MAINTAINING THE POROUS NATURE OF FRICTION COURSE

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AN IMPORTANT NOTE FOR THE READER

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EXECUTIVE SUMMARY

Friction course surfacing has been used on New Zealand road pavements since the early 1970s. The porous nature of this surfacing gives advantages of high skid resistance when wet, low noise, and excellent spray suppression when compared to other surfacings. Although the surfacing will last in excess of eight years, the voids in the surfacing tend to clog within three years, so that its full benefits are not available to the road user for over half its life.

Factors that contribute to the loss of the porous nature have been identified to be:

- entry of detritus,
- densification by traffic,
- adherence of detritus to binder,
- aggregate breakdown.

Of these, entry of detritus causing clogging is suggested to be the primary mechanism affecting New Zealand mixes.

The research project begun in 1992 reviewed international literature of techniques that could be applied to increase the time that friction course maintains its porous nature. The review found that very few comparative trials have been reported, and although a number of techniques were available information was insufficient to recommend their immediate adoption to New Zealand.

Techniques reported were designed to:

- resist entry of detritus, by
    - increasing the void capacity of the system,
    - modifying the hydraulic properties, or
    - limiting detritus entry;
- reduce densification; or
- clean the friction course.

The report recommends research into the following two areas that have the potential to maintain the porous nature of friction course significantly longer than is now experienced:

- Modifications to the mix design through the use of a more open aggregate skeleton, coupled with the use of polymer modified binders;

- Laying the material at a greater thickness.

Both these approaches are based on the premise that, if the initially constructed layer has a higher void capacity than that presently used, it should take longer to clog before it loses its porous nature.

ABSTRACT

Friction course surfacing has been used on New Zealand road pavements since the early 1970s. The porous nature of this surfacing gives advantages of high skid resistance when wet, low noise, and excellent spray suppression when compared to other surfacings. Although the surfacing will last in excess of eight years, the voids in the surfacing tend to clog within three years, so that its full benefits are not available for over half its life.

A literature review was carried out in 1992 to identify techniques that could be used to maintain the porous nature of friction course for a longer period of its life than it currently gives.

Factors that contribute to the loss of the porous nature have been identified and the entry of detritus is suggested as the primary mechanism affecting New Zealand mixes.

Recommendations for research and field trials into techniques to increase the effective life are given. These techniques are based on increasing the initial void content by changes to the mix design and by increasing the layer thickness.

1. INTRODUCTION

Friction course surfacing for road pavements has been used in New Zealand since the early 1970s. It has been used extensively to provide a free draining skid-resistant surface that is also the quietest surfacing available.

The basic material consists of a very open aggregate skeleton comprised of a high percentage of coarse aggregate bound with a bituminous binder. The maximum aggregate particle size in New Zealand mixes has been 14 mm and it has normally been hot laid at a thickness of 25-30 mm.

The open aggregate skeleton results in a high air voids content of the mix (greater than 15%) compared with normal asphaltic mixes which are designed to have air voids in the 3-5% range.

The high voids result in a very porous, free draining surface which, when first laid, has the following advantages over other surfaces:

- high skid resistance when wet;
- reduced speed dependency of skid resistance;
- reduced spray;
- reduced noise.

The first mixes laid in New Zealand in the 1970s had an air voids content of about 16%. Modifications to Transit New Zealand Specification TNZ P/11 in 1984 required the mix to have a more open grading and an air voids content of greater than 20%.

In New Zealand, when laid on structural asphaltic concrete such as a motorway, friction course tends to fail through loss of the aggregate from the surface. Typically this is expected within a life of approximately 8-10 years, but its free draining characteristics are lost within approximately 3-4 years.

Although the porous, free draining characteristics of friction course give it unique advantages over other surfacings, if these are lost within the first half of its life then its full benefits are not available to the road user.

This project was initiated in 1992 to review international literature of methods that could be applied to increase the time that friction course maintains its porous nature, and to recommend research that should be performed to evaluate the most promising technique.

