Pavement design for specialist surfacings
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G Arnold, A Stubbs and J Vercoe
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NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

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Abbreviations and acronyms

DSR	dynamic shear rheometer
FWD	falling weight deflectometer
OGPA	open graded porous asphalt
SAMI	strain alleviating membrane interlayer
Transport Agency	New Zealand Transport Agency

Contents

Executive summary

There are a range of different specialist surfacings on the market, for example, the coloured surfaces used at bus stops and calcined bauxite high-friction surfacings used at intersections and off ramps. These specialist surfacings are not bitumen based but are typically polyurethane or epoxy resin based. Some of these surfacings have not met their life expectations and the New Zealand Transport Agency (Transport Agency) in their request for research proposals asked:

- How do we ensure the existing road and the new surfacing are compatible in terms of their respective stiffnesses to ensure the surfacing will deliver the expected life?
- What do we do when the stiffness is not compatible?

The Transport Agency also stated in the research tender document that some surfacings such as slurry seals and calcined bauxite needed a certain minimum pavement stiffness or maximum curvature, to ensure the surfacing would adhere to the pavement for its intended life.

In addressing the above questions, the researchers conducted a limited study into specialist surfacings, which focused initially on flexibility and developing limiting pavement deflection criteria. It was hypothesised that the specialist surfacing could not be used in places with high pavement deflections. However, it was found that all the specialist surfacing resins, except one, were highly flexible and should cope with very high pavement deflections. In fact, the flexibility of the resins showed they could cope with rut depths in excess of 10mm. The asphalt itself would crack before the specialist surfacing resins did. Nevertheless, one important property for the specialist binders to have is flexibility. Four of the five specialist binders showed exceptional flexibility and thus flexibility criteria could be developed to exclude the fifth product that was more brittle than the other products (although some field data is needed to give reasons why this product should be excluded through a specification change).

The initial research proposal focused on flexural beam tests to measure strength and flexibility; however, the researchers in agreement with the Steering Committee and the Transport Agency extended the research scope to include the Leutner shear test for bond and asphalt strength. This is a simple and promising test. Results clearly showed that four of the five specialist surfacing resins required the asphalt surface to be water cut while one resin showed exceptional performance giving full bond strength on fresh asphalt surfaces that were not water cut. Full bond strength is achieved when the Leutner shear strength at break is equal to the asphalt shear strength indicating failure in the asphalt and not the bond. Field cores could also be tested in the Leutner shear test to determine whether or not full bond strength was obtained.

Results from this study determined a Leutner shear test for bond strength could be included in a specification for specialist surfacings, with the pass criterion being when the bond strength exceeds the shear strength of the asphalt mix. However, further research is needed on a test for flexibility as the large scale flexural beam tests on the resin binder only were difficult to interpret in terms of determining a pass or fail result. Binder property tests like the dynamic shear rheometer or a direct tensile test could be more appropriate.

Abstract

Leutner shear tests to measure bond strength and flexural beam tests to measure flexibility were conducted on specialist surfacing resins used in New Zealand for coloured and high-friction surfacings. The flexural beam tests found the specialist surfacing resins, except for one, to be very flexible at 5 and 20 degree test temperatures. This flexibility showed that the specialist surfacing resins should be able to cope with high pavement deflections and rut depths up to 20mm and the underlying asphalt would crack before the specialist surfacing did. Leutner shear tests showed one out of five resins tested on fresh asphalt cores achieved full bond strength (the same as the asphalt mix shear strength) and all resins achieved the full bond strength when the asphalt surface was water cut before applying the specialist surfacing resin.

1 Introduction

1.1 Background

There are a range of different specialist surfacings on the market, for example coloured surfaces used at bus stops and calcined bauxite high-friction surfacings used at intersections and off ramps. These specialist surfacings are not bitumen based but are typically polyurethane or epoxy resin based. Some of these surfacings have not met their life expectations and the New Zealand Transport Agency (Transport Agency) in their request for research proposals asked:

- How do we ensure the existing road and the new surfacing are compatible in terms of their respective stiffnesses to ensure the surfacing will deliver the expected life?
- What do we do when the stiffness is not compatible?

The Transport Agency also stated in the research tender document that some surfacings such as slurry seals and calcined bauxite needed a certain minimum pavement stiffness or maximum curvature to ensure the surfacing remained adhered to the pavement for its intended life.

To address the above questions the research originally proposed to focus on flexural beam testing. The bending beam simulates bending of the specialist surfacing in the pavement under the wheel load. Testing would thus determine whether or not the specialist surfacing binder would have enough flexibility to cope with deflection due to the traffic loadings, or would determine the maximum pavement deflection that would not damage specialist surfacing material. However, the Steering Group meeting changed the focus of the research to include a significant amount of Leutner shear bond tests to measure the strength of the bond between the specialist surfacing and the asphalt. The Leutner test was also used to measure the shear strength of a range of different asphalt mixes as it could be the asphalt mix that failed, rather than the bond, due to the high stopping forces on the high-friction surfacing.

1.2 Objectives

As a result of the Steering Group meeting, the principal objectives of the research were changed to:

- determine the stiffness and tensile strength of a range of specialist surfaces binders in flexural beam tests
- develop pavement deflection criteria from the flexural beam test results on the specialist surfacing binder
- develop a lab testing method that enabled pavement deflection criteria to be determined for any new specialist surfacing (ie catered for a range of different specialist surfacing mixes with different material properties)
- determine the maximum rut the specialist surfacing could deflect into without cracking and a methodology to estimate the rut depth of the underlying pavement
- develop acceptance criteria with a test method for bond strength using the Leutner shear strength test on a range of specialist surfacing mixes and asphalt types

- develop criteria for maximum difference between thermal expansion of the specialist surface and asphalt underneath to ensure the specialist surface did not fail prematurely.

The Steering Group agreed to focus the research on testing epoxy and polyurethane binders used in coloured and high-friction calcined bauxite surfacings and not to cover slurries, although these could be assessed in the future using the flexural beam and Leutner shear bond tests.

2 Literature review

This research project used the flexural beam and Leutner shear strength bond tests to assess the specialist surfacing binders. The background and details of these tests are described in this chapter.

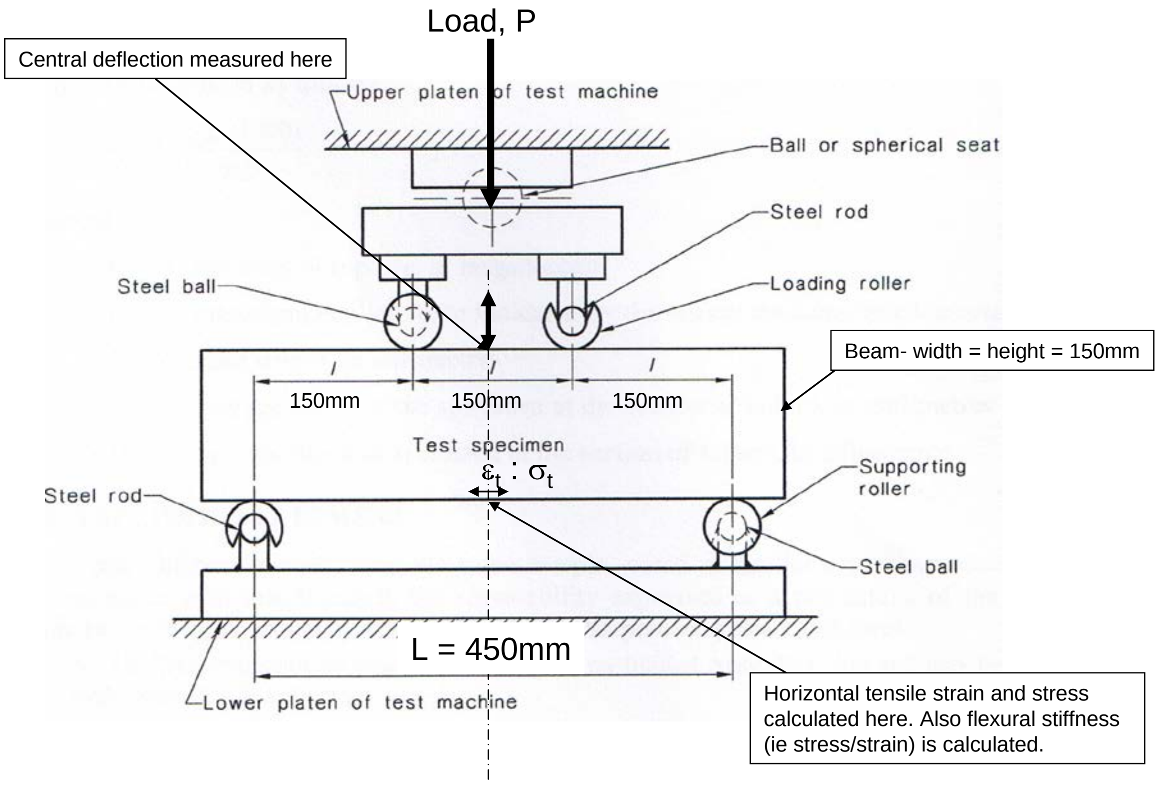
2.1 Flexural beam test

Flexural beam testing loads support beams while recording central deflection on top of the beam (figure 2.1).

Figure 2.1 Flexural beam test

Source: Austroads (2008)

Figure 2.2 Diagram of the flexural beam test (note dimensions are example only. Span can also be 300mm for 100 by 100mm beams or any width and depth)



Prior to fatigue testing, strength tests are undertaken by applying a constant load rate P (figure 2.2) until the sample breaks or no further load can be sustained. The strength of the specimen is simply the maximum load P.

Applying a repetitive load, usually for 100 cycles, allows the flexural modulus/stiffness to be calculated. The fatigue life is the number of repetitive load cycles required until the modulus is half the initial modulus. Flexural stiffness is calculated using equation 2.1:

$$S_{max} = \frac{23PL^3}{108wh^3\delta}$$

Equation 2.1

Where:

- S_{max} = flexural stiffness in Pascals
- P = peak force in Newtons
- L = beam span
- w = specimen width in metres
- h = specimen height in metres
- δ = peak mid-span displacement in metres.

The flexural beam test has recently been used for the design of stabilised pavements in New Zealand (www.nzta.govt.nz/resources/research/reports/463/index.html). The Austroads pavement design guide (Austroads 2004) together with the pavement design software CIRCLY allow the designer to check the life of cement bound layer ('stabilised material' in figure 2.3). To ensure the stabilised material maintains strength over the design life it is important that the stabilised material has sufficient thickness and is well supported to prevent a return to unbound behaviour. To ensure this occurs a tensile strain criterion (life N = $(k/strain)^{12}$) found from flexural beam tests should be used in the design.

