DETERMINING THE EFFECT OF SUPER FINE TILLITE FILLER IN AN ASPHALT LAYER

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Abstract

An investigation into the cause of premature failure of a premix asphalt layer on a road in South Africa identified the filler material in the mix as the main cause. The failure was characterised by signs of dryness and an increase in permeability within a few months of laying the asphalt; distress was evident even while the project was still in progress. Later phases of deterioration were stripping of binder from surface stone, pumping and crocodile cracking. The asphalt was within specification and no immediate cause was apparent. Specialised testing was conducted on the recovered binder, detailed filler grading, X-ray diffraction (XRD) tests, X-ray fluorescence spectrometry (XRF) tests and isotope dating. The ashing of the recovered binder indicated that a super fine filler material was present in the mix. It was determined that the origin of the super fine filler material was mostly tillite. The stiffening effect of the superfine filler material was quantified by the Rigden voids test, and by testing the filler binder mastic. Binder film thickness and mix stiffness calculations quantified the influence of the observed super-fine tillite filler size material in the asphalt mix, and were used to explain the mechanism of distress.

1. INTRODUCTION

An asphalt wearing course on a national road in South Africa showed unexpected distress in 2003 during and immediately after construction. This deterioration and distress of the continuously graded asphalt occurred within 3 to 6 months after actual laying of the mix. The signs of the pre-mature distress were observed over virtually the whole length (22km) of the project and were in various stages of deterioration. The asphalt was within specification and there was no immediate cause for the distress.

The original project was defined as special maintenance with minor light rehabilitation portions. The existing pavement was overlaid with an asphalt surfacing, and where obvious structural inadequacies were identified, in-situ deep milling was used to provide needed structural strengthening.

During the project construction period, limited areas of distress on the earliest sections were evident. The first visual surveys indicated that the surfacing showed signs of dryness, brittleness, and an increase in porosity and permeability. The extent of the area affected grew to cover most of the 22km length of the project. Over the following months, further deterioration occurred in the form of rolled-in chip loss, aggressive stripping of binder from surface stone, white fines pumping after rain, crocodile cracking and release of more white fines. The final stage of visually observed surface related deterioration appeared like crocodile cracking with obvious signs of water intrusion into the under laying base.

Image of typical early cracking, fines occurrence and crocodile type cracking on a section of the road (August 2003)

Permeability measurements were done during construction and later in the laboratory as well as in the field. Air and water permeability test results, done on cores from the road during construction and taken during the time of investigation (6 months later) on site, showed an increase of 10 to 100 fold in permeability values. This increase in porosity and permeability values was associated with evidence of aggressive stripping, and a whitish fluid was observed to be flowing from the surface cracks directly after rain. The release of these fines in the whitish fluid accelerated the stripping and associated increase of porosity. The increase in permeability of the surfacing layer was also evident by water flowing out of freshly milled sections and was capture in photographic records.

Anecdotal confirmation that the cause of the distress observed had its origin in the surfacing layer was obtained during the initial visual survey. It was observed that the premature cracking with white fines pumping also occurred on the bridge decks. This strongly suggested the cause of distress was not structural, since the bridge decks acted effectively as a "rigid pavement" support. Furthermore, for up to 6 months after the initial visual survey, nil or limited rutting was observed. Rutting would have been expected if the cause was inadequate structural support.

An independent structural analysis was then undertaken using Falling Weight Deflectometer (FWD) results, and the original detailed design report of the consulting engineering joint venture firm audited, and both confirmed that the structural integrity of the as-built pavement structure was not the cause of this distress.

2. ASPHALT MIX AND PAVING OPERATIONS

The continuously graded asphalt premix used on this project was a mix design that had been successfully used in the past in this region. A harder 40/50 penetration grade bitumen binder is normally used in this (warm humid climatic) region to help cater for durability and mix stability (Wyatt and Thomson, 1994).

The mix was designed as a medium continuously graded mix of 40mm with rolled in chips. The mix was designed with 5.1% binder content. The addition of 1% lime as filler material was required to prevent stripping. This brought the upper specification limit of the percentage passing the 0.075mm sieve to 10%; the production mix averaged 7.6%. The mix was a blend of tillite crushed stone, tillite crusher run and tillite plus sand fines.

The mix was laid to specification. A Marshall void content of between 4% and 5% was achieved according to construction control records and prescribed densities were achieved.

This specific mix was primarily designed to resist deformation in the asphalt surface layer and therefore it was to be expected that it might exhibit possible harshness and potential difficulty with constructability in the compaction operations. Such mixes are at risk of being manufactured at higher temperatures. Inspection of the construction data, and discussions with the plant operating personnel, revealed that above average high mixing temperatures (around 175^{o}C), long hot-bin storage episodes (also at about 170^{o}C) and high paving temperatures (165^{o}C average) existed which are potential contributing factors of pre-mature failure and cracking (Malan et al, 1987). Possible exposure to episodes of rapid cooling may have been an additional contributing factor, but no detailed site temperature records were available.

