Comparative Pavement Rehabilitation Designs including Gipave

Report by N H Thom

October 2021

1.0 INTRODUCTION

This document reports on a design exercise commissioned by Kent County Council (KCC) with the aim of illustrating the expected performance of rehabilitation designs incorporating the material known as 'Gipave', in comparison with other currently-used alternatives.

The design examples were agreed with KCC and are based on the following sites:

- A226 Gravesend Road
- A226 Rochester Road
- A227 Wrotham Road
- Florence Road

The constructions range from a thin (ca. 50mm) asphalt overlying granular base and subbase to a thicker asphalt overlying concrete. Use of Gipave in both the surface course and binder course will be explored.

Gipave includes an additive in the binder, typically at a dosage rate of 5% by mass. In this report the effects of this material will be compared to the case with no binder additive and also to a generic polymer modified binder.

2.0 DESIGN APPROACH

The designs reported herein make use of an approach termed OLCRACK originally developed at the University of Nottingham (Thom, 2000), and relating to cracking failure only. It differs from the assumptions typically made in analytical pavement design in that top-down crack development is explicitly predicted in addition to bottom-up. The system also allows prediction in reflective cracking cases. Traditional analytical pavement design relies on a so-called fatigue characteristic relating the tensile strain developed at the base of the asphalt layers under a standard axle load to the life of the pavement before significant crack development. This is usually based on laboratory testing together with a 'transfer function' to translate to site conditions, specifically to account for the fact that cracks propagate differently in a road compared to a laboratory specimen. The resulting equation is of the form:

$$\text{Life (msa)} = A\,\varepsilon_t^{B}$$

where ε_t is the maximum tensile strain at the base of the asphalt, A and B are constants.

In contrast OLCRACK relies on an interpretation of laboratory fatigue testing that generates a crack propagation equation. The rate of crack growth is related directly to the strain in the region of the crack tip as follows:

$$\text{Crack propagation rate (mm per load application)} = C\,\varepsilon^{D}$$

where ε is the tensile strain in the region of the crack tip, C and D are constants.

To make use of this equation strains are calculated at the top and bottom of the asphalt (top – just outside the wheel contact; bottom – under the centre of the contact). The equation then gives crack propagation rates, both top-down and bottom-up. The cracks are allowed to propagate a short distance and the strains are then re-calculated, giving new crack propagation rates. After several iterations the cracks have propagated from top and bottom and met. Naturally, this is still an idealisation of reality, but potentially a more realistic one than that of traditional design.

Predictions from OLCRACK have been compared to standard National Highways designs to demonstrate that a correct order of magnitude is achieved in standard cases. Additional comparisons have also been made for reflective cracking cases. These comparisons are believed sufficient to suggest that OLCRACK predictions are approximately correct. However, the more important point is that relative performances of different pavement solutions are likely to be sensible due to the specific inclusion of top-down cracking and reflective cracking.

3.0 FAILURE TYPES EXPECTED

3.1 Thick pavements

Experience on major highways is that cracking is a top-down phenomenon. This has led to the concept of a long-life pavement and it means that the surface course and binder course play key roles in determining the life of the pavement between major maintenance interventions. OLCRACK will predict this top-down cracking. It will also predict concurrent bottom-up cracking, although it is probable that this prediction is unduly conservative due to the phenomenon of crack healing, which is thought to occur more rapidly at depth due to increased overburden pressure.

The two key asphalt properties affecting crack development are stiffness and fatigue resistance. In the case of thick pavements, the stiffness of the surface course and binder course materials have a significant effect on the local strains around any top-down crack that develops. The fatigue resistance, which is quantified by the relationship between strain and crack growth rate, is clearly also highly significant.

3.2 Thin and medium pavements

It is usually difficult to state categorically where cracks in thin pavements originate. However, theory suggests they should be predominantly bottom-up. This implies that the material of most consequence is that towards the bottom of the asphalt, which would be the surface or binder course in a thin pavement, or a base layer in a medium-thickness pavement.

Strains are dominated by bending of the asphalt layer. This is influenced by asphalt stiffness, although in thin pavements the dominant influence is likely to be the stiffness of the supporting base and foundation layers. Fatigue resistance of surface and binder course materials will only be of significance where they extend to the base of the asphalt.

3.3 Reflective cracking situations

Reflective cracking can be both top-down and bottom-up. In the case of thermally-driven cracking – not covered by OLCRACK – it is most likely to be top-down because of the greater temperature changes experienced at the surface. If traffic-driven – predicted by OLCRACK – it depends critically on the quality of load transfer across underlying cracks or joints. Thus, in some cases the stiffness and fatigue characteristics of the surface course are highly influential, in others less so.