Flexural beam tests allow the designer to determine their own mix of specific design tensile strain criteria which will result in more appropriate and economic pavement designs. A range of moduli and strengths is obtained depending on the stabilised mix (figure 2.4), thus it is important to do the tests.

Figure 2.3 Pavement design

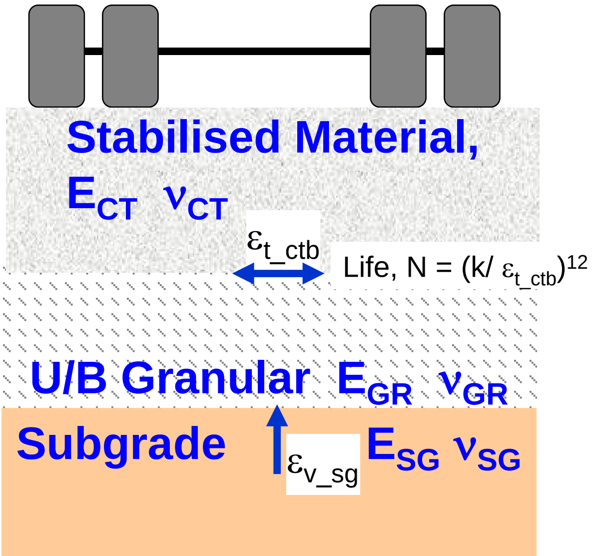
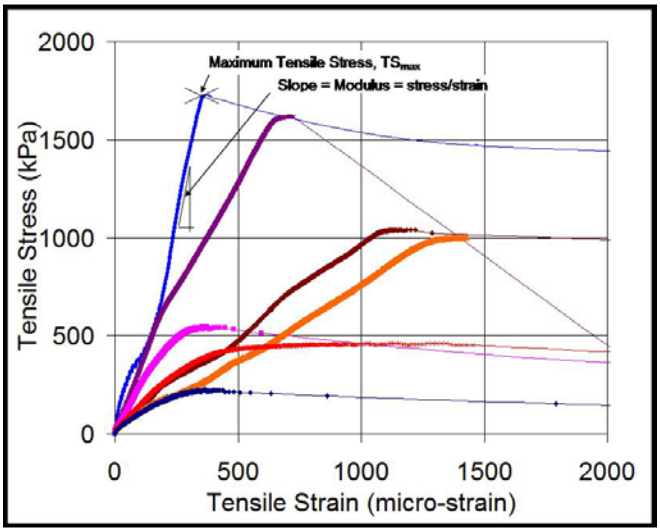


Figure 2.4 Flexural beam breakage tests



The constant 'k' in the fatigue equation, N = $(k/strain)^{12}$ is determined by the maximum stress and modulus from the flexural beam breakage test as found by Arnold et al (2011) to ensure the working tensile stress is below 40% of the beam tensile strength (TS_{max}).

$$k = \frac{1.265 \times TS_{max}}{modulus} \quad \text{Equation 2.2}$$

The flexural beam tests will determine the maximum strain and stress at break for the specialist surfacing binders. These values can then be used to determine the maximum pavement deflection and rut depth that is possible before the specialist surfacings may break or crack.

2.2 Leutner shear test

The Leutner test was developed in Germany in the late 1970s as a simple means of undertaking a direct shear test on the bond between two asphalt layers. The test applies a constant shear displacement rate across the interface under investigation and the resulting shear force is monitored. The test is normally carried out on cores comprising at least two layers and the standard loading (displacement) rate and temperature are 50 mm/minute and 20°C, respectively. The Leutner shear test is different from the direct shear box test because normal force is not applied. Applying a normal force which would better replicate traffic loading adds unnecessary complexity and ultimately an extra expense to the test. This is because the bond strength is considered adequate when it exceeds the shear strength of the asphalt mix. Applying a normal force will increase both the bond strength and the shear strength of the asphalt and is considered to result in the same conclusions in terms of identifying resins with a bond strength that is less than the shear strength of the asphalt. The shear test apparatus for this study was a modified Leutner shear apparatus which introduced a 5mm gap into the shear plane to avoid misalignment between the interface to be examined and the shear plane of the Leutner load frame. The peak shear stress, displacement at peak shear stress and shear stiffness modulus were determined during the test.

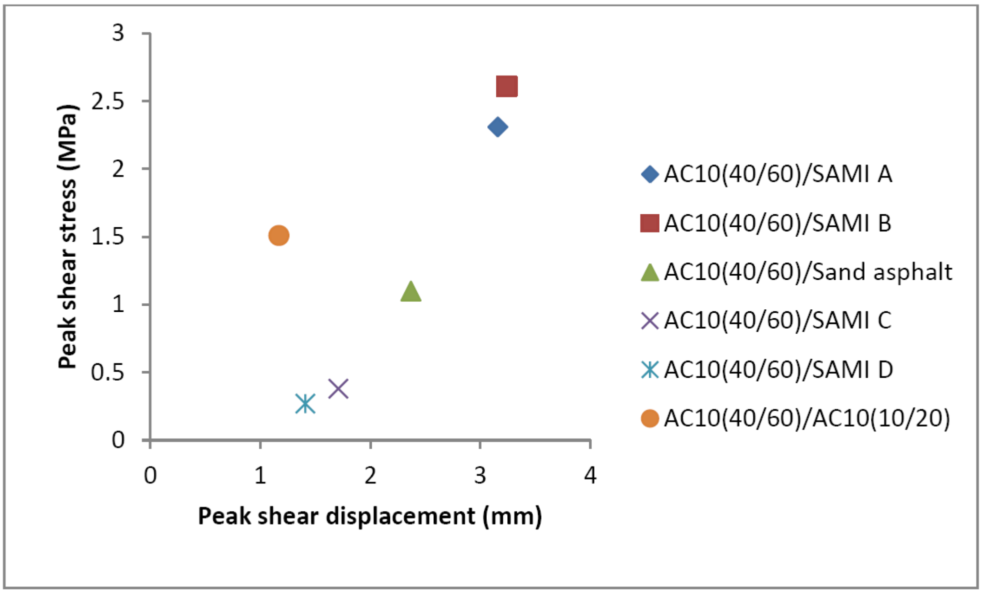
The peak shear stress is the maximum value of shear stress, determined as the maximum force divided by the initial cross sectional area of the specimen when tested. Displacement at peak shear stress is the displacement at the maximum value of shear stress of a specimen when tested and the shear stiffness modulus is the peak shear stress divided by the displacement at the peak shear stress of a specimen when tested. The Leutner shear test apparatus is shown in figure 2.5.

Figure 2.5 Leutner shear test apparatus

Research at University of Nottingham (Moses 2011) investigated the bond strength of a strain alleviating membrane interlayer (SAMI) to the base asphalt layer using the Leutner shear test on cores shown in figure 2.6. Results of this research on SAMI bond strength are illustrated in figure 2.7. Similar tests were conducted on cores bonded with specialist surfacing resin to compare the bond strength of the different products and determine pass/fail criteria based on the strength needed from heavy vehicle breaking forces and/or the strength needed to exceed the shear strength of the underlying asphalt.

Figure 2.6 Leutner shear test cores on SAMI bond strength research at Nottingham

Figure 2.7 Leutner peak shear strength on cores bonded with SAMI from research at Nottingham



Source: Moses (2011)

3 Laboratory testing – flexural beam test

3.1 Flexural beam test

About 15 different suppliers of specialist surfacings were asked to supply their specialist surfacing binder to the Road Science laboratory for manufacture of beams for testing. A total of five different specialist surfacing binders were received for testing as the different suppliers often used the same product. The manufacturer's instructions were followed to mix the two components of the binder, which were then placed in a steel beam mould to harden. Once hardened, the large 150mm square and 526mm long beam was removed and cut into four beams that were approximately 75mm square and 535mm long. Pictures of the beams tested are shown in figure 3.3a

Results of the flexural beam tests at 5°C and 20°C are shown in table 3.1 and figures 3.1 and 3.2.