The drum mix asphalt plant was still operating when the investigation started.

Lime was initially added via the aggregate conveyor belt (probably during the trial mix laying). It was later added with a pump and pipe system. The plant had no baghouse fines filter system, but instead a cyclone dust collector system which sucked off dust and air right at the point where the feed-in pipe for the lime addition was positioned as can be seen clearly in the photo alongside.

The mix met specification, and the contractor achieved densities as well as met the void content specification with no penalties associated.

3. INITIAL MIX RELATED LABORATORY INVESTIGATIONS

3.1. Binder

Retained samples of the 40/50 penetration bitumen binder were tested, as well as binder recovered from cores taken from the road. Testing was by the laboratory of the CSIR against the SABS 307 specification. These tests confirmed that the binder itself was sound, chemically stable and durable, and complied with the specification.

The recovered binder had a lower penetration value than the virgin binder of the retained samples, as expected. The drop in penetration expected from the hardening during mixing, laying and being in-service, but it was a greater drop than Rolling Thin Film Oven Test testing on the virgin binder suggested.

3.2. Filler and lime in the mix

CSIR tested cores of recently laid mix taken from the road (hereafter called road cores). The observed aggressive stripping is typical of mixes with little or no lime added, and raised doubt about the presence of the prescribed 1% lime. Invoice records were requested in late 2003 to provide proof of the addition of the prescribed 1% lime. This information was not received until months later, and in the meantime the investigation had to proceed. Given the assurances that the 1% lime was added, the focus of the investigation shifted to the filler and filler binder mastic portion of the mix as a possible source or origin of the failure mechanism.

Construction was ongoing during this stage of the investigation in August/September 2003, and so samples of the lime being added at that time were requested. The persons taking the sample were directed to take a sample from the lime feed-in mechanism ("pump and pipe" system shown in the photo before). This sample from the pump looked like lime, but had a sandy and gritty feel to it. This was later described as "bogus lime" in the testing. Lime was taken from sealed bags in the store at the plant to use as a benchmark and reference in the tests. Samples of the raw materials were taken to prepare laboratory briquettes.

Grading analysis on the road cores showed high percentages of filler sized material (percent passing 0.075mm sieve), which could not be reconciled with the grading quality control records from site. One possible explanation for the difference was CSIR procedure of wet sieving the fines and filler fraction, and using solvent extraction. The filler proportion from the road cores was just above the 10% upper specification limit on the 0.075 mm fraction.

The CSIR made up briquettes in the laboratory to the approved job mix (hereafter called CSIR briquettes). It was observed during the laboratory mix make-up that very fine dust seemed to adhere to the larger tillite aggregate.

3.3. Ash test

The ash test is used to detect the presence of super fines (particles in the 5 micron diameter range). It is not possible to remove super fines in binder or recovered binder by means of the standard recovery laboratory procedure. In the ash test, the binder is burnt and the ash residue contains the retained super fines. The test was used by the CSIR and correlated with mix stiffening behaviour (van Assen et al, 1994). The ash test was done on the CSIR briquettes. The ashing of these laboratory prepared mixes indicated that the binder itself only contributed to 0.1% ash content while the binder plus the prescribed filler content pushed the ash content up to 1.9%. When the 1% specified lime portion was added, the ash content increased to 2.3%.

This is slightly above the 2% trigger value set by van Assen et al. (1994), above which stiffness and pre-mature asphalt cracking may occur in an asphalt premix. Of more concern, ash tests on road cores produced ash content values as high as 4.6%. A plant-sample of asphalt was then taken (August 2003) and also resulted in 3.7% ash content. The implication of these ash tests was that the super fines content in the filler had at least doubled somehow in mix production. The high super fines content endorsed the potential for early cracking.

At that stage of the investigation, it was again reported that the 1% prescribed lime was added and so the focus of the investigation shifted elsewhere.

4. TILLITE GEOLOGICAL PROPERTIES

The tillite material was identified as the next logical source of the observed excess super fines in the mix. The suspicion arose that additional filler sized material from the dusty tillite aggregate may have landed in the mix during the mixing process.

4.1. Basic geological properties

An engineering geologist undertook a preliminary geological investigation on the quarry that was the source of the tillite aggregate. Tillites are basically fines originating from glacial abrasion action that formed deposits of fines which, over geological time, have compressed into hard composite material. Weinert (1980) indicated that tillites can be highly variable even within a single quarry, and tillite needs detailed attention and geological investigation. Little such information was available from this tillite quarry.

The tillite source rock in the quarry was a finely grained material with thin calcite lenses present. It was speculated that this calcite presence may have added to additional filler sized material purely due to the softness of this material which may have abraded during mixing operations. Initial geological tests also alluded to the oxidation potential of the tillite when heated. It was speculated this might lead to volume change and the freeing of secondary minerals. The possibility existed that the elevated mixing temperatures, coupled to the extended hopper storage episodes, may have had a detrimental physio/chemical interaction between the binder and tillite filler material.