2. LITERATURE REVIEW

A literature search of the following databases held by Works Consultancy Services Ltd's TeLIS Library was performed:

- Dialog
- NZBN
- Dynix

Although literature associated with the description and advantages of friction course was obtained, relatively few publications described controlled experiments or investigations into techniques that maintain the porous nature of the material.

3. FACTORS CONTRIBUTING TO LOSS OF POROSITY

Factors identified in the literature that contribute to the loss of porosity of friction course are:

- entry of detritus;
- densification by traffic;
- adherence of detritus to binder;
- aggregate breakdown.

3.1 Entry of Detritus

The clogging of the voids by dust, dirt and tyre rubber is generally regarded as the major factor affecting the loss of porosity (Van Heystraeten and Moraux 1990; Ruiz et al. 1990; Booth 1991; White 1976).

This loss is normally more apparent outside the wheeltracks, and is considered to be a function of the pumping action of tyres. In the wheeltracks, this pumping action will tend to force dirt out of the pores. Outside the wheeltracks dirt tends to get lodged in the pores, thus creating a damming effect that slows the flow of water to the pavement edge.

This damming effect is most evident on the shoulders of the pavement where water flowing from the unclogged wheeltracks is stopped by the clogged pores. The water then reappears on the surface and flows across the road.

3.2 Densification by Traffic

Although friction course mixes are regarded as being resistant to densification under traffic loading and rutting (Pérez-Jiménez and Gordillo 1990; Huet et al. 1990) some initial densification does occur, and this has an adverse effect on permeability. This effect is illustrated in Figure 3.1, taken from the test track data of Huet et al. (1990).

The test track data show four different mixes, detailed in Table 3.1. Figure 3.2 shows the change in void content of these mixes during the trial. Because the tests were performed on a test track, loss of permeability and voids is directly associated with traffic densification and is not affected by detritus. The air voids in mix 1, which had pure bitumen as the binder, decreased from 17.1% to 12.4% during the test. Mix 4, with a different aggregate grading and the incorporation of fibres, showed little change from its initial void content of 23.2%.

Table 3.1 Details of the mixes used on the trial sections on a test track (from Huet et al. 1990).

Mix	**1**	**2**	**3**	**4**
Binder type	Pure asphalt cement	SBS asphalt cement	SBS asphalt cement	Pure asphalt cement
Fibres	-	-	-	1
Grading curve	0/14	0/14	0/14	0/14
Gap	2/10	2/10	2/6	2/6
Quality control				
Binder content (pha)	4.1	4.8	4.2	5.6
Filler content (%)	5.4	5.6	5.6	9.5
Grading curve				
Passing 2 mm (%)	13	15	16	14
Passing 6 mm (%)	17	17	24	23
Passing 10 mm (%)	24	24	57	55
On-site thickness (cm)	4.2	3.4	3.8	4.2

pha = parts per hundred of the aggregate

3.3 Adherence of Detritus to Binder

The viscosity characteristics of the binder are believed to affect the adherence of detritus in the voids (Booth 1991). Booth reported that ethylene vinyl acetate (EVA) modified binders tended to "skin", and thus are "less prone to absorb foreign dust and grit".

Although conceptually the harder binders could be considered to be effective in reducing the adherence of dirt, they will also reduce densification. However, no reports of controlled studies of the build-up of detritus in the voids have been found.

3.4 Aggregate Breakdown

Friction course consists of a high percentage of coarse aggregate, and its strength comes from the stone to stone contact. In comparison to dense graded mixes, contribution from the interlocking effect of smaller particles between the stones is minimal.

Figure 3.1 Permeability of core samples from four mixes (mixes 1- 4) trialled on a test track (from Huet et al. 1990).