Figure 3.1 Flexural beam tests on specialist surfacing resin at 5°C

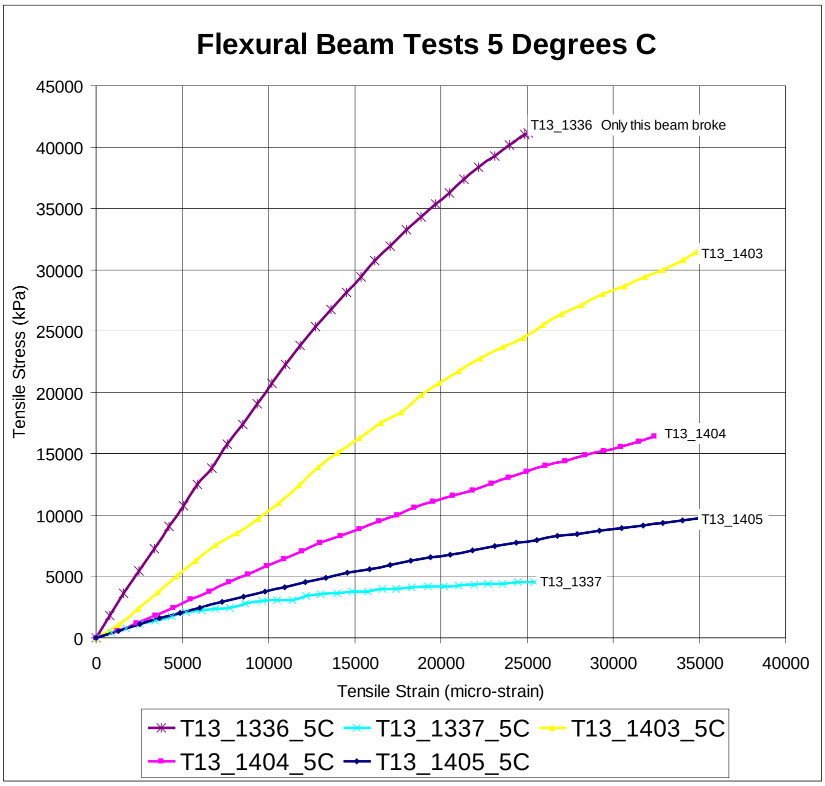


Figure 3.2 Flexural beam tests on specialist surfacing resin at 20ºC

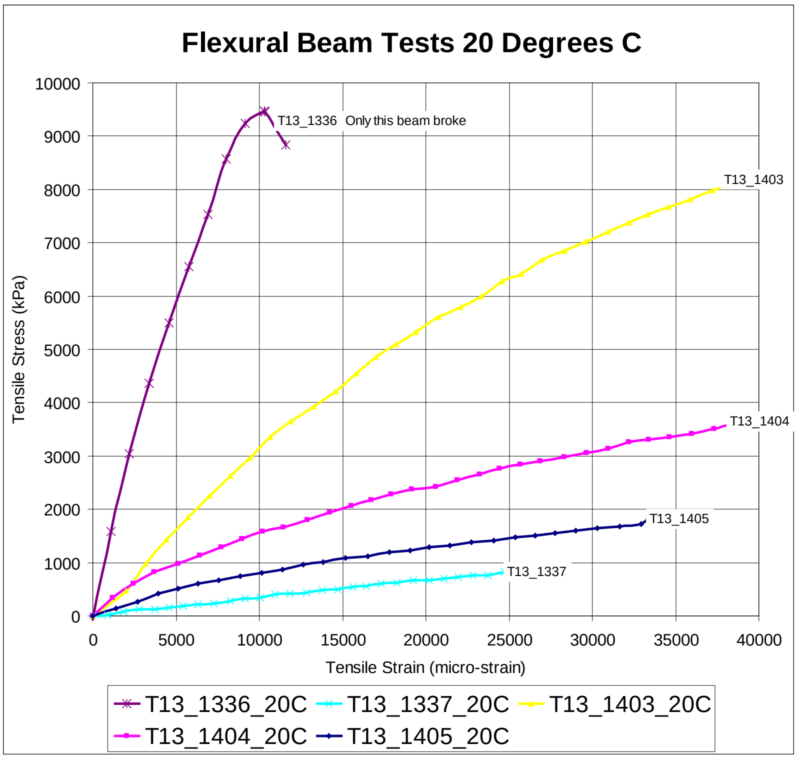


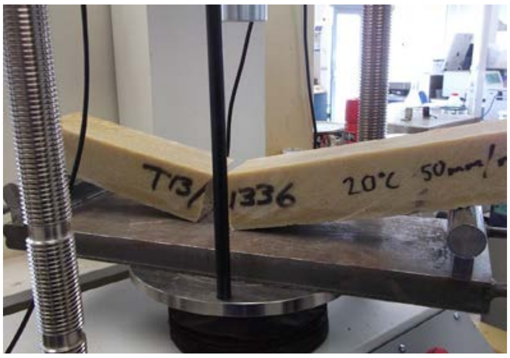
Table 3.1 Summary of flexural beam tests

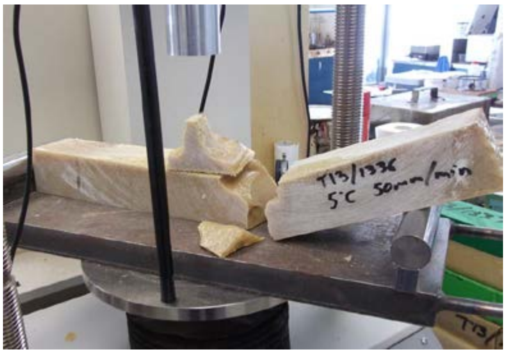
Beam #	Maximum tensile stress (MPa)	Maximum tensile strain (%)	Maximum beam deflection (mm)	Linear modulus (MPa)	Did the beam break?
T13_1336: 5C	41	2.5	23.8	2036	Yes
: 20C	9.5	1.03	8.9	1010	Yes
T13_1403: 5C	*31*	*3.5*	*24.3*	1041	No
: 20C	*8.3*	*3.9*	*25.8*	313	No
T13_1404: 5C	*16.4*	*3.2*	*24.1*	591	No
: 20C	*3.6*	*3.8*	*24.7*	162	No
T13_1405: 5C	*9.8*	*3.5*	*23.7*	385	No
: 20C	*1.9*	*3.3*	*21.9*	84	No
T13_1337: 5C	*4.6*	*2.5*	*24.1*	311	No
: 20C	*0.83*	*3.9*	*25.8*	35	No

Note: Values in italics are not the maximum values as the beams did not break but rather the test stopped at the deflection limit of 25mm.

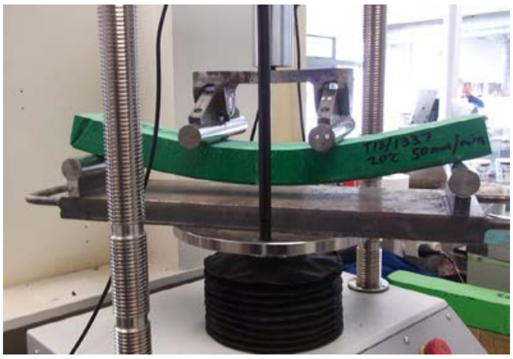
Figure 3.3a Photos of flexural beam tests on specialist resins

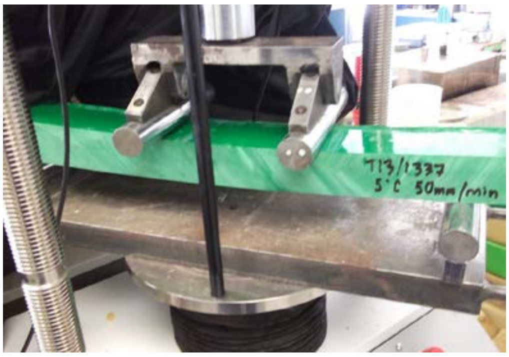
T13/1336



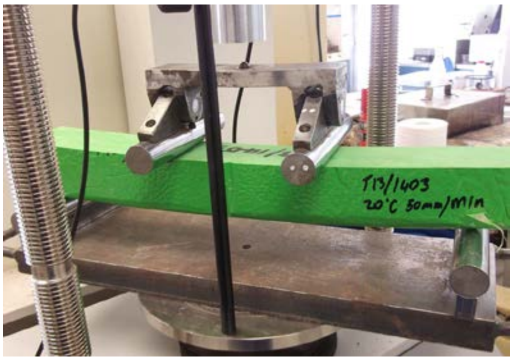


T13/1337





T13/1403



T13/1404

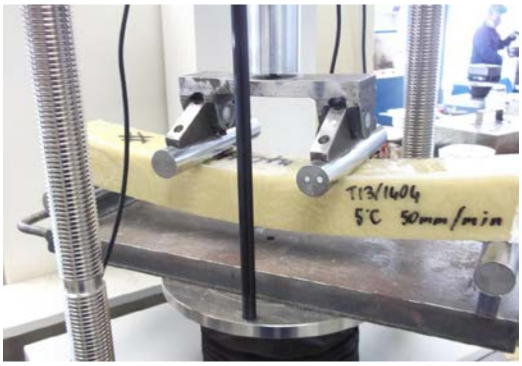


Figure 3.3b Photos of flexural beam tests on specialist resins

T13/1405

In summary, all the flexural beam tests except T13_1336 showed exceptional flexibility, being able to deflect 25mm and possibly higher at 5°C and 20°C test temperatures. The T13_1336 did have some flexibility and deflected 9mm before the beam broke. Pavement elastic deflections under a heavy truck wheel loads are around 1mm and at worst 3mm for a weak pavement. Thus in this deflection range all of the specialist surfacing binders are expected to cope; however, the less flexible T13_1336 is more likely to fatigue and crack. Roads can also rut over time and a rut of 10mm is not unusual, particularly at intersections. Should the road rut, all surfacings except T13_1336 are predicted to be able to bend within the shape of the rut, although the high tensile strength for some of the binders may result in the binder wanting to straighten out and could delaminate if the underlying pavement has a 10mm rut while the specialist surfacing wants to remain straight. Further, ruts in pavements (as indicated in figure 6.2) can be quite sharply curved (high curvature) due to narrow lane widths, or tightly curved horizontal geometry, resulting in little wander in heavy vehicles. These more sharply curved ruts could cause cracking of the specialist surfacings while the large scale flexural beam test does not replicate the sharp curved ruts. Thus, the results of the flexural beam tests conducted in this research should be used cautiously.

The beam tests showed that when the temperature reduced from 20°C to 5°C the stiffness and strength increased four to five times. This same change in strength and stiffness may not be mirrored by the underlying asphalt, which at low temperatures could crack and become brittle while the specialist surfacing resin will remain flexible. The different properties of the asphalt and specialist surfacings could be another mechanism causing early failure.

In addition, there are many road sites that have not rutted but the specialist surfacing material has still cracked and thus another mechanism like thermal forces could be the reason.

4 Laboratory testing – Leutner shear test

4.1 Leutner shear test

The Leutner shear test was initially conducted on a range of asphalt mixes with the results shown in figure 4.1. Next the bond strength was measured on one high-strength asphalt type Mix15FX as this would enable an estimate on the Leutner shear test for other mix types the specialist surfacing was bonded to. If the Leutner shear test result (shear strength) on the specialist surface bonded to the high-strength asphalt mix was higher than the shear strength found for another asphalt mix (see figure 4.1) then the resulting shear strength for the specialist surface bonded to another asphalt mix would be equal to the shear strength of the asphalt mix as the asphalt mix would fail in shear first.

Results of the shear strength testing of the asphalt mixes only show the lowest shear strength with the porous asphalt mixes (PA10 and PA14). The test temperature of 20°C did not show any improvement with shear strength using polymer. However, if the tests were completed at 40°C and 60°C, the polymer asphalt mix would be expected to retain shear strength while the other asphalts with standard bitumen grades would reduce in shear strength.

Specialist surfaces resin was also placed on the asphalt cores to check bond strength using the Leutner shear test. The bond strength was checked on an asphalt core as produced and the other on a core where the surface was water cut before applying the specialist surfacing resin to the asphalt core. Results are shown in the figures below.

