendix C (CSRA: 1987).

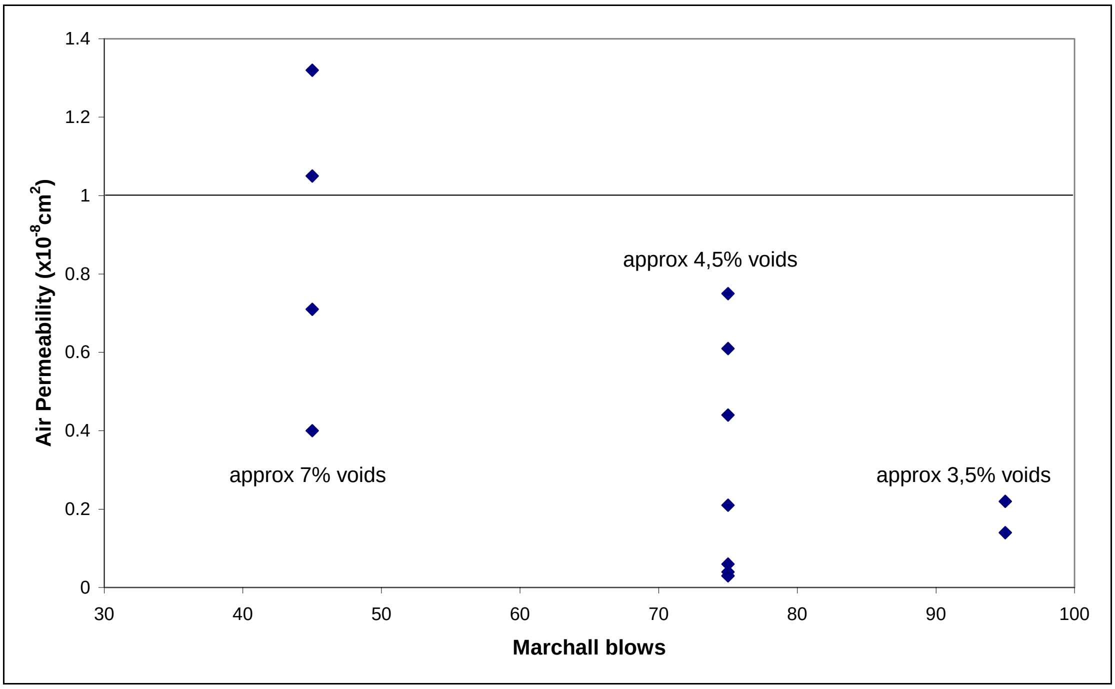

Figure 1. Comparison between different Marshall compaction levels and air permeability (medium continuously graded).

Figure 2 presents a comparison between air permeability as measured on laboratory prepared briquettes (60 mm thick) and field core samples (25 mm thick). Although the average void content on the cores was 1,5 times higher than the average of the briquettes, the average air permeability on the field cores was considerably (15 times) higher than the average air permeability on the laboratory briquettes. It should be noted that the thickness of the cores also played a significant role in the measured permeability value.