4.2. Detailed geological investigations

An engineering geologist specialist from CSIR undertook further investigations into the tillite material. The site and the tillite quarry were visited in October 2003. In brief the rock face, where the tillite for this contract came from, appeared more fractured and fissured than the other sections of the quarry. Cracks and fissures often were filled with thin calcite layers. It was observed that a fine dust covered the aggregate in the stockpiles on site.

Representative samples of tillite were requested. The samples supplied were crushed in the CSIR laboratory and a sample of each fraction heated in a laboratory oven at 200°C for 6 hours, in an attempt to replicate the sample remaining in hot storage prior to use. It was not possible with the available laboratory equipment to simulate the drying of the sample as it passed through the burners (probably about 800°C) into the plant. However, exposure of the tillite to a cool oxy-acetylene flame resulted in a rapid change in colour from the characteristic dark blue/grey to a brown material, indicative of oxidation of the ferrous iron in the tillite to ferric iron. The change from the ferrous to the ferric oxidation state would have obvious implications in terms of disruption of the chemical structure of the material, as additional oxygen is included in the mineral structure. It was therefore concluded that the tillite had potential for volume change with associated freeing of secondary minerals purely due to the heating during the mixing process in the asphalt drum mixer. This had the potential to cause micro-cracking of the asphalt in service.

There were significant difficulties with screening the fine materials in the CSIR laboratory, particularly the heated tillite material. It "balled-up" and it is likely that this behaviour may have contributed to improper coating with the binder during mixing. It was concluded that if present in excessive proportions, there may in fact have been small balls of “free” filler material in the asphalt, as other filler material would possibly already have absorbed the lighter oils in the binder fraction. These balls would allow filler sized material to be freed upon further cracking and stripping, and to appear as the milky white fluid observed on the recently constructed road directly after rain.

The fraction of the heated tillite material which passed the 0.425 mm sieve, appeared to have strong hydrophobic or surface tension action when it was wetted. In a beaker of water, the material “floated” on the surface for over 12 hours before sinking into the water. The raw (unheated) tillite fines sank into water within a minute or two. This physical behaviour, not picked up by other standard tests, was seen as highly significant and a strong indicator of stripping potential.

4.3. Tillite laboratory testing

A series of additional tests on tillite samples from the quarry were done by the CSIR laboratories. These tests involved a modified Texas Ball Mill test series, where steel balls, water and heating of the sample were varied. It also involved water absorption tests and sand equivalent tests (standard and extended). These tests showed no unusual results and are not discussed here. However, the grading of the tillite filler portion produced by laboratory crushing (heated and raw) showed an extremely fine gradation determined by laser technology. Up to 90% were less than a diameter of 10 micron in both the raw and heated condition (i.e. were in the super fines size range). The grading of this material thus produced is shown in Figure 1 to follow. This super fine fraction reflected that the geological origin of tillite was fine rock flour and indicated the potential for producing super fines in asphalt during the abrasion action of mixing.

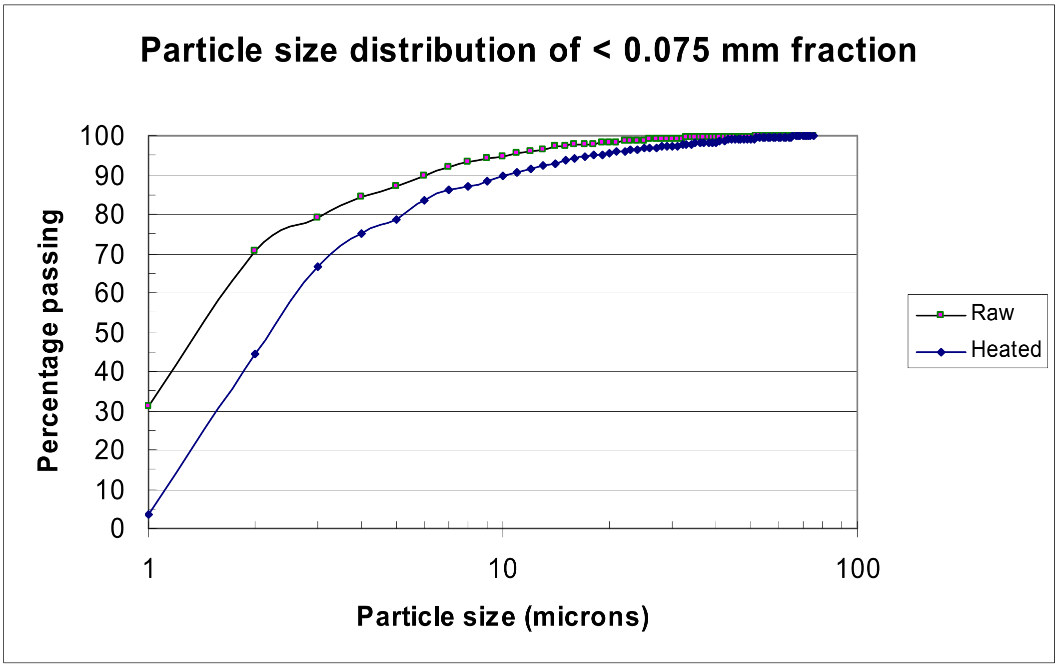

Figure 1. Grading of the tillite filler material.