Figure 4.1 Leutner shear tests on asphalt only cores

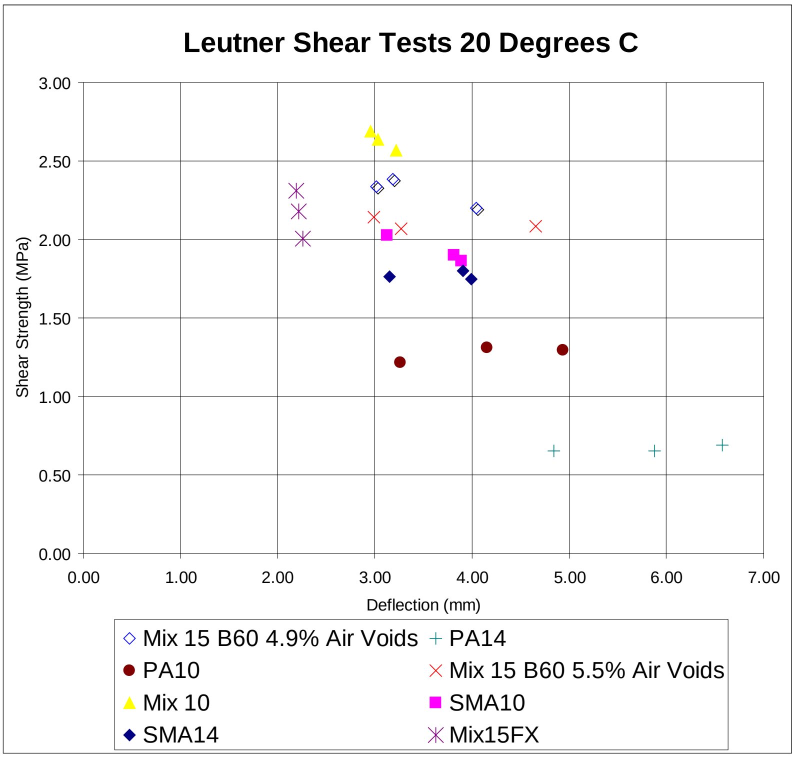


Figure 4.2 Leutner shear test results for specialist surfaces bonded to Mix15FX at 20°C (note the black line shows results for shearing through the asphalt core only)

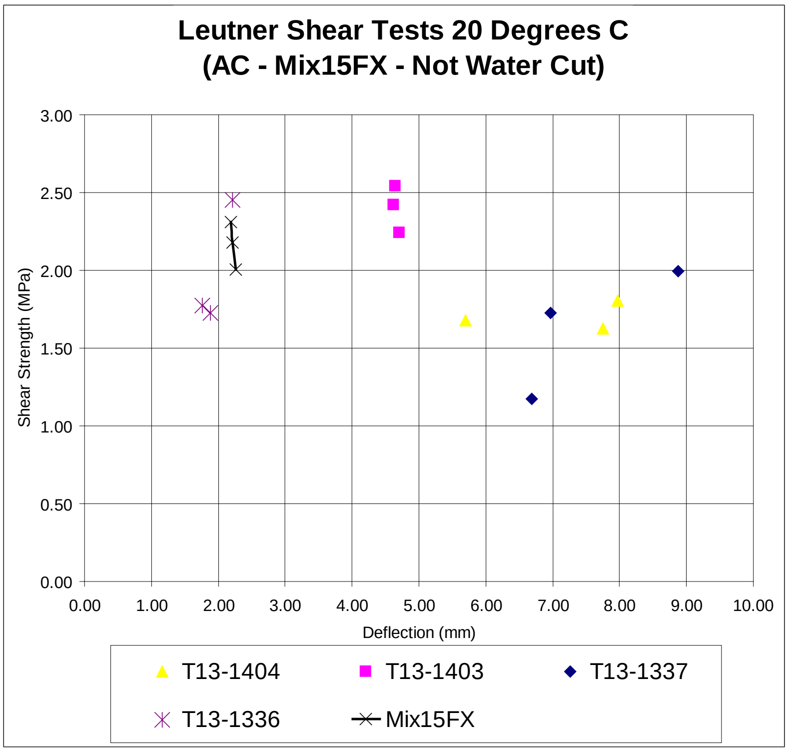


Figure 4.3 Leutner shear test results for specialist surfaces bonded to a water cut Mix15FX at 20°C (note the black line shows results for shearing through the asphalt core only)

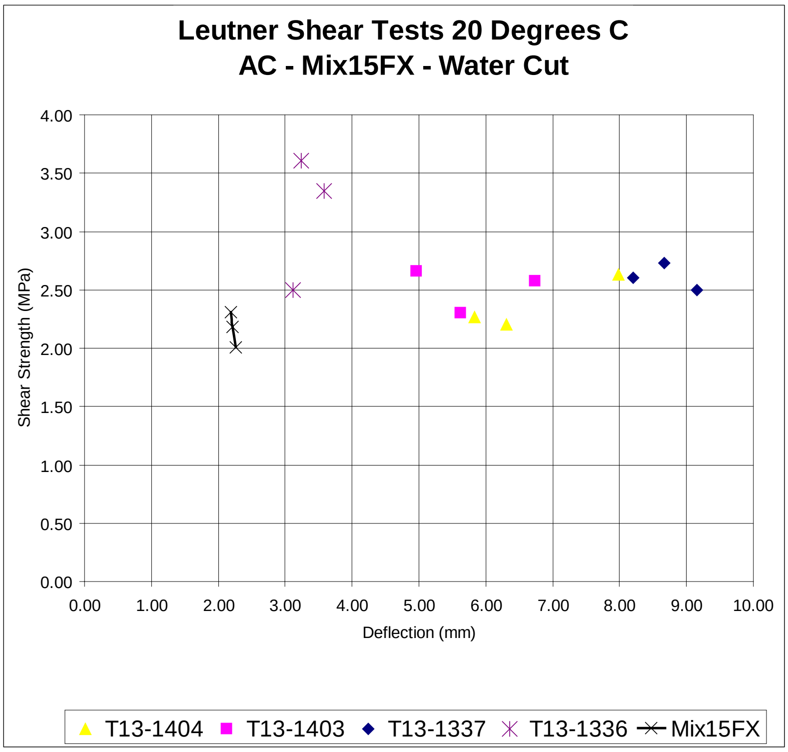


Figure 4.4 Leutner shear test results for specialist surfaces bonded to Mix15FX at 5ºC

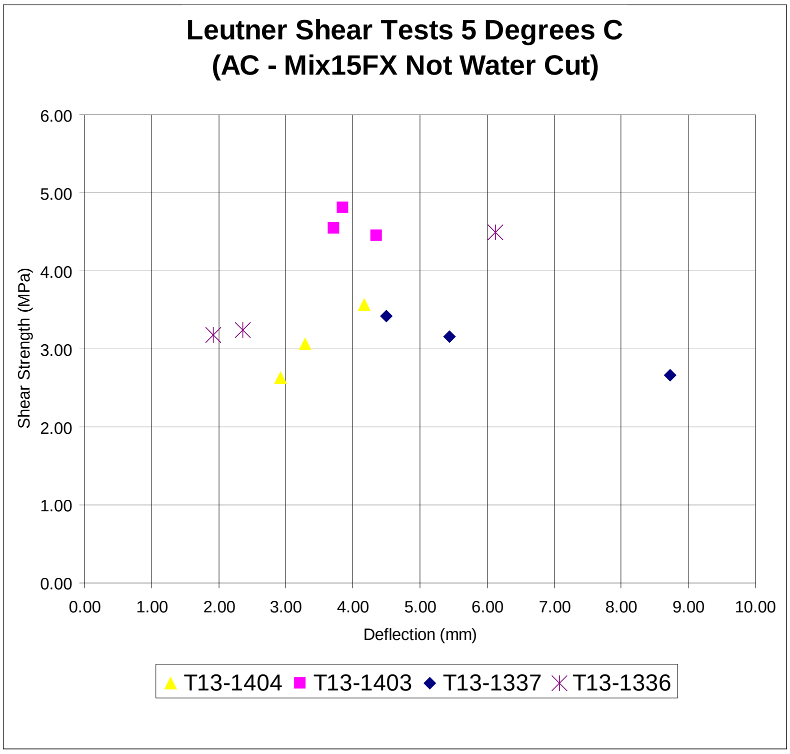
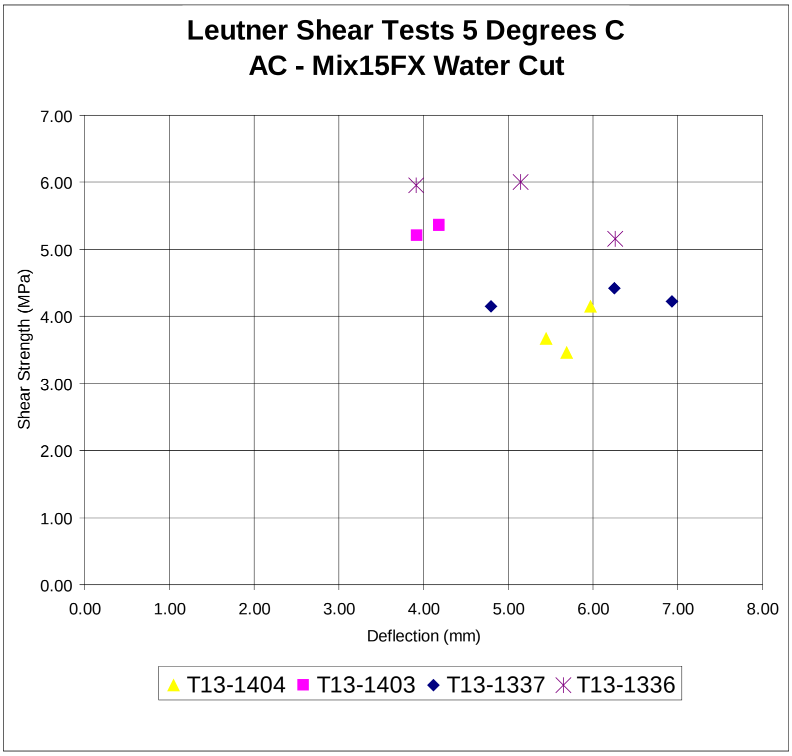


Figure 4.5 Leutner shear test results for specialist surfaces bonded to water cut Mix15FX at 5ºC



Results of the Leutner shear tests show there is a benefit in bond strength if the asphalt surface is water cut. In fact for a water-cut asphalt surface the bond strength is the same or slighter higher than the shear strength of the asphalt for all the specialist surfacing resins. The bond strength found from the binder in test T13_1403 was not affected by the asphalt surface condition and showed that water cutting was not required. A possible criterion in a specification for the Leutner test is the bond strength must meet or exceed the shear strength of the asphalt. However, a low shear strength asphalt should not be an excuse for a product that results in a low bond strength. Therefore, a better approach is to specify minimum bond strength and a shear strength of the asphalt mix suitable for the expected traffic stresses. Tests done on fresh asphalt cores without water cutting are a more conservative approach but would limit the pass rate to only one product. Further, an advantage of the Leutner test is that it can be completed on post construction cores to check for bond and asphalt shear strength, although additional surfacing product will need to be added in the lab to enable a suitable grip for the test. T13_1336 has the least deflection in the Leutner tests indicating a more brittle material compared with the other specialist surfacing binders. This was also supported by the flexural beam breakage test which indicated T13_1336 was the binder with the least flexibility.