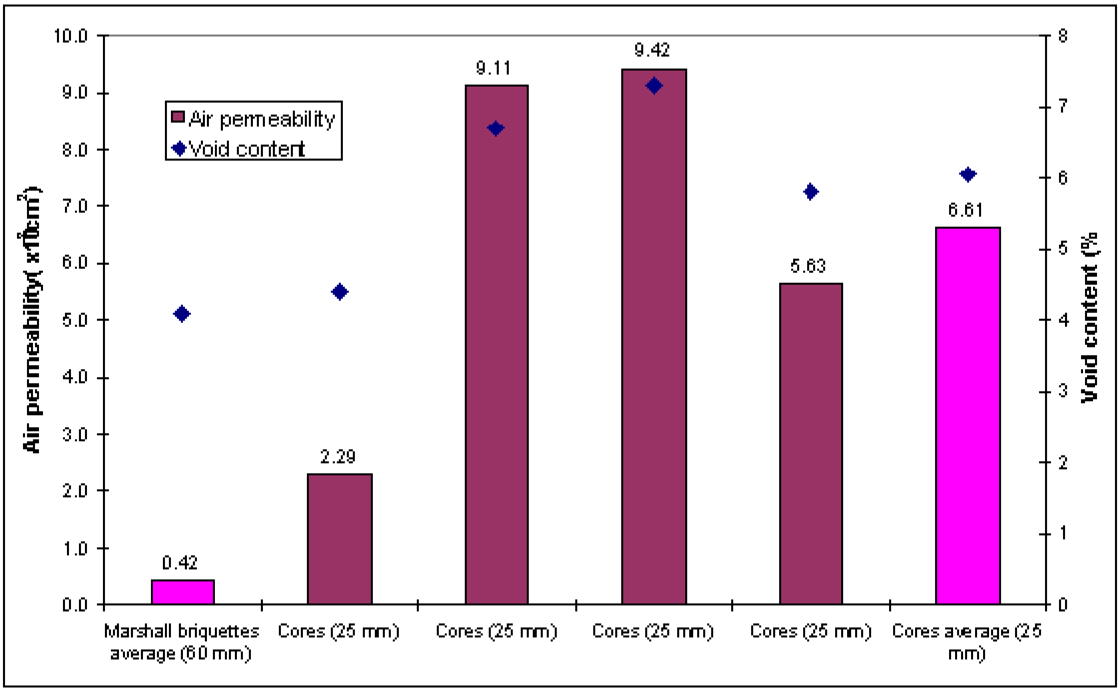

Figure 2. Comparison between laboratory briquettes and core samples (medium continuously graded).

Figure 3 presents a comparison between the air permeability on cores with rolled in pre-coated chips and cores without it on a 40 mm asphalt surfacing layer. This figure indicates that the air permeability of a 40 mm asphalt layer can be increased to a value of far over 1 x $10^{-8}cm^2$) with the addition of rolled in chips.

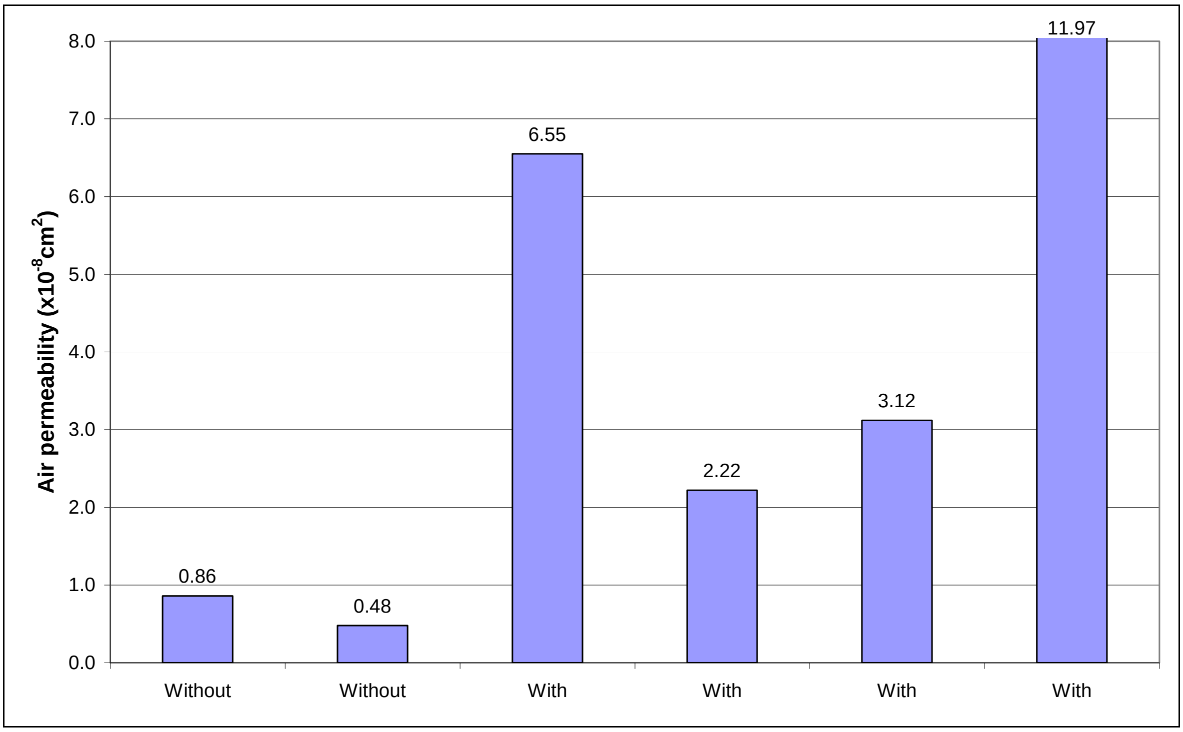

Figure 3. Comparison between air permeability of cores (medium continuously graded) with and without rolled in chips.