5. FURTHER FILLER LABORATORY INVESTIGATION

5.1. Binder mastic tests

The ash test had already indicated excessive filler in the road cores. Mastic samples were prepared in the laboratory from binder and tillite filler (passing the 0.075mm sieve) fines with the addition of varying percentages of natural tillite filler and hydrated lime. The ash test was performed on these mastic samples. Further testing was done on the mastic and on binder recovered from the mastic. Softening point and viscosity tests were also done on the mastic combinations (NAPA, 1999). The results of these tests are shown in Table 1.

Table 1: Test results of various laboratory prepared mastic combinations

Sample description	Mastic Softening point, (°C)	Mastic Viscosity @ 60 °C (Pas)	Mastic Binder Content % (m/m)	Recovered binder Viscosity @ 60 & 135 °C, (Pas)		Recovered binder Soft pt (°C)	Recovered Binder Ash % (m/m)
Std grading	63.1	550	45.0	349	0.507	53.7	1.9
Std Grad+ 1% Lime	67.0	980	42.9	332	0.505	53.3	4.5
Std Grad + 1% lime+ 5g heated tillite fines	67.1	790	41.6	420	0.558	55.4 (60 hrs benz)	4.2
Std Grad + 1% lime + 5 g raw tillite fines	67.6	284 Failed	41.0	406	0.550	55.4 (60 hrs benz)	3.7
Std Grad + 1% lime + 5g raw tillite fines	66.6	1170	41.3	270	0.511	54.1	3.2
Std Grad + 1% lime + 10g raw tillite fines	67.4	1318	40.6	276	0.522	54.0	3.6

Note: The virgin binder had a softening point of 54 °C.

The interpretation of the results from Table 1 are briefly discussed as follows:

Since the 1970's, dust collection systems (baghouses) have been used to capture fines from asphalt plant exhaust systems. Baghouse fines have been successfully used as mineral fillers, but they have a stiffening effect on the mastic. NAPA (1999) suggest that the increase in softening point (of the mastic should be less than 11^{o}C above the softening point of the virgin binder to limit the stiffening. The softening point of the mastic of the original mix without lime increased from about 54^{o}C to 63^{o}C, which indicated that the original mix would have been a marginally difficult mix to pave, but not impossible. However with the other combinations of binder, filler and lime, the mastic softening point increased with more than the 11^{o}C threshold. The addition of the extra filler would have changed the mix such that it would have been stiff and even brittle during the paving stages.

The addition of tillite filer and/or lime increased the viscosity of the resultant mastic mixes, as expected, and showed a significant increase with increasing super-fines contents.

Excessive stiffening of asphaltr mix has been reported by some researchers (Anderson, 1987 and Anderson et al 1992), due to the reinforcing effect of filler, or as a result of an excessive quantity of filler such that the filler is no longer floating in the binder. Anderson (1987) illustrated this by varying baghouse fines (filler sized) content with 1% lime and showed that the viscosity of the binder-filler mastic rises almost exponentially as the filler portion increases. This same exponential stiffening effect with variance in filler content as simulated in the CSIR laboratories is evident from the viscosity measurements in Table 1.

5.2. Rigden voids determinations to quantify stiffening behaviour

Further quantification of the stiffening effect of the filler presence can be had by relating the Rigden voids (Anderson, 1987 and NAPA, 1999) and filler/binder ratio. In this case filler/binder ratio was kept constant and matched to the project's design 5.1% binder content and the midpoint of the specification grading for filler (percent passing 0.075mm sieve) which was 7.6%. The NAPA (1999) relationship of Rigden voids versus filler/binder ratio by mass was used to indicate the asphalt stiffening behaviour in terms of acceptable or unacceptable ranges. The results from this graphical classification are summarised in Table 2. The results clearly indicate that the prescribed filler portion plus the specified 1% lime would have given a mix that would have been marginal in terms of stiffening behaviour. Any addition of the other sources of filler shown in Table 2 would have been unacceptable in terms of mix-stiffening behaviour purely based on the volumetric aspects captured by the Rigden voids values.

The implication for the asphalt mix under investigation was clear. The ash test results, discussed earlier, provided proof that additional filler material was present in the mix as laid on the road.. This scenario of stiffening of the mix due to additional filler sized material was therefore highly plausible. Even if lime was substituted by other filler sized material, this stiffening effect would not have diminished. The further addition of filler sized fines, over and above the lime substitution, would have noticeably increased the stiffness. The high percentage of filler present in the mix on the road clearly pushed the mix from a normal stiff to virtually a brittle state. If lime was omitted or substituted the mix would also have had increased stripping potential.