Figure 4.6 Leutner shear test blocks for T13_1336 specialist surfacing product

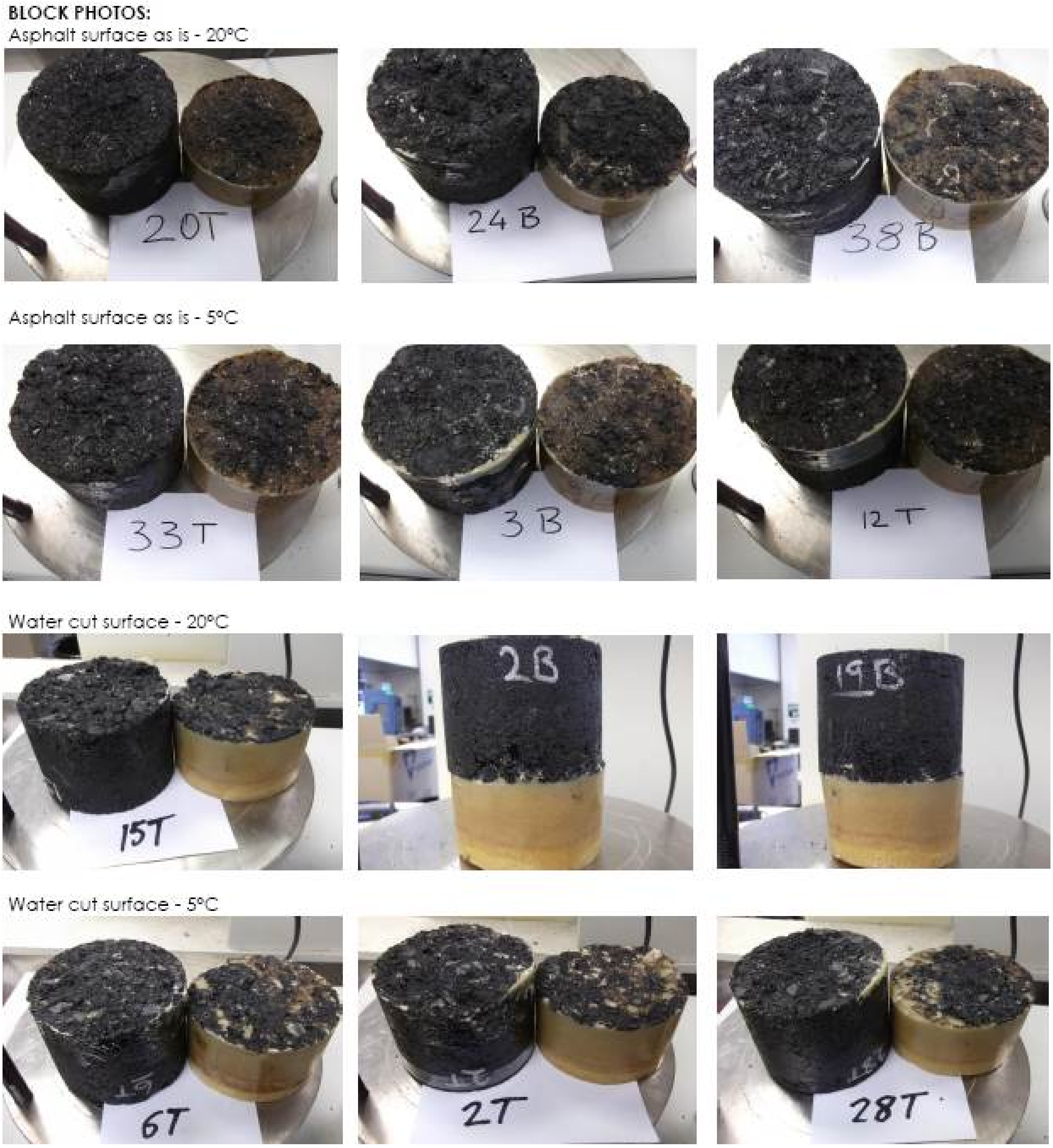


Figure 4.7 Leutner shear test blocks for T13_1337 specialist surfacing product

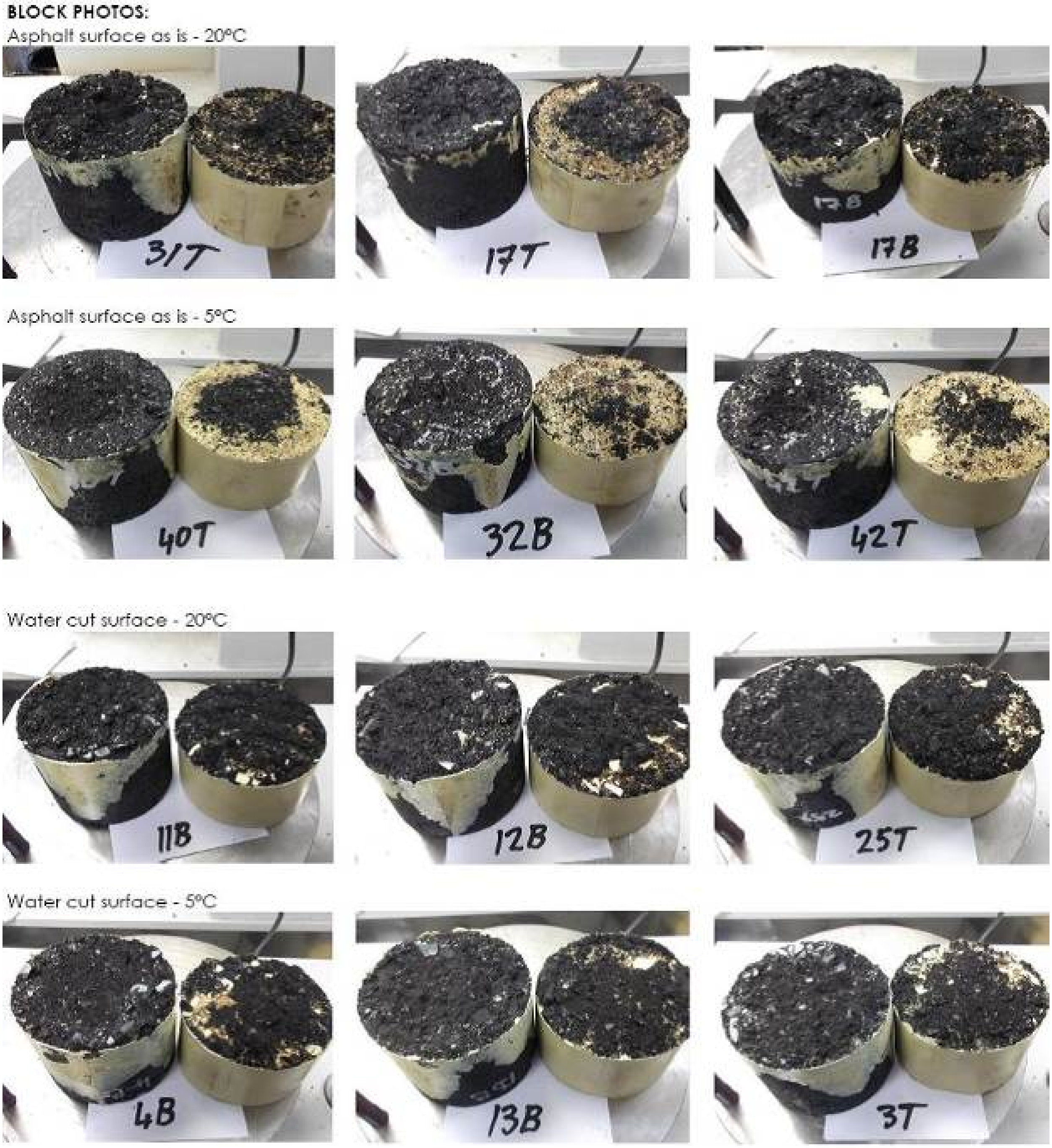
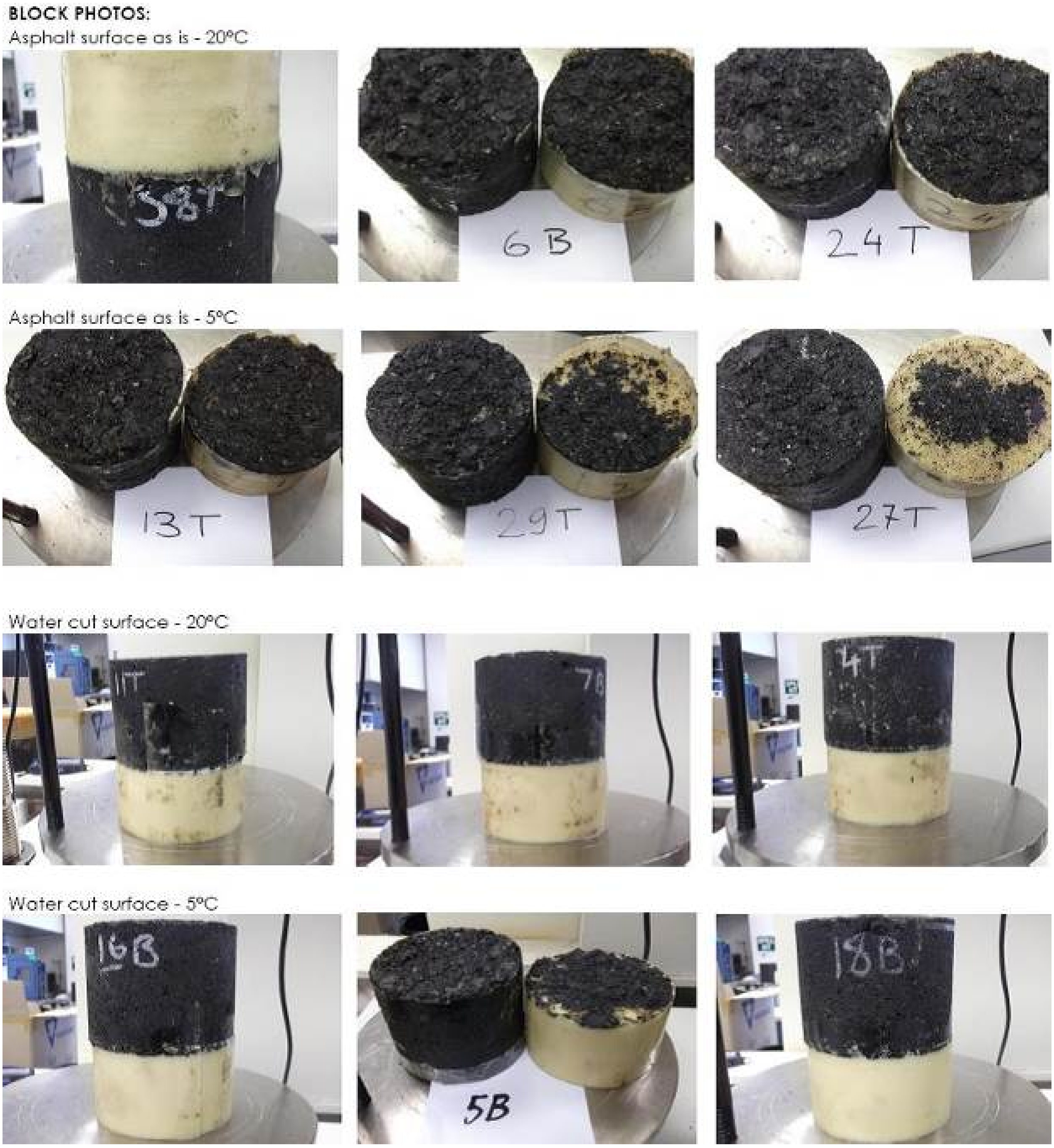


Figure 4.8 Leutner shear test blocks for T13_1403 specialist surfacing product

Figure 4.8 Leutner shear test blocks for T13_1404 specialist surfacing product



5 Thermal effects

Thermal stresses at the bond interface can be induced by changes in temperature where the specialist surfacing and underlying asphalt expand and contract at different amounts. These additional thermal stresses could break the bond if they exceed the bond strength found by the Leutner shear test.