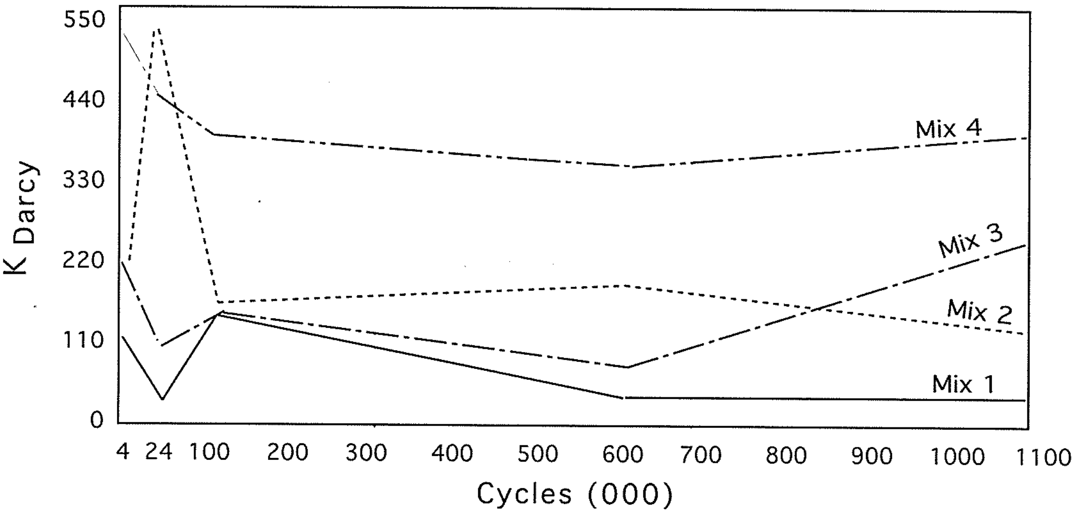
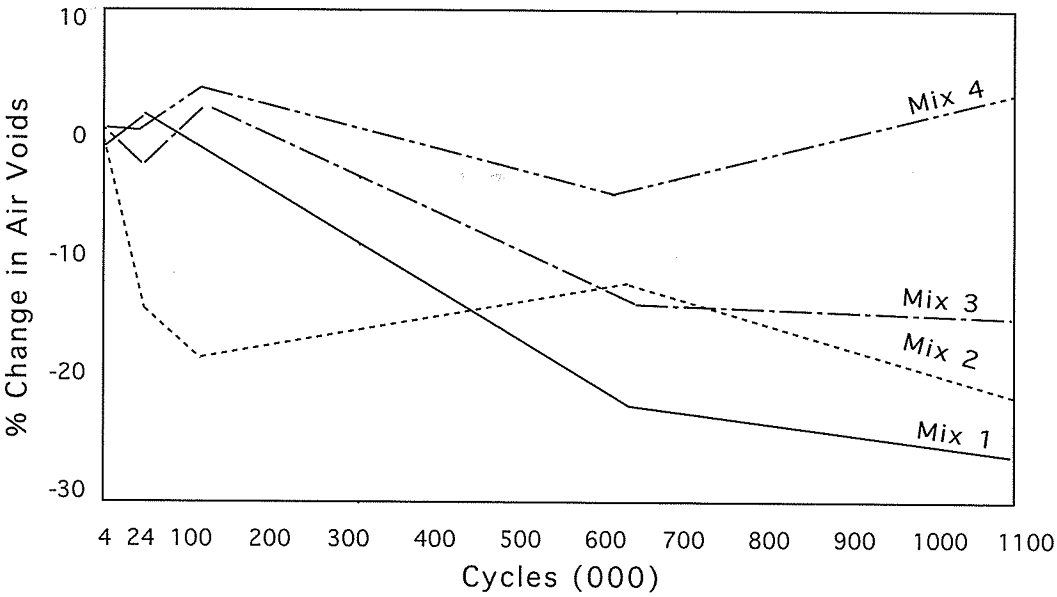


Figure 3.2 Relative changes in void contents in four mixes (mixes 1- 4) trialled on a test track (from Huet et al. 1990).



However, the very high stone-to-stone-contact stresses that develop under traffic loading can lead to aggregate breakdown (Raciborski et al. 1990). Fines generated from this breakdown will tend to fill the voids. For example, Raciborski found that relatively soft aggregate, such as limestone, broke down faster than hard coarse aggregates.

In New Zealand, coarse aggregate for friction course is required to conform to the strength requirements of sealing chip. This ensures that only high strength aggregate is used. Thus, in most cases, under New Zealand traffic conditions, aggregate breakdown is not normally expected to be significant.