Traditionally, the air permeability of an asphalt layer was evaluated using laboratory prepared briquettes without rolled in chips. Figures 1 to 3 indicate that this is not necessarily a true representation of what is happening in the field. It is therefore possible that a asphalt mix may conform to the specifications if evaluated by using laboratory prepared briquettes, but may be highly permeable in the field due to the compaction, layer thickness and presence of rolled in chips. The void distribution of a Marshall briquette is substantially different to that of a rolling-wheel compaction. Hence, even at the similar void contents, the air and water permeability of briquettes and cores will be different. It is recommended that the permeability of asphalt layers be evaluated on field cores extracted from the constructed pavement.

Permeability test results on a medium continuously graded asphalt surfacing from a number of projects have been collected and are presented in Figure 4. The tests were all done on cores and the water permeability tests were done according to a test method described by Choubane et al (1998). The results presented indicate a clear trend between void content and permeability.

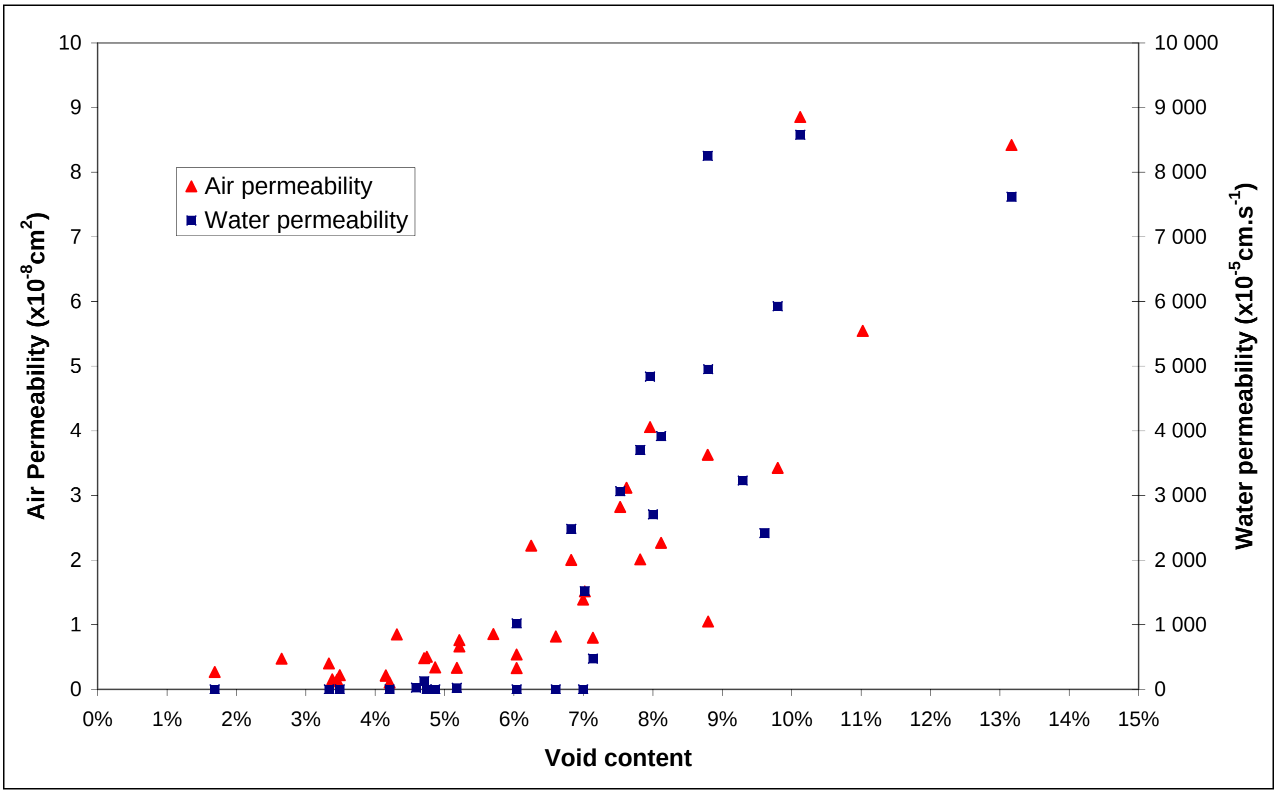

Figure 4. Medium continuously graded asphalt permeability test results.