It was now evident why the elevated mixing and paving temperatures were used in practice: so that compaction could be achieved. But it was likely that the harshness and inherent brittleness could induce micro-cracking even during construction.

Table 2. Classification of asphalt stiffening behaviour according mastic filler mix Rigden values.

Filler combination	Stiffening behaviour	Rigden Voids
Natural tillite filler+ prescribed filler +plus lime	Marginal	40
Cyclone dust collector filler only	Strongly unacceptable	62
Pump Waste filler	Unacceptable	46
“Bogus lime”	Strongly unacceptable	54-57

5.3. Filler grading tests

The uncertainty about whether lime was truly added led to an investigation of the basic characteristics of all materials of filler size which may have been associated with the mix. At least three different sources of filler material were identified as well as the lime. The first source was referred to colloquially as “bogus lime” which was described earlier as having been sampled from the lime pump feed-in system at the start of the investigation in 2003. In early 2004, samples were taken from the bottom gate of the cyclone dust collector at the asphalt plant. These samples are referred to as cyclone dust fines. Early in 2004 further samples were taken from the pump feed-in system in the feed-in pipe. These samples are referred to colloquially as pump waste. Lime samples from the bags found in the store at the plant were also sampled to use as benchmark and reference in the tests done by CSIR.

Particle size distribution was done with laser equipment at the CSIR on all these samples of filler sized material. In Figure 3 the grading analysis is shown for all the filler sized material sampled. A number of observations can be made:

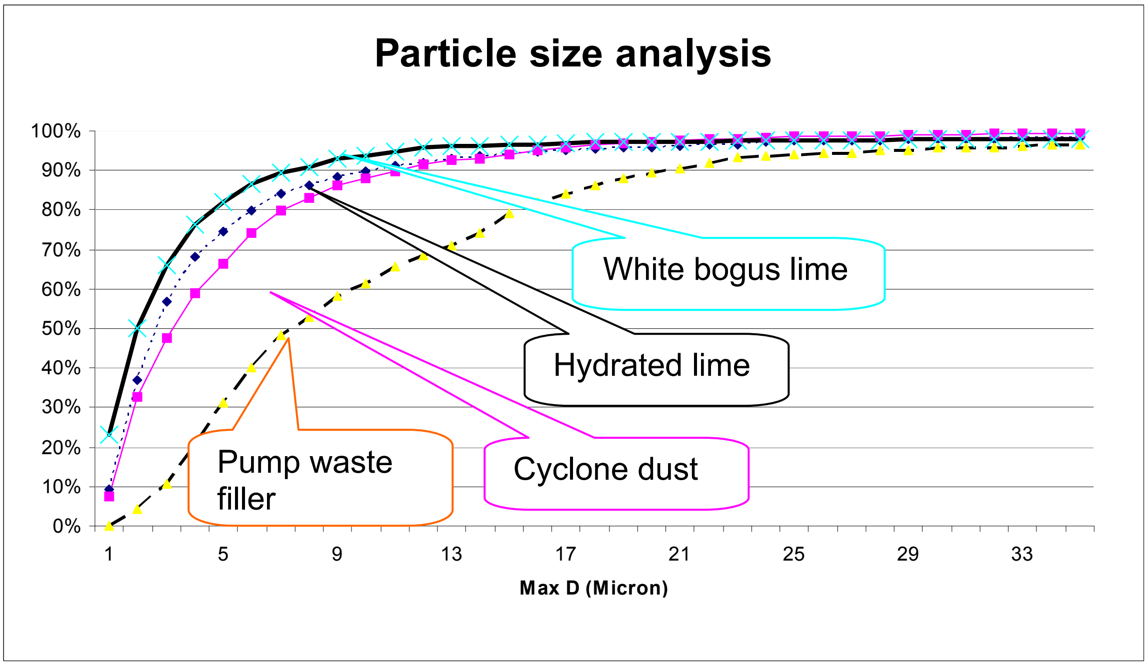

Figure 3. Filler material sampled particle size analysis

- All the filler material was extremely fine as more than 90% of the lime, cyclone dust filler and ”bogus lime” passed the 10micrometer size. More than 90% of the pump waste fines passed the 20micrometer size.
- The hydrated lime, cyclone dust filler and “bogus lime” had very similar gradings with only the pump waste filler showing a discernable difference.
- All these sampled filler sized material had gradings similar to the tillite filler material as reported in the geological investigation. This was circumstantial evidence that considerable amounts of the excess filler present in the mix could have been tillite.

5.4. Surface area and binder film thickness calculations

The aggregate surface area and binder film thickness were calculated for the mix. The performance, and especially the durability, of the asphalt are correlated to these. The general concept is that as the fineness of an aggregate increases, so does its surface area, and the greater the surface area, the lower the binder film thickness surrounding the aggregate particles.