3.5 Summary

The main factors that appear to limit the porous life of friction course are:

- entry and retention of detritus;
- densification by traffic;
- aggregate breakdown.

Under New Zealand road conditions the first of the above is considered to be the most significant. As only the highest strength aggregate is used in friction course, there is little scope for improvement through attempting to limit aggregate breakdown.

4. MAINTENANCE OF POROUS NATURE OF FRICTION COURSE

Techniques to maintain the porous nature of friction course can be divided into those designed to:

- resist entry of detritus;
- reduce densification;
- clean friction course by using high pressure water and/or suction methods.

4.1 Resistance to Entry of Detritus

Changes to Transit New Zealand Specification TNZ P/11 in 1984 (Transit New Zealand 1984) increased the void content of the material from approximately 15% to greater than 20%. This tended to lengthen the time before the materials clogged because of entry of detritus. Increasing the void content can have two effects:

- an increased volume of voids in which detritus can be accommodated or lodged;
- a changed rate of water flow which washes out detritus.

Techniques to lengthen the time before clogging occurs can be grouped as those designed to:

- increase the void capacity of the system;
- modify the hydraulic properties, and
- limit detritus entry.

4.1.1 Increased Void Capacity

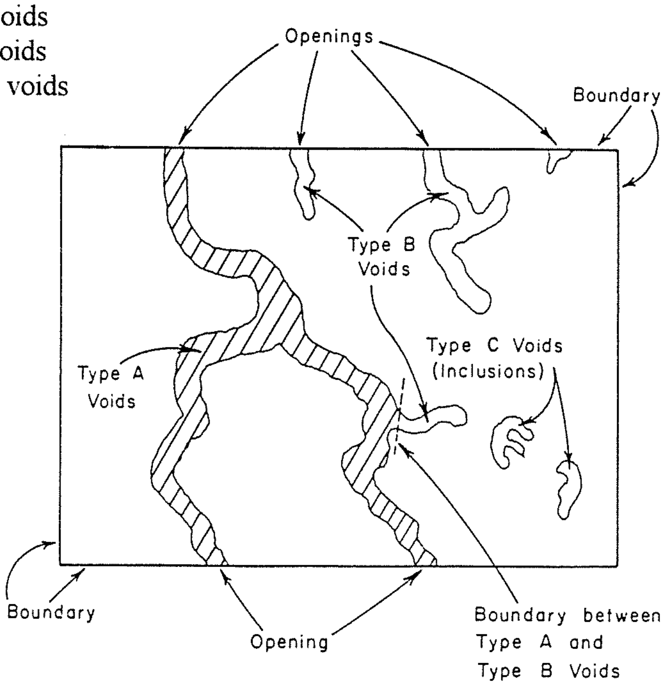
If the total void volume of the friction course layer was to be increased, it would obviously be able to accommodate more detritus. Increased void volume could be obtained by designing the mix to have a even higher void content than currently used, by increasing the layer thickness, or both.

When determining air void content of asphaltic mixes, voids can be assessed as either accessible or inaccessible. *Accessible air voids* are inter-connected and are accessible from the surface boundaries. *Inaccessible voids* are small pockets inside the mix matrix that are not accessible from surface boundaries. This distinction between accessible (types A and B) and inaccessible (type C) voids is illustrated in the figure (Figure 4.1) from Smith (1976). Using this distinction Smith found a better correlation between permeability and accessible air voids than between permeability and total air voids. Smith also found that a mix with approximately 20% total air voids may only have 12% that are accessible. However, mixes with total air voids of 24% may have as much as 20% accessible air voids. Such wide differences between mixes is a function of aggregate grading, shape, percentage crushed, and binder content.

Mix designs based on the accessible voids content, and not solely on total voids, could increase the storage capacity of friction mixes.

Figure 4.1 Classification of accessible and inaccessible air void types (from Smith 1976).