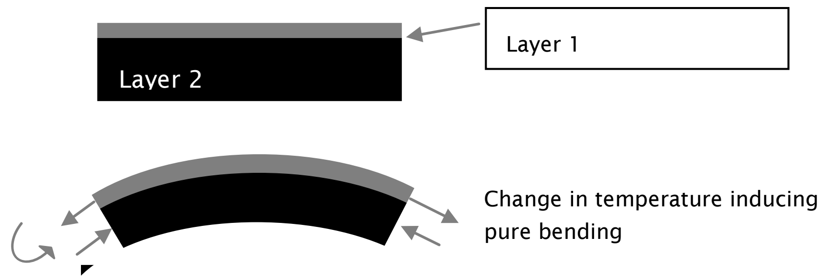
This section describes the thermal stresses and strains that are induced between specialist surfaces and the asphalt underneath.

5.1 Simplified theoretical model

A model to predict the stresses and strains induced from thermal effects is presented below. The model is based on the pure bending of two surfaces that are attached to each other when there is a temperature change ΔT.

The model assumes the material is isotropic and elastic – this is considered appropriate for low or intermediate temperatures at less than 20˚C. Each layer has a different coefficient of thermal expansion/contraction. An illustration of the model is pictured in figure 5.1 below.

Figure 5.1 Schematic of the bending in the two layers occurring due to thermal contraction/expansion



This phenomenon can be explained by a thermal stress being induced by a thermal effect.

Thermal strain = mechanical strain

$$\sigma 2= (\alpha 2 - \alpha\ 1)^{*}\ \Delta T^{*}E2^{*}/(1-\upsilon) \quad \text{(Equation 5.1)}$$

$$\sigma 1= (\alpha 2 - \alpha\ 1)^{*}\ \Delta T^{*}E1^{*}/(1-\upsilon) \quad \text{(Equation 5.2)}$$

where:

$\sigma 1$ = stress in layer, 1 (kPa)

$\sigma 2$ = stress in the bottom layer 2 (kPa)

$\alpha 1$ = thermal coefficient of layer 1 (1/ºC)

$\alpha 2$ = thermal coefficient of layer 2 (1/ºC)

ΔT = change in temperature (ºC)

E2 = modulus of layer 2 (kPa)

υ = Poisson's ratio

Calculating the strain becomes: ε or the measured changed in length ΔL over the original length L

$$\varepsilon 1 = \sigma 1 \,/\, E1 = \Delta L / L1 \qquad \text{(Equation 5.3)}$$

$$\varepsilon 2 = \sigma 2 \,/\, E2 = \Delta L / L1 \qquad \text{(Equation 5.4)}$$

The stresses in layer 1 and layer 2 (σ1 and σ2) when determined can be compared to the bond strength found in the Leutner test. If these thermal stresses exceed the bond strength then the bond could be expected to break and the specialist surfacing would delaminate from the asphalt.

5.2 Recommended developments

Based on this model, an empirical test can be carried out to measure the maximum strain and stress for a given change in temperature.

The test would need to be in a controlled temperature environment, where this temperature change could be monitored. The length change of the original specimens would also need to be measured. The gradient of these two variables would be the thermal coefficient. Further research is required to determine if there is a suitable test that could be adopted. *ASTM D7051 – 05 (2013) Standard test method for cyclic thermal shock of SBS-modified bituminous roofing sheets with factory-applied metal surface* could be a suitable standard for further investigation.

6 Pavement deflection criteria

6.1 Introduction

The original Transport Agency research brief indicated that pavement deflecting under a heavy wheel load is a reason why specialist surfacings fail early, and a pavement deflection and curvature limit is required to prevent this from occurring. It appears from the flexural beam testing that most specialist surfacing resins are very flexible, can tolerate high strains (>40,000 microns) and deflect more than 25mm without breaking, and thus are able to deflect along with the pavement without cracking. One specialist surfacing product was more brittle than the others but the maximum strain at break was approximately 10,000 microns while typically most asphalts will break at strains around 1500 microns and hence the asphalt will break before the specialist surfacing does.

Current linear elastic theory using CIRCLY in pavement design shows the thin specialist surfacing directly under the wheel load is always in compression and the tensile strain is at the base of the underlying asphalt layer. However, there are many other factors to consider that will result in tensile strains and stresses in the surface that could cause cracking from the top down.

6.2 Top down cracking

It is now well accepted that top-down cracking (ie cracking that initiates at or near the surface of the pavement and propagates downward) occurs commonly in asphalt surfaced pavements. The phenomenon has been reported in many parts of the USA (Roque and Ruth 1990; Myers et al 1998; Uhlmeyer et al 2000), as well as in Europe (Gerritsen et al 1987; De Freitas et al 2005), Japan (Matsuno and Nishizawa 1992) and other countries (Rju et al 2008). This mode of failure cannot be explained by traditional fatigue mechanisms used to explain load-associated fatigue cracking that initiates at the bottom of the asphalt layer as CIRCLY calculates.

At least two major mechanisms would need to be considered to predict top-down cracking initiation. One mechanism is related to the bending-induced surface tension away from the tyre (ie bending mechanism), which governs crack initiation in asphalt layers. The other mechanism is associated with the shear-induced near-surface tension at the tyre edge (ie near-tyre mechanism), which also explains crack initiation. The damage induced by either mechanism becomes more critical as ageing progresses. Ageing occurs top down over time caused by sunlight and oxygen and thus the ‘thicker’ the asphalt surface the longer it will take to ‘age’ the full depth of the asphalt surface.

6.3 Bending-induced surface tension

The bending-induced surface tension comes from the specialist surface bending into the shape of the road as it deforms under a heavy wheel load. The specialist surface has to stretch to form the shape of the deformed road as shown in figure 6.1. This stretching is a result of the straight undeformed specialist surface being shorter than the deformed specialist surface. Adding to this bending is rutting of the pavement underneath which further requires the specialist surfacing to stretch to fit within the rutted wheel path as shown in figure 6.2.

Rutting dominates by far the amount of bending-induced surface tension and thus the amount of rutting needs to be minimised through good pavement design. Increasing the thickness of the asphalt will reduce the stresses and strains in the aggregate and subgrade layers, which in turn will reduce the amount and rate of rutting of the pavement and thus reduce the stretching of the specialist surfacing. Rut depth prediction models developed from permanent strain repeated load triaxial tests (figure 6.6) can be used to calculate the reduced amount of rutting as a result of increasing the thickness of the asphalt surface (figures 6.3, 6.4 and 6.5).

Figure 6.1 Stretching tension

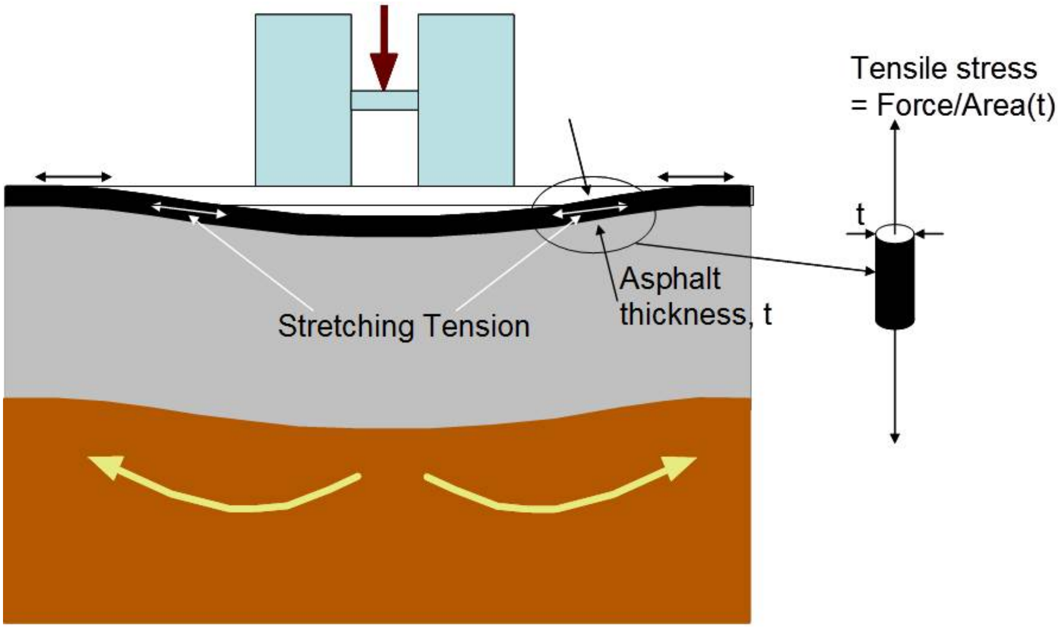


Figure 6.2 Rutting and shoving in the aggregate layers causing more stretching of the asphalt

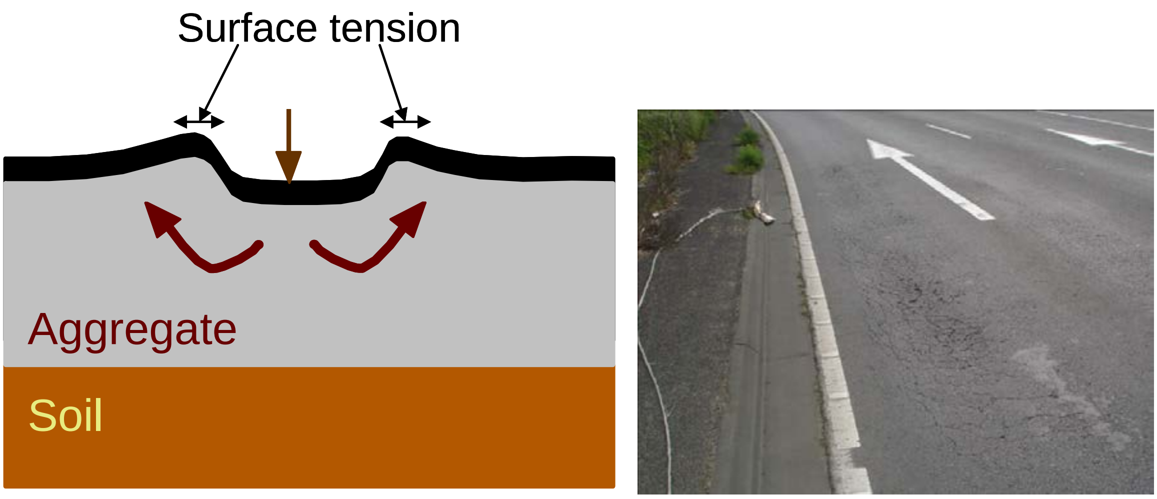


Figure 6.3 Increase in life in granular pavement layers for poor quality aggregate with increase in asphalt surfacing thickness