Figure 5 and 6 presents the air and water permeability results from the above tests on a log-linear scale with a regression line fitted through the data points. If an air permeability value of 1 x 10^{-8}cm^2 can be regarded as a maximum, and a water permeability of 100 x 10^{-5}cm.s^{-1} as a maximum the maximum allowable field void content would be 6,5% (93,5% density). For a design mix with a production void content of 5%, the acceptance limit for density would be 92% (97 - 5), which would result in air and water permeability results of approximately 2 x 10^{-8}cm^2 and 600 x 10^{-5}cm.s^{-1} respectively. If conditional acceptance is introduced, the density could go as low as 91 %, further increasing the permeability of the layer.

A well designed, well constructed mix could therefore fail in terms of permeability because of a too low density to close the pores and reduce the permeability (but still within the density specification). A study of the correlation between the field asphalt permeability and field density should be undertaken on all projects where the permeability of the asphalt mix is of importance. The result of this study should be used to determine the minimum density specification.

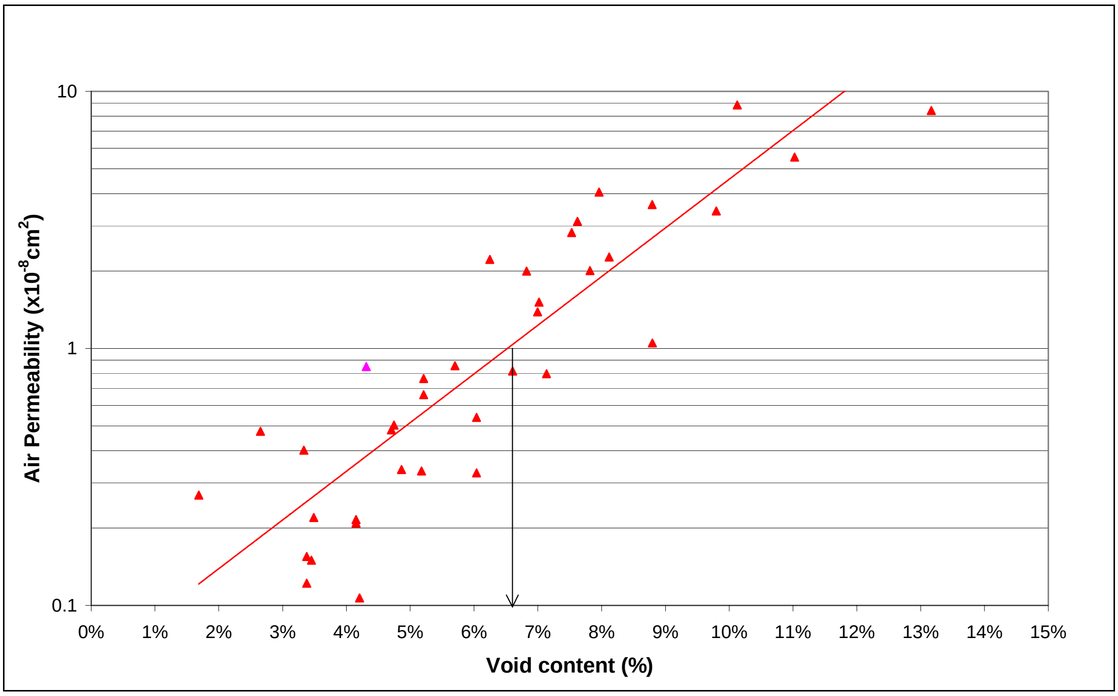

Figure 5. Air permeability vs. air voids (medium continuously graded).