Type A: accessible voids
Type B: accessible voids
Type C: inaccessible voids



In New Zealand, friction course is typically laid at thicknesses of 25-30 mm. European literature (Van Heystraeten and Moraux 1990; Ruiz et al. 1990; Perez-Jimenez and Gordillo 1990; Huet et al. 1990) refers to using thicknesses of 40-50 mm, and the significant free draining characteristics of their pavements are still evident after 5-7 years. This apparent doubling of life over the life of pavements in New Zealand could be attributed to these greater layer thicknesses.

It is self evident that if the layer thickness is doubled then, with the same mix, the storage capacity is doubled.

Friction course 50 mm thick has been used at least once in New Zealand on the Wainuiomata Hill road, near Wellington. The aim of this thick layer was to increase the water storage capacity because the road geometry of this steep road causes water to drain along rather than across the road. The mix used has a top size of 20 mm. However, the larger 20 mm aggregate results in a coarser surface texture, thus generating more noise than a 14 mm aggregate. Size 14 mm is used in layer thicknesses of 40-50 mm in Europe to minimise noise.

4.1.2 Modified Hydraulic Properties

If the flow of water can be increased through the friction course then it would tend to wash the detritus through, thus increasing the time before clogging occurs.

One method of increasing the rate of water flow is to increase the void size in the mix by using a large top size of aggregate. This will however result in greater noise generation which, in some areas, may be unacceptable.

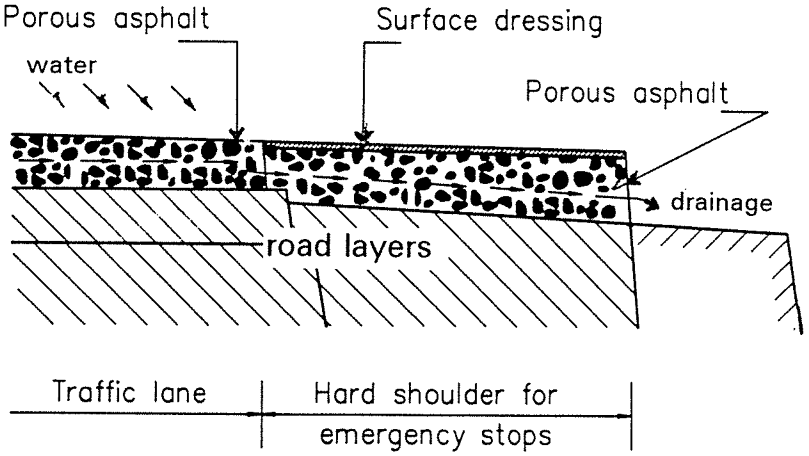
Another method is to construct the friction course in two layers: a bottom layer consisting of a 20 mm top size and 30-40 mm thick, covered by a layer of 12 mm top size and 20 mm thick. This system has a low noise surface which, because of its smaller void size, also acts as a filter for the underlying layer. Traffic will tend to pump the dirt through the top layer into the bottom layer. Water can therefore wash out the fine dirt fractions through the larger voids more easily than would occur if the small aggregate sized mix was used throughout.

4.1.3 Limited Detritus Entry

On dusty or dirty roads, detritus entry can be limited in a number of ways. For example, strict policing of truck spillage from, say, a quarry; or maintenance of drainage to prevent flooding of dirt over the pavement during storms.

An innovative approach is advocated in Belgium (Van Heystraeten and Moraux 1990) where the shoulder area is covered with a chipseal (Figure 4.2). In the wheeltracks, traffic pumping tends to keep the friction course clean. However, detritus is pumped to the shoulders of the road where slower water flow rates mean it is trapped more easily. The principle is to limit entry of the detritus to the shoulder area by covering it with a surface dressing. Van Heystraeten and Moraux do not give details of the type of surface dressing used, but standard surface dressing techniques could not have been used because they would have caused significant drainage of the sealing binder into the friction course voids.

Figure 4.2 System to avoid clogging using chipsealing surface on the road shoulder (after Van Heystraeten and Moraux 1990).



4.2 Reduction of Densification

As the void capacity of friction course is increased, the risk of densification and shoving under traffic increases. It is common practice in countries other than New Zealand to use additives to the bitumen to limit this behaviour.