The filler fraction has the highest contribution to the surface area, and the concern of high amounts of filler and super-fines present in the mix made it important to quantify the effect of these. Chapuis and Legare (1992) provided a method for determining the surface area of fine aggregates and fillers in bituminous mixtures from geometrical considerations which shows good agreement between predicted and measured surface areas. These surface area calculations are shown in the Table 3. The results clearly show the importance of the surface area from the overall design benchmark grading when the surface area for the lime, cyclone dust, pump waste or “bogus lime” filler and implications for stiffening behaviour if these super fine filler materials occur in excessive quantities in the mix.

Table 3. Calculated surface areas of sampled filler material

Material	Surface area (m^2/kg)
Overall design grading	7.17
Hydrated lime	253.58
Cyclone dust collector filler	246.32
Pump Waste filler	292.18
Bogus lime filler	178.83

The effect of additional filler on binder film thickness was then calculated for varying percentages of added lime or filler. The calculation of aggregate film thickness is approximate because of differences in aggregate shape and texture. One well-known approximate method is that of Hveem (TRH 8, 1987). This uses the percentage aggregate passing various sieves from 4.75mm to 0.075mm in the calculation based on empirical factors. In this case the design grading was varied by adding various percentages of the “bogus lime” to the mix [this "bogus lime" is termed w.sand in Figure 4].

The effect on the resultant calculated binder film thicknesses are shown in Figure 4. It is evident that by adding increasing amounts of filler (super-fines) it significantly decreases the binder film thickness of the asphalt.

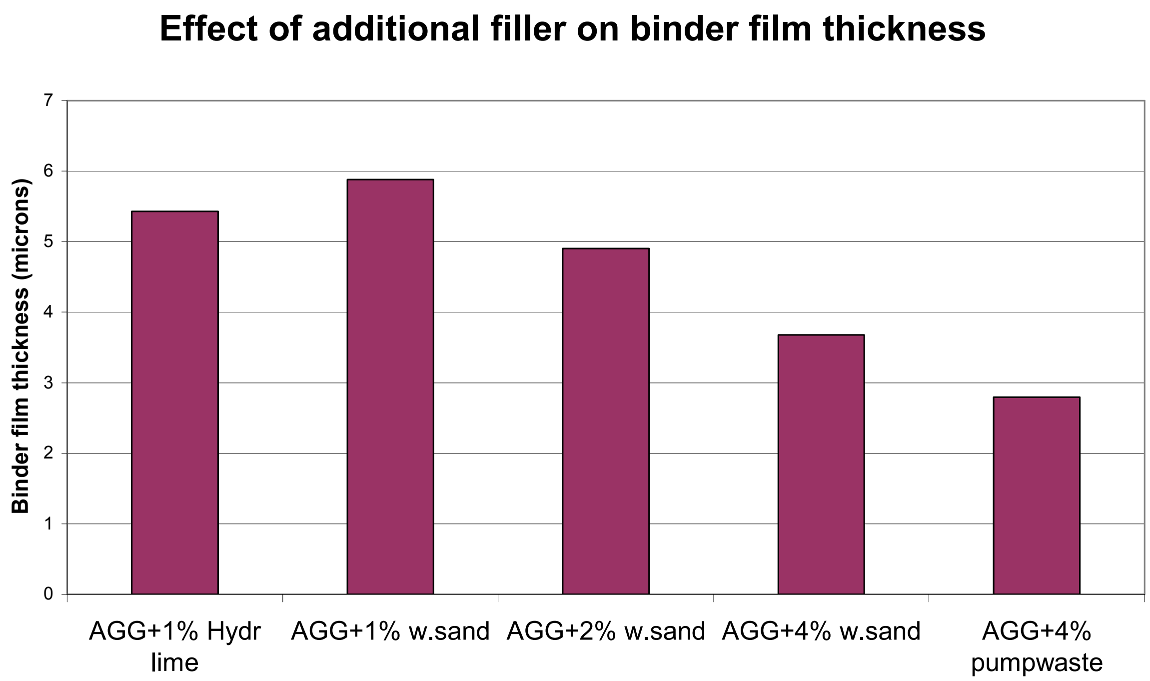

Figure 4. Binder film thickness with various additions of super fines

For the asphalt mix under investigation such excessive super fines present in the mix would have lead to a significant reduction in durability, especially as the film thickness dropped below the 5 micron level. It is clear that if, as suspected, the filler material was more or less doubled, it would have resulted in a dry and abrasive mix with construction problems. Again it provides an explanation for the elevated mixing and paving temperatures to overcome compaction difficulties.