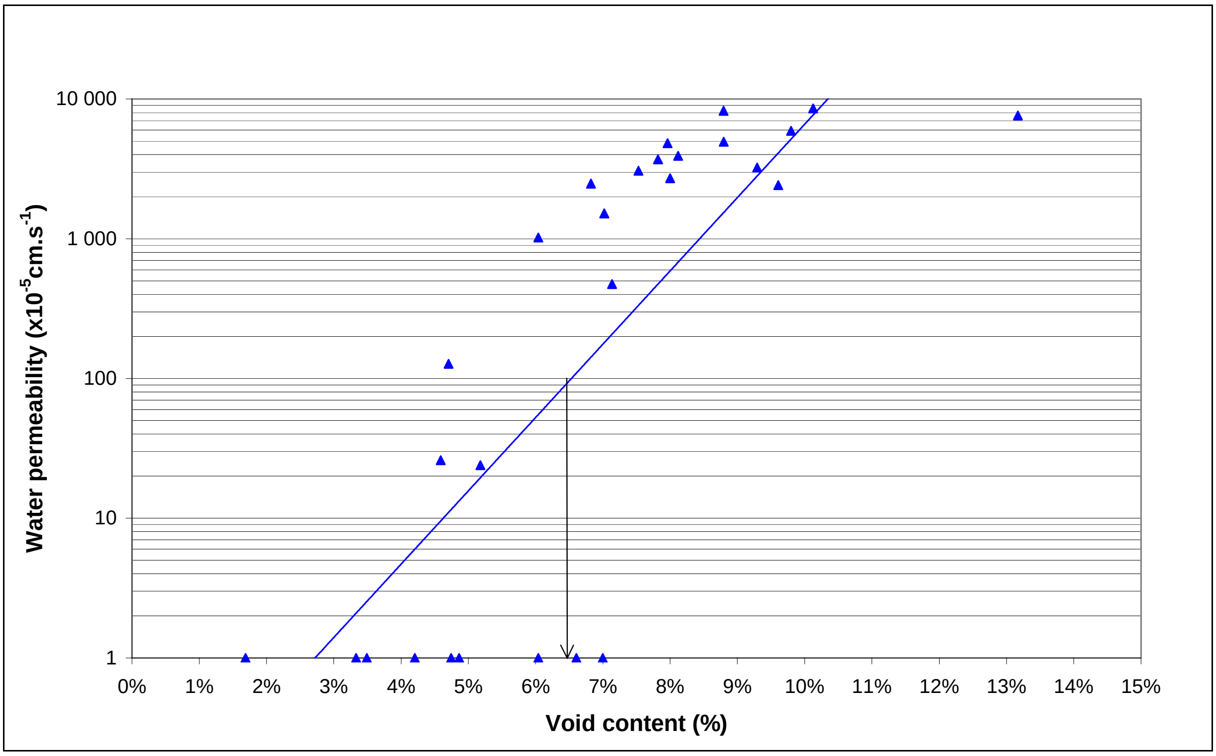

Figure 6. Water permeability vs. air voids (medium continuously graded).

3.2 Stripping of Binder

Bitumen stripping occurs when the bitumen looses its adhesion to aggregates in the asphalt mix. This usually occurs with the presence of moisture in the asphalt layer and is worsened when traffic loading cause high pore pressures within the asphalt surfacing. It is impossible for bitumen to displace water on the surface of an aggregate and stick to the aggregate, while it is possible for water to displace the bitumen from a bitumen coated aggregate. The more difficult it is for water to displace the bitumen, the less sensitive the mix is to stripping. The stripping potential of an asphalt mix can be evaluated by the Modified Lottmann test (Lottmann, 1978). The Riedel and Weber test was originally developed to test the bitumen adhesion for surfacing aggregates. In 1978 Lotttmann developed a test based on freeze-thaw cycles to evaluate the moisture sensitivity of asphalt mixes. The test was subsequently modified to one cycle (from the original 18 cycles), hence the name Modified Lottmann test.

The Interim South African Hot Mix Asphalt design guideline (HMA, 2001) provide guidelines for the moisture susceptibility of asphalt mixes in Southern Africa. These guidelines are presented in Table 1. Details of the interpretation of these values and the modified Lottmann test are presented in the HMA guideline (HMA, 2001) and are not repeated here. No details on the definitions of Low, Medium and High Permeability are presented in the HMA guideline document. The moisture susceptibility are presented as a percentage of the tensile strength of the conditioned sampled to the unconditioned sample. (Tensile strength ratio).

Table 1. Moisture susceptibility criteria (HMA: 2001).

Climate	**Permeability**		
	Low	**Medium**	**High**
Dry	60%	65%	70%
Medium	65%	70%	75%
Wet	70%	75%	80%

Table 2 shows results of moisture susceptibility results of a mix that conformed with all the specified requirements, except the moisture susceptibility test, which failed dismally. Initially, as a cost saving measure, no active filler was added to the mix and various options were explored to correct the moisture susceptibility without adding lime. Polyamine and cement were available on site, while lime needed to be imported from a neighbouring country, hence the decision to explore alternatives without lime. A moisture susceptibility of 65 % was aimed for on this project.

Table 2. Influence of various additives and active fillers on moisture susceptibility results.