Additives that have been used include:

- SBS (styrene-butadiene-styrene) polymer
- EVA (ethylene vinyl acetate) polymer
- natural rubber
- recycled rubber
- Mobilplast™
- Shell™ epoxy
- Chemcrete™
- fibres

The maximum binder content that can be used in friction course is governed by the amount of binder that will drain from the aggregate during storage and transport. As additives tend to increase the high temperature viscosity of the bitumen, they allow a higher binder content to be used at the same handling temperature. Higher binder contents result in a greater film thickness on the aggregate which could also reduce the rate of binder hardening. However, higher binder contents do lead to a reduction in air voids. Modification to the aggregate grading and the use of additives can be effective, as was shown by Huet et al. (1990) and as discussed in Section 3.2 of this report.

The usual approach when designing a binder modification is to keep the same content of modified bitumen as used when the bitumen is not modified. The binder modification is designed to increase the strength of the binder to help resist deformation but also to maintain as open a structure as possible. The added strength given by using binder modification may lengthen the life of the surface.

Extensive trials of additives were carried out in England by the Transport and Road Research Laboratory (TRRL). Daines (1991) reported on these trials, some of which were laid in 1984 and others in 1987. The mixes in all cases used a 20 mm-top sized aggregate laid 50 mm thick. Effective spray reduction was sustained for more than 7 years on the test road with a mix using 100 penetration grade unmodified bitumen. It was concluded that it was too early to be positive about the benefits of additives. Additives that allowed a higher binder content also resulted in a lowering of the permeability. The UK Department of Transport (1991) have issued an advice note suggesting that 5% of natural rubber in the bitumen is an accepted additive for allowing a higher binder content to be used in the heaviest traffic sites (>3000 commercial vehicles per day) to enhance durability.

The British research appears to have concentrated on limiting densification rather than investigating clogging through detritus retention.

4.3 Cleaning Methods

High pressure water was trialled in Auckland, New Zealand, around 1980 (T. Somerville, pers.comm. 1991), as a means of cleaning detritus out of friction course but without success.

If detritus tends to be absorbed in the binder film, as stated by Booth (1991), it is unlikely that any washing or vacuuming technique could restore permeability.

Trials were being carried out in Europe (Van Heystraeten and Moraux 1990) with a combination of water, sweeping and vacuuming, in the hope of restoring some of the drainage characteristics. Although trials are referred to in the literature, no formal trial reports have been cited.

Thus, until a viable system is proven, cleaning systems cannot be regarded as a realistic maintenance treatment for friction course.

5. NEW ZEALAND EXPERIENCE

As stated in the introduction, New Zealand has used two friction course specifications: NRB P/11 : 1975 and TNZ P/11 : 1984. The 1975 specification was based on a voids content of approximately 15% and used 180/200 bitumen. This soft binder was used because its use was considered to be more durable than harder grades.

A series of trials was carried out in Auckland, New Zealand, using 80/100 and 60/70 grade bitumen (Somerville 1986) from 1971 to 1978. These results indicated that the mix lost its free draining characteristics within 18 months and its spray reduction qualities in 3-4 years. It was noted that the harder bitumen tended to keep the free draining characteristics of the mix slightly longer, with no adverse effects on its long-term life. The surfaces were replaced after approximately 15 years.

Mixes used in Wellington, New Zealand, laid to the NRB P/11 : 1975 specification but using 80/100 bitumen, also tended to last 15 years before loss of aggregate necessitated resurfacing.

Friction course laid according to the TNZ P/11 : 1984 specification, which recommends initial void contents of greater than 20%, have tended to have shorter lives, especially in areas of higher traffic stress. For example, mixes laid in Christchurch, New Zealand, in 1980 are showing signs of distress in 1992 and are due for resurfacing. A life of 10-12 years can be expected from these mixes on sites not subjected to heavy braking or turning.

6. PERMEABILITY REQUIREMENTS FOR FRICTION COURSE

The loss of permeability of friction course is noted by the motorist as increased spray from traffic and as free water lying on the surface. Although these effects are a function of the properties discussed in Section 3 of this report, it is also a function of the rainfall intensity and the length of the drainage path.