5.4 Durability estimations from derived modulus values

The durability of asphalt mix can be monitored by the changes in derived asphalt modulus. A relationship between the binder film thickness and the aged modulus properties (both short term and long term) of asphalt mixtures, has been previously quantified for a binder/aggregate combination by Kandhal and Chakraborty (1996). This combination had a grading similar to the grading under investigation, and used a binder similar to a 60/70 pen bitumen. Equations were presented to estimate the resilient modulus after short term ageing (construction) and long term ageing (equivalent to 5-10 years service on the road).

$$Mr_{\text{short term}} = [2069.9 - 273.15\,\mu + 10.53\,\mu^2]*6.89 \quad \text{MPa with} \quad R^2 = 0.99$$

$$Mr_{\text{long term}} = [3267.6 - 456.75\,\mu + 17.55\,\mu^2]*6.89 \quad \text{MPa with} \quad R^2 = 0.99$$

With Mr =asphalt modulus and μ=binder film thickness

These equations were used to predict the magnitude of change in asphalt modulus upon ageing, for varying binder film thicknesses. The film thickness was varied according to the amount of fines present and the predicted modulus is given in Table 4. In this case only varying percentages of bogus lime was added to the mix in lieu of the prescribed 1% hydrated lime. The predicted modulus is not the same as the modulus of the asphalt under investigation, but the relative effect of increased filler on decreasing binder film thickness and thus resilient modulus, gave additional explanation for the observed asphalt brittleness and stiffness.

Table 4. Resilient modulus calculations based on film thicknesses

Material	**Resilient modulus short term ageing**	**Resilient modulus long term ageing**
Aggregate Grading+1% Hydr lime	6184 MPa	8996 MPa
Aggregate Grading +1% bogus lime	5704 MPa	8190 MPa
Aggregate Grading +2% bogus lime	6780 MPa	9993 MPa
Aggregate Grading +4% bogus lime	8321 MPa	12575.MPa
Aggregate Grading +4% bogus lime	9570 MPa	14666 MPa

It was noted that the predicted change in stiffness due to long term (5-10 years) ageing for the aggregate grading + 1% hydrated lime material from 6184 to 8996 MPa was similar to the difference in stiffness in the short term (construction) between the benchmark aggregate + 1% hydrated lime material and the aggregate + 4% bogus lime filler material (from 6184 to 9570 MPa). This indicated that the addition of extra filler could be equivalent to 5-10 years of ageing, and explained the site observation that the newly laid asphalt [with excess filler] had the appearance of an aged asphalt. These are indicative figures, but served to explain why the asphalt under investigation seemed to age so quickly if accepted that additional super fine filler had to be present in the mix as the ash tests indicated.

5.5. Filler composition analysis

X-ray diffraction (XRD) analysis and X-ray fluorescence spectrometry (XRF) analysis on all the sampled filler sized material to determine which material did contain hydrated lime and which not. This was benchmarked against the actual hydrated lime (from the sealed bags in the asphalt plant store). It should be expected that the pump waste and bogus lime should be similar, and they should both be the same as the hydrated lime reference sample.

The X-ray diffraction (XRD) analysis of the filler sized material sampled is shown in Table 5. It clearly showed that the hydrated lime and the sample from the cyclone dust collector fines (sampled early in 2004) had very similar chemical compositions. However the pump waste filler (sampled early in 2004) had no calcite, portlandite or graphite. It seemed to be closer to the composition of the raw tillite filler analysed and shown in Table 5. The “bogus lime” (sampled in 2003) had relatively high calcite proportions, as well as the same minerals which are present in the natural tillite.

The XRF analysis is shown in Table 6. These results confirmed the XRD results. It is significant that SiO_2 (silica dioxide) did appear in significant proportions in the ”bogus lime” and the pump waste filler samples. CaO (calcium oxide) appeared in the cyclone dust filler in more or less the same proportion than that in the actual lime tested. The “bogus lime” had less than half of that portion of calcium oxide.

It was clear from the mineral composition of the “bogus lime” that substantial calcite proportions found its way into this material. Based on observations of the presence of calcite intrusion in the tillite used in the sector of the quarry it was plausible that tillite filler could have been used instead of lime.

The conclusion reached on the chemical composition of the lime from the sealed bag in the store at the asphalt plant was that it was old and had already begun hydrating or cementing. This is based on the presence of the portlandite compound. It appears therefore that the about 300 bags found in the store on site may have been there for a while.

The chemical reactivity of the various fillers with hydrochloric acid and the colour change with phenolphthalein (not shown here for reasons of space) indicated that the calcite in the “bogus lime” filler material sampled was highly reactive and strongly suggested the possibility of quicklime formation, as had been suggested elsewhere.

6. VERIFICATION OF ACTUAL LIME DOSAGE

Subsequent to these tests on the filler materials being done, the asphalt plant operator advised in mid-2004 that invoices could only be found for part of the prescribed lime quantities. Eventually, invoices indicated that less than 15% of the prescribed 1% lime was purchased. The actual lime percentage dosage, as could be reconstructed from the invoice records and information from the asphalt plant, indicated a very low and variable dosage throughout the project. It was likely that about a maximum of 0.3% lime was added during the construction of the trial sections, and during production the lime addition was reduced in some cases to as low as 0.04%. Therefore it could be concluded that the calcite presence in the cyclone dust collector samples appeared to be due to the low lime dosages which may have been mixed with the normal tillite dust and may have been blown out and lost through the mixing process and caught in the cyclone dust collector. The position of the feed-in pump was positioned very close to the cyclone dust collector extractor at the end of the drum. This in itself could explain why much of the little bit of lime added was sucked off, due to the lower specific weight of lime, into the cyclone dust collector.