Mix additives or active filler	**Moisture susceptibility result (Laboratory prepared mixes)**
No additives, no active filler	58,7 % 48,2 %
Polyamine added, no active filler	46,4 % 48,2 %
No additives, no active fillers, High P0,075 (P0,075 mm > 10)	3,2%
1% cement as active filler	41,9 %
1% lime as active filler	75,0 %
2% lime as active filler	50,5 %
	Moisture susceptibility result (Plant mixes)
No additives, no active filler	47,0 %
1% lime added – mixed with sand	52,9 %
1% lime added – injected in drum with bitumen	77,1 %

From this study it was then decided to add 1% lime to the mix, since all the other additives and active fillers did not correct the moisture susceptibility. It appears that the addition of 2 % lime changed the volumetrics of the mix and could be a possible reason that it did not correct the moisture susceptibility

Lime was initially introduced into the mix by means of a hopper system and entered the continuous mixing drum with the aggregate. Moisture susceptibility results from the plant trial mixes indicated that the moisture susceptibility of the plant mix was down to 53 % with 1% lime. The mixing plant was then modified to introduce the lime at the same place as the bitumen. Moisture susceptibility results from the plant trials after the modification were 77 %. This indicated that active fillers, if not introduced correctly into the mixing drum, could be blown out of the drum and not find its way into the asphalt mix. This could result in higher voids than anticipated and subsequently high permeability and moisture susceptibility.

It is therefore important that the moisture susceptibility of an asphalt mix should be evaluated on the plant mix also and not only on the laboratory mix. The moisture susceptibility of underlying asphalt layers should also be investigated when overlaying existing asphalt layers, because moisture may be trapped underneath the new overlay and cause the old asphalt layer to strip and fail.

Insufficient coating of the aggregates due to high viscosity of the binder might also lead to stripping, but no research could be found on a relationship between stripping of asphalt mixes and binder viscosity.

3.3 Permanent Deformation

Permanent deformation in asphalt layers is one of the biggest problems experienced in asphalt layers over the last number of years. The Interim guidelines for the design of hot mix asphalt in South Africa (HMA, 2001) provides guidelines to prevent or limit the rutting potential of an asphalt mix. The mechanism of rutting and the influence of various mix parameters on asphalt rutting are discussed in the above mentioned document.

The guidelines and testing recommended is only applicable to asphalt mixes that are subjected to loads typically encountered on roads. Few guidelines exist for extra heavy duty pavements where the loading rate is slow or even static. Recent experience at a major airport revealed that a mix that was well designed against rutting according to guidelines commonly used, deformed where large fully laden aircraft move slowly or stood stationary on the asphalt surfacing for a few minutes. The dynamic creep tests and Mobile Micro Load Simulator (MMLS) (Epps et al., 2001; Molenaar et al., 2004) rutting tests were all within the specification. The high loads of aircraft (100 - 300 kN wheel loads with 1400 – 1600 kPa tyre pressures) at a very slow loading rate might cause the asphalt to flow under the extreme loading conditions, while similar loads at a short loading rate might be less damageable. This condition is worse during high pavement temperatures commonly encountered in certain parts of Southern Africa... It should be noted that the basic design philosophy for airfield pavements is significantly different to that of road pavements. Whereas asphalt bases and surfacings on roads should be designed for toughness, airfield asphalt bases and surfacings should be designed for strength. The test types and test protocols should be very different.

It is therefor important that testing should be customised (rate and temperature) to allow for the operating conditions of the asphalt layer. If the rate of loading is slow, testing should be adjusted to allow for the conditions without crossing the boundaries for what the test was designed for.

3.4 Mix Design and Densification Under Traffic

Since the 1940's most asphalt mix designs were done using the Marshall design method and the main objective was to assist asphalt technologists to choose an appropriate binder content with which to begin field construction. It is important to understand, that if the service conditions for which a mixture is being designed are different from those for which the design method was developed, the mix design may not be adequate for service even though it is designed according to the method. It is incumbent upon the user to understand the limitations of a design method to ensure that the method is used appropriately.

In order to design asphalt mixes in the laboratory which will sustain the loads imposed on it by traffic, laboratory compaction should be to the same general density (and therefore void content) to which traffic will finally compact it under service conditions. I not, the traffic levels may be so high in service that the mix may be compacted to such a density that the void content is too low and instability of the mix results. Alternatively, traffic levels may be too light, that the compaction energy used in the laboratory produced a density too high for the actual traffic level. This could result in low durability in the field. It is critical that the selection of laboratory compaction level in the design of a asphalt mix will relate to adequate field performance.