Friction course acts as a reservoir during rain and the water normally flows below the pavement surface to the edge of the pavement into side drains. In times of heavy rainfall even new friction course can become saturated when the water inflow rate is greater than the rate that it can flow to the shoulders.

In the design of friction course, both the climate and pavement geometry (number of lanes, crossfall, longitudinal grade) should be taken into account in determining the thickness and void content of the surfacing. At present in New Zealand a standard thickness of 25 mm or 30 mm is used in all situations.

An estimate of the water drainage capacity of friction course was made by Smith (1976). He based his analysis on the Chezy-Manning equation for channel flow. This analysis was based on the concept of the rainfall intensity required to obtain saturation of the friction course at the edge of the pavement. The variables identified by Smith were:

- accessible voids;
- cross slope;
- longitudinal grade;
- pavement width;
- layer thickness.

For the normal case of a free draining edge, Tables 6.1 and 6.2 (from Smith 1976) give the rainfall intensity to obtain saturation at the pavement edge for a 20 mm-thick layer with zero longitudinal grade.

Table 6.1, for friction course with 15% accessible air voids, is considered to be typical of friction course tested to the current TNZ P/11 : 1984 specification with 20% total air voids.

Table 6.2, for friction course with 22% accessible air voids, is considered to be typical of a mix produced with 25% total air voids. This condition is at the most open end allowed by the TNZ P/11 : 1984 specification, but may be typical of newly placed friction course.

According to Smith, the rainfall intensity required to obtain saturation is directly proportional to accessible mix voids and layer thickness.

Figure 6.1, based on Tables 6.1 and 6.2, shows the effect of layer width and accessible air voids on the rainfall intensity required for saturation. Figure 6.1 is for a 20 mm layer, so if the thickness was to be doubled, the rainfall required to saturate would double.

Figure 6.1 Rainfall intensity (mm/hour) required for a friction course of different layer widths, which is 20 mm thick on slope 1/100, with air voids capacity ranging from 0 - 30%, to reach saturation.