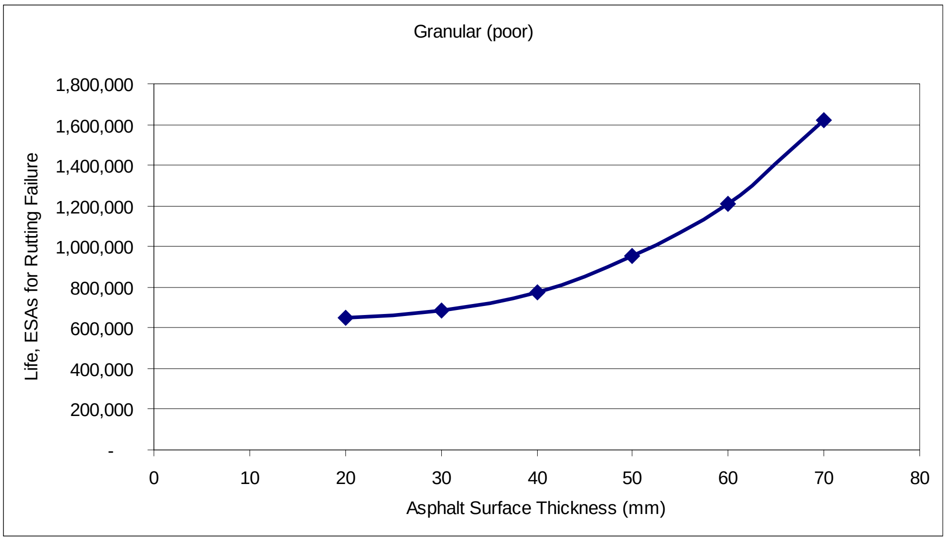


Figure 6.4 Increase in life in granular pavement layers for average quality aggregate with increase in asphalt surfacing thickness

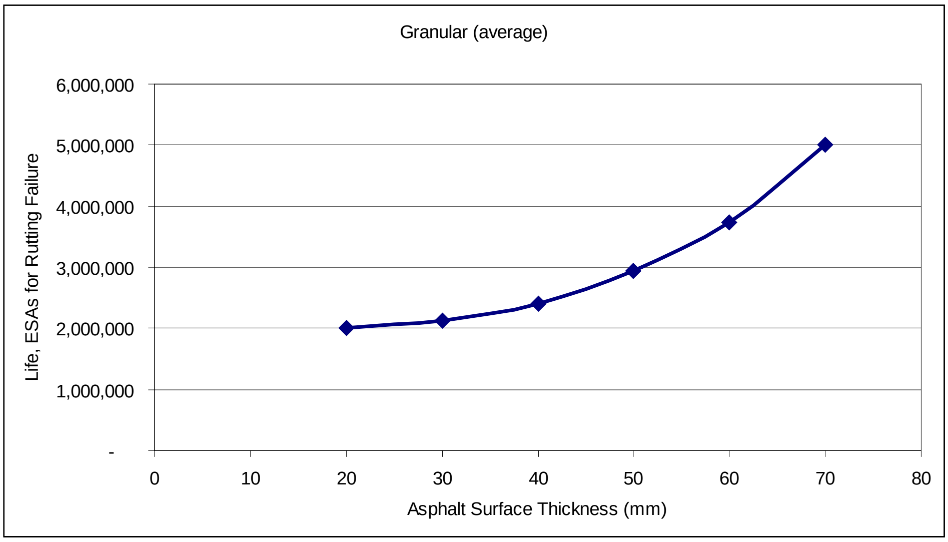


Figure 6.5 Increase in life in granular pavement layers for very good quality aggregate with increase in asphalt surfacing thickness

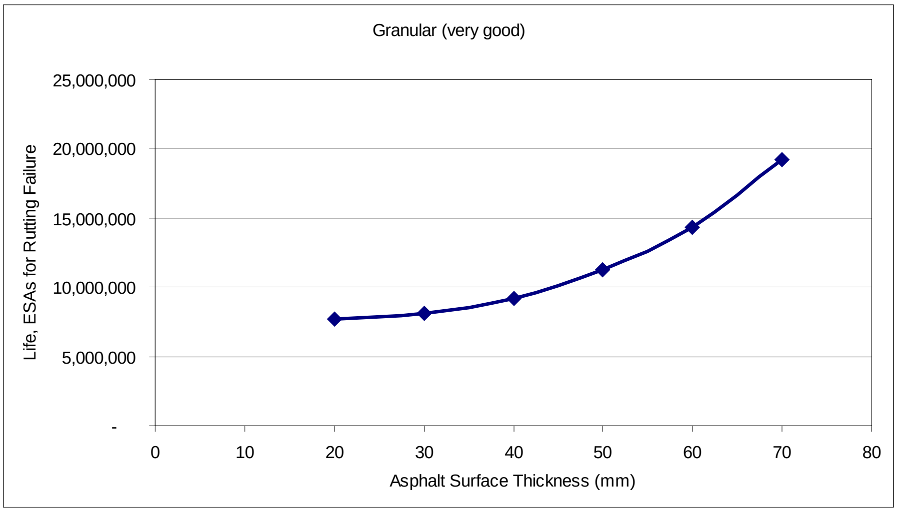
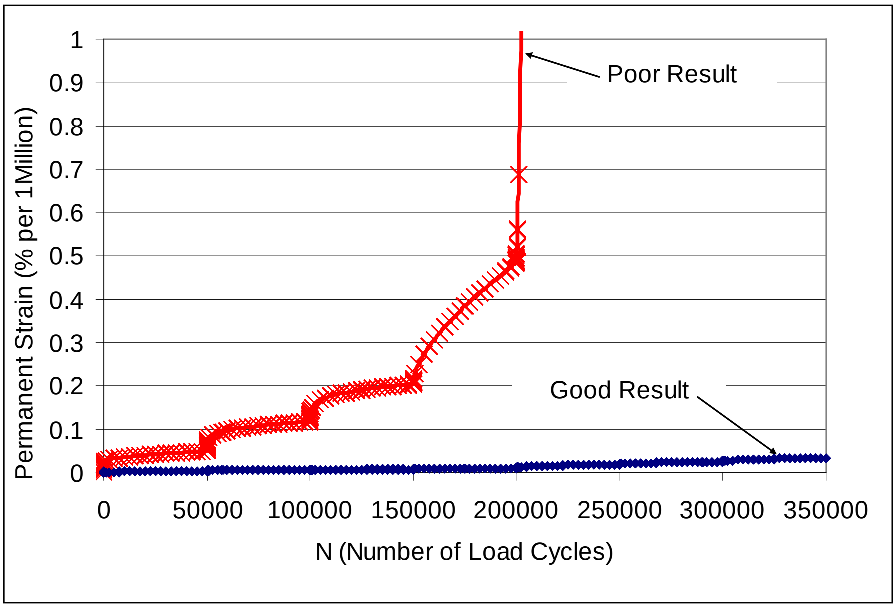


Figure 6.6 Typical output from multi-stage repeated load triaxial test in accordance with NZTA T/15



6.3.1 Pavement curvature

The pavement curvature is often estimated by calculating the difference between the pavement surface deflection at the centre of the load and 200mm from the load and often referred to as D_0-D_{200} and measured using the falling weight deflectometer (FWD). Using the radius of curvature theory the surface tensile strain can be calculated from the D_0-D_{200} curvature value. An example is shown below:

The tensile strain in the top of the asphalt from the curvature (D_0-D_{200}) using the formula below and then the strain depends on the asphalt thickness.

If D_0-D_{200} equals 0.16mm

The radius of this curvature (R) (from geometry) is calculated from the formula below:

(2R-0.16)*0.16 = 200*200, whence R = 125,000mm

From elastic bending theory, the extreme strain in a layer that is y thick is from $\varepsilon/y = 1/R$

For 70mm thickness, $\mu\varepsilon$ = 70E6/125000 = 560 microstrain

This formula for converting D_0–D_{200} values to tensile strain was applied to a full range of curvature values including those values invoked by pavement wheel track rutting (figure 6.2). The tensile strains calculated are shown in table 6.1 where D_0–D_{200} values of > 0.2mm invoke high enough strains to cause fatigue of a typical asphalt. However, it is not until the tensile strains are calculated in the rutting range of D_0–D_{200}>5mm that they can cause enough strain (>10,000 micro-strain) to crack the specialist surfacing material as found from flexural beam tests (figure 3.3a). The formula shows that very thin asphalt surfaces can tolerate higher curvatures. Also this formula does not consider repeated loading as being the cause of fatigue cracking and thus under millions of repeated loads cracking would occur at a lower curvature limit.

Table 6.1 Surface tensile strain estimated from pavement curvature (D_0–D_{200})

		Asphalt surface thickness (mm)			
		25	50	75	100
	D_0–D_{200} (mm)	Surface tensile strain (microstrain)			
Elastic range as measured by FWD	0.05	62	125	187	250
	0.1	125	250	375	500
	0.15	187	375	562	750
	0.2	250	500	750	1000
	0.25	312	625	937	1250
	0.3	375	750	1125	1500
	0.35	437	875	1312	1750
	0.4	500	1000	1500	2000
	0.45	562	1125	1687	2250
	0.5	625	1250	1875	2500
	0.55	687	1375	2062	2750
	0.6	750	1500	2250	3000
	0.65	812	1625	2437	3250
	0.7	875	1750	2625	3500
	0.75	937	1875	2812	3750
	0.8	1000	2000	3000	4000
	0.85	1062	2125	3187	4250
	0.9	1125	2250	3375	4500
	0.95	1187	2375	3562	4750
	1	1250	2500	3750	5000
	1.2	1500	3000	4500	6000
	1.4	1750	3500	5250	7000
	1.6	2000	4000	6000	7999

		Asphalt surface thickness (mm)			
		25	50	75	100
	D_0-D_{200} (mm)	Surface tensile strain (microstrain)			
	1.8	2250	4500	6749	8999
	2	2500	5000	7499	9999
	2.2	2750	5499	8249	10,999
	2.4	3000	5999	8999	11,998
	2.6	3249	6499	9748	12,998
	2.8	3499	6999	10,498	13,997
	3	3749	7498	11,247	14,997
Rutting range	5	6246	12,492	18,738	24,984
	10	12,469	24,938	37,406	49,875
	15	18,645	37,290	55,935	74,580
	20	24,752	49,505	74,257	99,010
	25	30,769	61,538	92,308	123,077
	30	36,675	73,350	110,024	146,699

6.4 Shear-induced near-surface tension at the tyre edge

Researchers Douglas (2009) and De Beer et al (2002) used special load cell mats to measure the contact stress exerted by truck tyres on every square centimetre of the road surface. What they found was that tyre sidewall stresses could be in the region of 1800kPa due to the steel reinforcement of the tyre. In pavement design it is often assumed that the tyre stress is uniform at around 750kPa. This high sidewall stress can directly shear the asphalt and specialist surface at the edge of the tyre causing a crack in the surface. Increasing the surface friction by using a specialist surfacing with calcined bauxite chips will increase the braking forces. The high-friction surfacings can increase the coefficient of friction in the wet from 0.2 to 0.96 (Izeppi et al 2010) and thus the 1800kPa tyre force results in a horizontal shearing force of 1800kPa*0.96 = 1.7MPa. In braking, however, the load can transfer to the front tyres and this horizontal shearing force could double to 3.5MPa. The Leutner shear test on asphalt mixtures other than open graded porous asphalt (OGPA) found that shear failure occurs between 1.7 MPa and 2.5MPa. OGPA failed in shear at 0.6MPa for the PA14 and 1.3MPa for the PA10. Therefore, high-friction calcined bauxite surfaces should not be placed on low shear strength OGPA surfaces as the OGPA will fail in shear from truck braking forces.