During the development of the Marshall method, 50 blows per side were adopted as a standard and tests on test sections with loads of 66,7 kN (345 kPa), 164,4 kN (759 kPa) and 266,7 kN (1 379 kPa) showed no increase in density after trafficking (Roberts et al., 1996). During the 1940's and 1950's the size and weights of aircraft increased with subsequent increase in tyre pressures. The WES study determined that the surface density continued to increase with the application of high-pressure loads. Based on data from the laboratory and field studies, adjustments were made to the original Marshall criteria, including the laboratory compaction effort that was raised to 75 blows per side.

Most of the asphalt mixes in Southern Africa are designed based on the Marshall method with 75 blows per side. It appears that confidence in the gyratory compactor is increasing and it is being used more often in the mix design process. However, it still appears that most engineers based their judgement and decisions regarding asphalt mix design on the Marshall design method. The Marshall method is an excellent method, but its applicability to some modern aspects should be investigated in more detail.

Since the traffic loading and the use of modified binders have changed significantly over the last 50 years, the following questions may arise regarding the Marshall mix design method.

- The influence of modified binders (with higher viscosity) on laboratory compaction. The relevance of temperature-viscosity charts for modified binders are also fairly unknown and are assumed to be linear in most cases.
- Does the number of Marshall blows per side give a fair indication of the compaction under modern traffic in the field. It is possible that the void content of mixes reduce significantly under traffic, resulting in flushing and instability of the mix.
- Is the Marshall method applicable for designing asphalt layers subjected to very heavy traffic.

The answers to these questions should be researched and it could prove that the Marshall method, with a few minor adjustments is suitable for certain pavements. Designers should however be cautious in designing an asphalt mix without relating the traffic loading and expected field density level to laboratory compaction.

3.5 Bitumen

The contamination of bitumen is an issue that has received a lot of attention in recent years and experience have shown that the consistency of some bitumens might have decreased since the 1980's Contamination of bitumen, usually by lighter solvents, may cause the bitumen to be softer initially, but with ageing the bitumen may become hard and brittle. It appears from recent experience in Gauteng that bitumens that do comply with SABS 307 have variable performance in the field. These contamination could happen during the manufacturing, transport or storing of the bitumen or during the production of the asphalt mix itself.

Soft spots that developed in newly paved asphalt surfaces are in most instances as a result of construction equipment leaking fuel or oils. Investigations into these "failures" often resulted in a lengthy study and expensive testing, while it could have been avoided by regular inspection of construction equipment.

3.6 Quality Control

Quality control should still be the most important aspect of asphalt design and construction. A well designed mix could be constructed to inferior quality should quality control procedures be neglected or even totally omitted. This is usually not the case with large asphalt projects, but as soon as costs become an issue, quality control is often neglected. Often quality control is regarded as being the responsibility of the engineer and contractors often neglect their own quality control because of this. A proper quality control plan that includes inputs from all the parties involved (designer, engineer, contractor and client), could reduce the number of failures due to bad workmanship.

Recently, on a asphalt surfacing overlay project, asphalt failures developed within a few months of construction. The same mix had previously proved to be successful on a number of other projects in similar traffic and climatic conditions. It is important to note that a mix design that worked on one project should not be copied for a next project without compliance testing as some of the mix constituents might have changed since the completion of the previous project. The five steps recommended by the National Roads Agency in their M2 Materials code of procedure manual (SANRAL, 2002) for the design of asphalt mixes should be followed closely to avoid supprises, the initial steps (e.g. laboratory design) should only be omitted if the design engineer is in agreement. Plant and pavement trials should always be done.

3.7 Surface Texture

Figure 7 presents the comparison between the application rate of rolled in chips and surface texture. According to the COLTO Standard specifications (COLTO, 1998) a texture depth of 0,6 mm to 1,0 is usually considered acceptable. From Figure 7, the application rate for rolled in chips should be more than 3,6 kg/m^2 to achieve this specification. Care should however be taken to prevent the mix from becoming permeable by a too high application rate. A detailed study on the influence of chip size and application rate on texture depth and permeability might lead to guidelines on the size and application rate of rolled in chips on different thickness and types of asphalt surfacing layers.