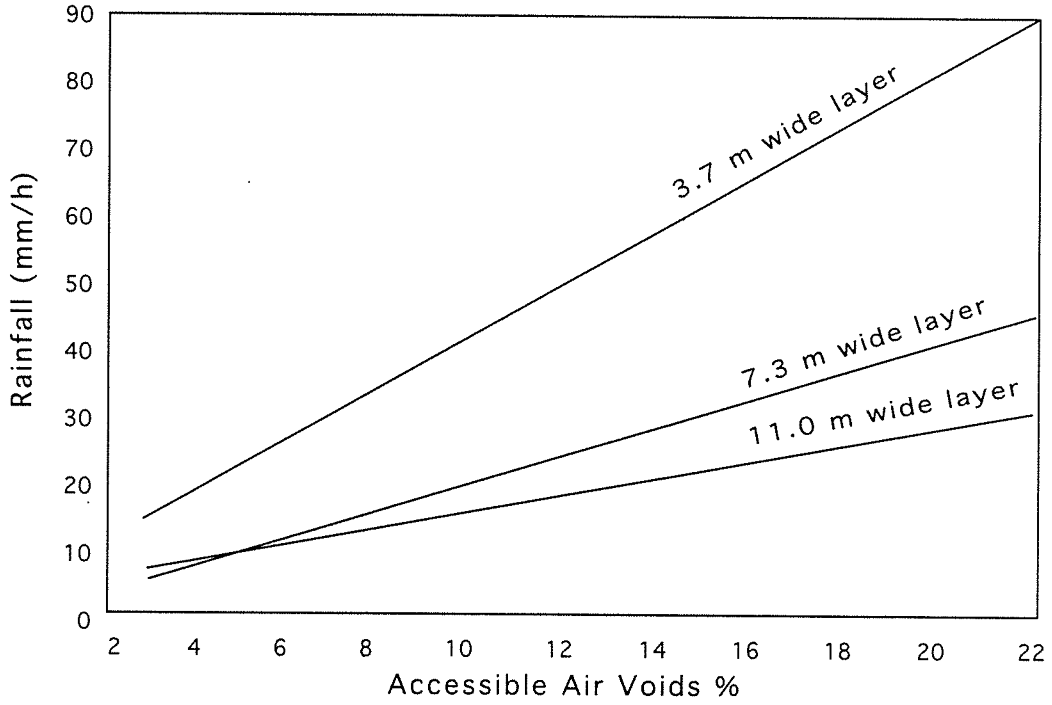


Table 6.1 Rainfall intensity (mm/hour) required to saturate friction course, which is 20 mm thick, with 15% accessible air voids, 0% longitudinal grade.

Pavement width (m)	Pavement cross-slope				
	1/400	1/200	1/100	1/50	1/25
3.6	22	30	43	62	86
7.3	11	15	22	30	43
11.0	7.3	10	14	21	29
14.6	5.5	7.8	11	15	22

Table 6.2 Rainfall intensity (mm/hour) required to saturate friction course, which is 20 mm thick, with 22% accessible air voids, 0% longitudinal grade.

Pavement width (m)	**Pavement cross-slope**				
	1/400	**1/200**	**1/100**	**1/50**	**1/25**
3.6	32	45	63	90	126
7.3	11	22	32	45	63
11.0	10	15	21	30	42
14.6	8	11	16	22	32

Although no references have been cited of field data to support Smith's analysis, his analysis does appear reasonable and gives a basis for determining friction course thickness under different climatic and pavement geometry conditions. The analysis also tends to support the concept given earlier that increased layer thickness could proportionately increase the permeable life of a surfacing.

Although a friction course layer may become saturated in heavy rain, this does not necessarily mean that skid resistance is significantly reduced. If the layer is still permeable then water will be dispersed quickly from the tyre/pavement interface, thus maintaining adequate skid resistance. Under saturated conditions, spray suppression and noise reduction properties will, however, be significantly reduced.

7. RECOMMENDATIONS FOR FUTURE RESEARCH

This review has cited only one New Zealand investigation into the change of the porous nature of friction with time (Somerville 1986). This investigation was performed on friction course laid to NRB P/11 : 1975 and does not reflect the rate of change that would be expected with material manufactured to the TNZ P/11 : 1984 specification.

In order to maintain as long as possible the porous nature of friction course, the as-laid mix should have as high as possible air voids content. This can be obtained in two ways:

- modifications to the mix design,
- construct the mix at a greater layer thickness.

Future research should explore both methods.

7.1 Mix Design

The air voids content of mixes used in 1992 in New Zealand is approximately 20%. Higher air voids could be obtained by changes to the aggregate grading. However, as the air voids content rises, the risk of aggregate breakdown, instability and fretting of the surface increases. The aim of future research is to optimise the durability of the mix and maintain its porous nature. There would appear to be scope for designing mixes with a higher initial air voids but maintaining a durable mix through the use of polymer modified binders. These binders may also result in less detritus being retained in the mix.

A two-phase research project should be undertaken in which:

Phase 1 would determine the changes in:

- total air voids;
- accessible air voids;
- void size;

in a range of mixes through changes to the aggregate grading and binder contents.

Phase 2, based on the results of Daines (1991) and Huet et al. (1990), would select the most promising polymer modified binders considered appropriate for New Zealand conditions for further investigation.

The effect of these binders should be investigated through a series of laboratory tests and field trials using the most promising mixes identified in phase 1.

Field trials comparing the performance of the mixes should compare differences in terms of permeability, noise, spray suppression, rutting and skid resistance.

7.2 Layer Thickness

Research into the benefits of increased layer thickness should investigate the following three systems:

- 50 mm layer using a 14 mm-top sized aggregate mix;
- 50 mm layer using a 20 mm-top sized aggregate mix;
- a two layer system using a 14 mm aggregate on the surface layer and a 20 mm aggregate as the base layer.

Comparative field trials of the above systems should be constructed, and the differences in terms of permeability, noise, spray suppression, rutting and skid resistance monitored.

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