Figure 6.7 Tyre contact stresses measured by De Beer et al (2002) (lateral units are in cm while longitudinal units are in mm)

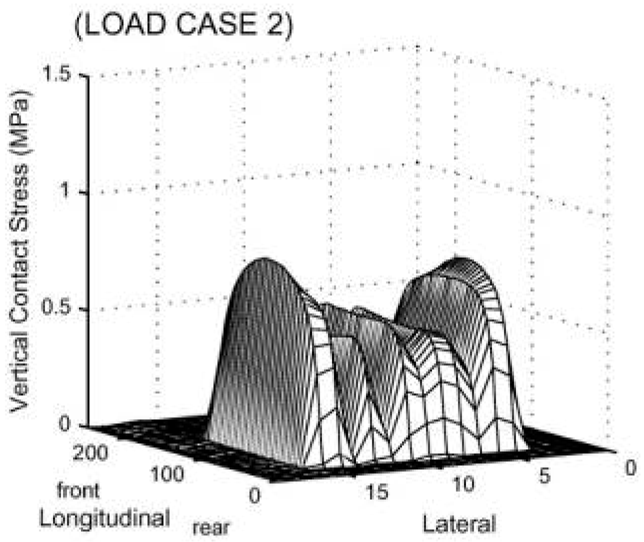


Figure 6.8 Tyre contact stresses measured by Douglas (2009) (longitudinal and transverse units are in cm)

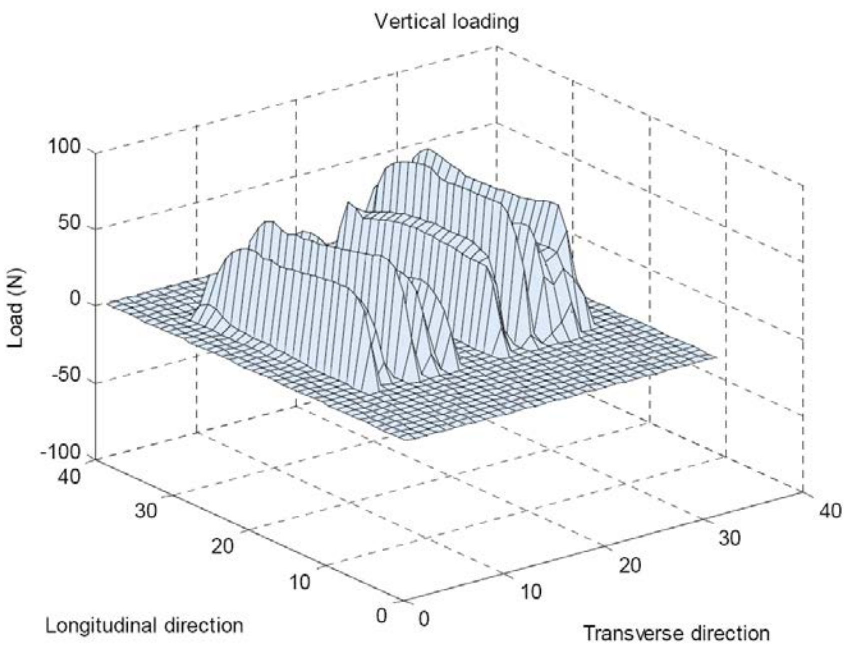
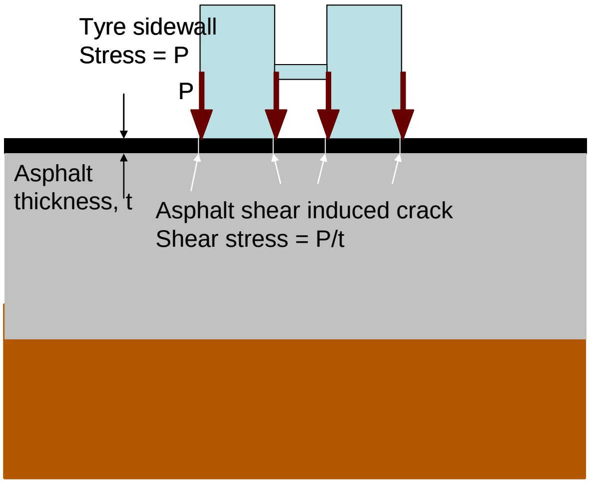


Figure 6.9 Shear stress calculation on asphalt



7 Specification criteria

7.1 Tensile strain criteria for 10mm pavement rutting

It appears that all the specialist surfacing products can sustain high tensile strains (>10,000 microns). Pavement analysis shows that those high levels of strains only occur in a pavement that has rutted at least 10mm. Nevertheless, it could be considered appropriate to develop a criterion for flexural beam bending that relates to the ability of the specialist surfacing to cope with a tensile strain caused by a rut depth of 10mm which is approximately related to a D_0-D_{200} value of 5mm and a tensile strain value of 25,000 microns for an asphalt thickness of 100mm. All the specialist surfacing resins met this criterion except for one.

7.2 Leutner shear bond strength criteria

Results from this study determined a Leutner shear test for bond strength could be included in a specification for specialist surfacings. A possible criterion in a specification for the Leutner test is the bond strength must meet or exceed the shear strength of the asphalt. However, a low shear strength asphalt should not be an excuse for a product that results in a low bond strength. Therefore, a better approach is to specify minimum bond strength and a shear strength of the asphalt mix suitable for the expected traffic stresses. Testing on fresh asphalt cores without water cutting is a more conservative approach but this would limit the pass rate to only one product. Further, an advantage of the Leutner test is it can be completed on post-construction cores to check for bond and asphalt shear strength, although additional surfacing product will need to be added in the lab to enable a suitable grip for the test.

8 Other tests

Two other tests used to study the properties of bitumen may be useful for determining if the rheological characteristics of the specialist surfacing binder are acceptable. The first test used for every bitumen in New Zealand is the dynamic shear rheometer (DSR) test (see figure 8.1). This uses a small 2mm bitumen sample on a plate and applies an oscillating torque to determine the bitumen viscosity at a full range of temperatures and loading speeds. This DSR test could be completed for the specialist surfacing binder to estimate flexibility at a range of temperatures and loading speeds and identify a temperature and loading speed where the binder may become too stiff and brittle and thus prone to cracking.

Figure 8.1 Dynamic shear rheometer test for binders

Figure 8.2 Direct tension tester for binders

The second test (see figure 8.2), which could replace the flexural beam test, is the direct tension tester. Small dog-bone shaped specimens of binder are stretched apart until they break using a constant strain rate. The test records load versus tensile strain and the dog-bone samples can be warmed up or cooled in a oven or freezer to test at different temperatures. This is a simple test and easier to do than flexural beam tests, and the tensile strain at break can be determined.

9 Conclusions

This was a limited study on specialist surfacings with the initial focus on flexibility and developing limiting pavement deflection criteria. The understanding of the behaviour and requirements for specialist surfacings and their supporting pavement structure was advanced significantly by the research, which identified that contrary to initial belief specialist surfacings can be used in places with high pavement deflections. Apart from one resin the specialist surfacing resins are highly flexible and will thus cope with very high pavement deflections. In fact, the flexibility of the resins showed they could cope with rut depths in excess of 10mm (although this might not be the case for high curvatures). Most asphalts will crack before the specialist surfacing resins do, while some asphalt mixes high in fines and bitumen can rut without cracking. Nevertheless, one important property for the specialist binders to have is flexibility. Four of the five specialist binders showed exceptional flexibility and thus flexibility criteria could be developed that would exclude the fifth product that was more brittle than the others.

The research also identified that the shear strength of asphalt and the shear bond strength of the specialist surfacing and asphalt interface are both important to the success of the specialist surfacing. Results of the Leutner shear test for bond and asphalt shear strength clearly showed that four of the five specialist surfacing resins required the asphalt surface to be water cut while one resin showed exceptional performance giving full bond strength on fresh asphalt surfaces that were not water cut. Full bond strength is achieved when the Leutner shear strength at break is equal to the asphalt shear strength indicating failure in the asphalt and not the bond. Field cores could also be tested in the Leutner shear test to determine whether or not full bond strength was obtained.

Results from this study determined a Leutner shear test for bond strength could be included in a specification for specialist surfacings. A possible criterion in a specification for the Leutner test is the bond strength must meet or exceed the shear strength of the asphalt. However, a low shear strength asphalt should not be an excuse for a product that results in a low bond strength. Also tyre breaking forces on a calcined bauxite high-friction specialist surfacing have the potential to exceed the shear strength of some asphalt surfacings. Therefore, a better approach is to specify a minimum bond strength and a shear strength of the asphalt mix suitable for the expected traffic stresses. Testing done on fresh asphalt cores without water cutting is a more conservative approach but this would limit the pass rate to only one product. Further, an advantage of the Leutner test is it can be completed on post construction cores to check for bond and asphalt shear strength, although, additional surfacing product will need to be added in the lab to enable a suitable grip for the test.

10 Recommendations

It is recommended that a industry steering group be established to discuss the findings of this research to determine suitable specification criteria and if appropriate further research.

A test method should be adopted or developed to determine the potential of thermal cracking as this could be a factor in causing the surface to crack as the flexural beam tests found that most resins have adequate flexibility and are not brittle.

Flexibility of the specialist surfacing resin could be better measured using binder property tests (DSR of direct tension).

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