It became clear that the “bogus lime” and pump waste fines, both sampled in the blue pump were mainly tillite in origin. The “bogus lime” had calcite which may have been due to variability of the calcite presence or due to low percentages of lime added. An isotope dating test was additionally done by the CSIR to establish this difference with the hydrated lime. The results are not shown here, but the conclusion from the CSIR laboratory report were as follows: “*It can, however, be concluded that the majority of the white fines were probably obtained from the crushing plant fines or from dried slurries produced from washing aggregate produced during crushing*. “

Table 5: Mineral composition as obtained by X- Ray Diffraction

Mineral Sample	Calcite	Portlandite	Graphite	K-feldspar	Plagioclase	Quartz	Mica	Kaolinite	Chlorite	III/Sm Interstrat.
Hydrated lime from bags on site	30	43	27	-	-	-	-	-	-	-
Cyclone dust collector fines	29	45	26	-	-	-	-	-	-	-
Pump waste fines	-	-	-	6	13	71	2	-	8	-
Bogus lime	29	-	--	28	6	36	-	-	-	1

Table 6: Chemical composition as obtained by X-Ray Fluorescence spectrometry

Sample Compound (- oxide)	**Hydrated lime (10-03-2004)**	**Cyclone dust collector fines**	**Pump waste fines**	**Bogus Lime**
SiO_2 - Silica	**2.78**	**2.86**	**72.38**	**44.04**
TiO_2 - Titanium	0.05	0.06	0.60	0.20
Al_2O_3 - Aluminum	1.24	1.25	11.79	4.14
Fe_2O_3 - Iron	0.89	0.84	4.21	1.43
MnO - Manganese	0.09	0.09	0.07	0.01
MgO - Magnesium	0.18	0.17	1.41	1.69
CaO - Calcium	**63.78**	**64.26**	**1.88**	**25.41**
Na_2O - Sodium	<0.05	<0.05	1.87	0.10
K_2O - Potassium	0.03	0.04	2.88	0.66
P_2O_5 - Phosphorus	<0.01	<0.01	0.16	0.03
Cr_2O_3 - Chromium	<0.01	<0.01	0.04	<0.01
L.O.I – Loss on ignition	30.76	30.27	2.30	21.55
Total	99.80	99.83	99.59	99.26
H_2O – Hydrogen (water)	0.38	0.44	0.08	2.16

The source of the material supplying the lime filler pump was probably cyclone dust collector filler material being recycled for part of the time, and at another stage pure tillite filler material was fed into the mix, as proved by the chemical analysis of the pump waste filler samples.

7. RECOMMENDATIONS

There are a number of specific recommendations regarding the mix design and paving, and a general recommendation that proper material investigations and design procedures can prevent a lot of onsite uncertainties. There were valuable lessons learnt which opened the possibility to report on this specialist investigation for broader learning.

- The demand for asphalt mixes with good rut resistance has led to mixes which are stiff and not easy to compact. The use of 40/50 penetration binder is seen in hot humid climates, however during the design stage, care should be taken not to aggressively optimise [minimise] the binder content as this will lead to construction difficulties.
- The addition of lime as an anti-stripping agent is a widely accepted practice. However, the effect of lime should be considered at the design stage, and if doubt exists about filler influence on constructability, the mastic [binder and filler portions including lime if specified], should be tested to ensure the softening point increase is not excessive.
- The CSIR ash test should be done as standard test during the mix design stage. If problems arise due to construction problems or early failures occur this test can be used as first check to monitor the influence and presence of filler material.
- When using tillite as aggregate in asphalt mixes, the long-standing warnings given by Weinert (1980) should be heeded to. Given the variability of tillite within a single quarry, new tests and surveys should always be done for each new project.
- In tillite quarries where calcite intrusions are present, extra care should be taken and additional tests should be done.
- The tendency to use standard asphalt mix gradings based on experience or use on similar work elsewhere, should be questioned. The aforementioned proven variability in tillite should be extended to even other material types. The mere fact that an asphalt mix with a specific grading from a specific source and mixed by known asphalt plant may have worked on another contract, even close by, but it does not mean that it will work on the next contract due to the changes in tillite material stated above as well as other contractual and site specific factors which may differ considerably.
- Dustiness of aggregate should be monitored to prevent additional filler material production. Proper wet sieving with solvent extraction on recovered binder should be done as a standard control measure.
- Rigden voids determining is a very basic volumetric test which has a lot of merit to be used as standard practice during the design phase as well as

manufacturing and paving to monitor binder volume relations. It can give clear early warnings of potential unacceptable mix stiffness.

- The practice of elevating temperatures of mixing operations, even within specification, should be done with care. Any delays in the mixing, paving and compaction process will have detrimental influences on the material properties and durability.

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