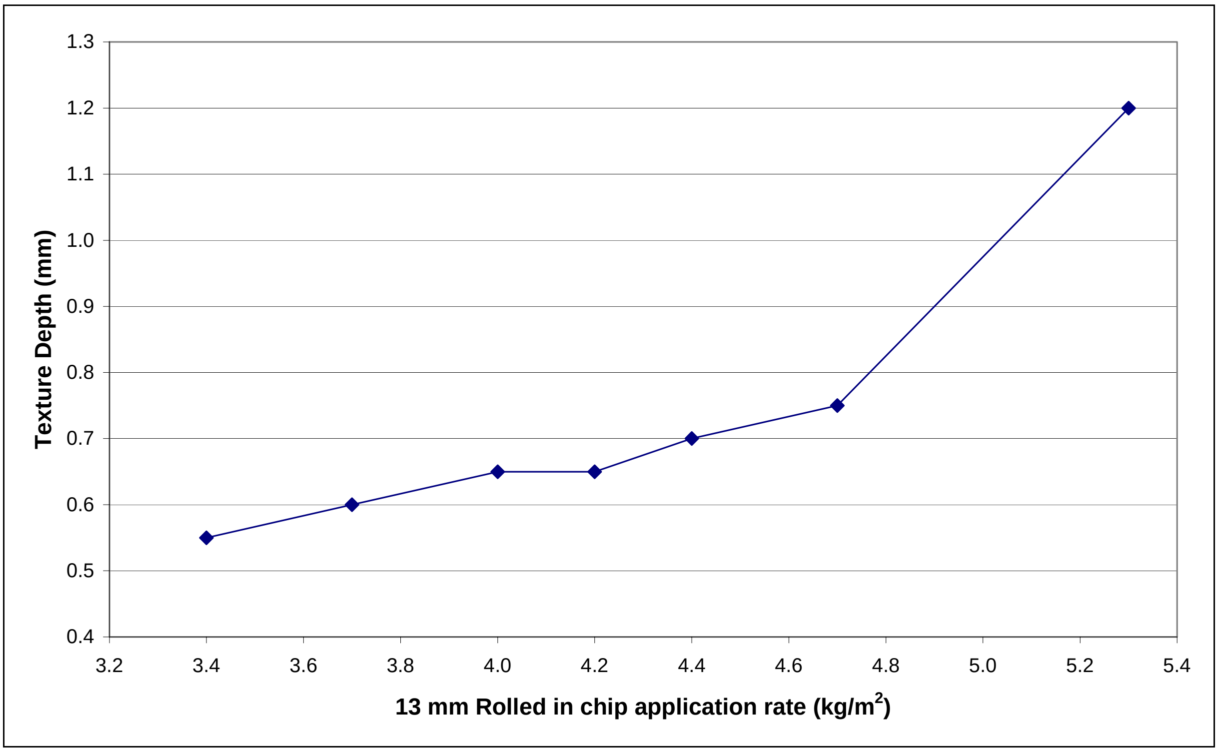

Figure 7. Comparison between rolled in chips application rate and surface texture.

4. CONCLUSIONS AND RECOMMENDATIONS

Permeability is currently not a major requirement in the design of asphalt mixes in Southern Africa and the detrimental effects of permeable asphalt mixes on asphalt and underlying layers are well known. The influence of void content on the permeability of an asphalt layer is significant and higher density requirements should be considered on thin asphalt surfacing layers. It is recommended that a permeability – density study be undertaken on projects where the permeability of the asphalt layer is important and that a density specification based on that study be introduced on a project to project basis.

The addition of active filler into a continuous drum mixing plant may result in most of the filler being blown out through the exhaust and careful consideration should be given to prevent this. It is recommended that the moisture susceptibility be tested on plant mixes also and not only on laboratory prepared mixes.

No guidelines exist on the influence of slow moving heavy loads on asphalt pavements and it appear that the existing tests used for evaluating these mixes are not necessarily applicable. Appropriate tests should be selected in the design of an asphalt layer as well as appropriate specifications for heavy duty asphalt mixes.

The Marshall method appears to be the most popular and widely used method in designing asphalt layers in Southern Africa. The applicability of the Marshall method and the use of 75 blows per side on modern traffic loading conditions and modified binders should be researched in more detail.

Temperature-viscosity charts for modified binders are assumed to be linear in most instances. The linearity of these curves should be verified and improved by further research.

The addition of rolled in chips have a negative effect on the permeability of a thin asphalt layer, but application rates below 3,6 kg/m^2 may result in texture depths below the specification. A further study on the influence of different sizes and application rates of rolled in chips and the influence thereof on the texture depth and permeability is recommended. This could lead to guidelines on choosing a applicable rolled in chip without compromising the permeability or texture depth.

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