4.0 DESIGN ASSUMPTIONS

4.1 Stiffness modulus

For unmodified materials the standard assumptions made in National Highways documentation are followed, namely 2500 MPa for SMA surface course and 4700 MPa for AC binder course.

In the case of Gipave, Appendix A expounds the justification for the design values chosen, referring to laboratory and site values from trials in Italy and also Oxfordshire. This data suggested that the assumption of a 15% increase in modulus due to inclusion of the Gipave additive was realistic. This gives design values of 2875 MPa and 5405 MPa for surface and binder courses respectively. The absolute values quoted in Appendix A include both surface and binder course together and so are intermediate between these two.

Polymer modified binders are not specified in current standards and vary considerably. In this report it is assumed that the modifier is of SBS (Styrene Butadiene Styrene) type, in which case no enhancement to stiffness modulus is expected.

4.2 Fatigue characteristic

This property is not covered by standards. For the designs reported here, using the OLCRACK system, the data required is that derived from indirect tensile fatigue tests. Interpretation protocols suggest that the data should be plotted on logarithmic scales as number of load cycles to failure against applied tensile strain. This generates an approximately straight line with an intercept on the strain axis, where log(no. of cylces) = 0, i.e. it is the strain required to fail the specimen in a single cycle.

For unmodified materials the intercept values used were 2200 and 1500 microstrain for surface and binder course respectively. The slope of the characteristic in both cases was 0.25. These values are those used in checking OLCRACK against standard designs, so as far as is possible they have been calibrated to provide realistic predictions.

Fatigue and indirect tensile strength data for Gipave is referenced in more detail in Appendix A. The recommendation is to accept a slope of 0.25 and take an intercept of 2800 microstrain.

The range of possible fatigue enhancements offered by polymer modification is wide. For purposes of this report it is assumed that the enhancement is the same as that of Gipave. Thus, in theory, the only difference between the effects of Gipave and polymer modification arises from Gipave's additional stiffness modulus.

5.0 PREDICTIONS

5.1 A226 Gravesend Road

Core information:	300 mm asphalt (SMA/HRA/AC/HRA); debonding between AC layers	
Design assumptions:	asphalt modulus = 4000 MPa (accounting for debonding) unbound foundation modulus = 100 MPa	
Predictions, 40 mm inlay:	SMA: Polymer modified:	11.6 msa 11.6 msa

	Gipave:	12.5 msa
Comment:	Bottom-up cracking is predicted to dominate due to relatively low stiffness foundation. There is very little top-down, therefore fatigue resistance of surface course is not critical. Gipave gives a minor improvement due to its superior stiffness.	

5.2 A226 Rochester Road

Core information:	200 mm asphalt (HRA/AC/HRA) – appears intact; overlying variable CBM or tar-bound material, typically 200 mm	
Design assumptions:	asphalt modulus = 5000 MPa CBM/tar-bound modulus = 2500 MPa unbound foundation modulus = 100 MPa	
Predictions, 40 mm inlay:	SMA:	20 msa to 30 mm top-down, 48 msa to failure
	Polymer modified:	30 mm max top-down, 49.5 msa to failure
	Gipave:	30 mm max top-down, 54 msa to failure
Predictions, 100 mm inlay:	SMA/AC:	16 msa to 30 mm top-down, 73 msa to failure
	Polymer modified:	50 msa to 30 mm top-down, 75.5 msa to failure
	Gipave:	50 msa to 30 mm top-down, 77 msa to failure
Comment:	Ultimate failure is still controlled by bottom-up cracking in both cases, hence the relatively small differences in life to failure. However both polymer modified and Gipave solutions show a significant slowing of top-down cracking. This implies a general reduction in surface deterioration such as ravelling and incipient pothole development. Experience suggests that when the prediction reaches about 30mm top-down, the cracks begin to be noticeable and to allow grit particles to penetrate; before that they are hairline.	

5.3 A227 Wrotham Road

Core information:	100 mm asphalt (TSC/HRA) – mainly intact but dry-looking; overlying either ca. 400mm concrete or variable thicknesses of asphalt and granular base – say 400mm total	
Design assumptions:	asphalt modulus = 3500 MPa **Either** concrete modulus = 20,000 MPa, joints/cracks @5m spacing **Or** old asphalt / granular base modulus = 400 MPa unbound foundation modulus = 100 MPa	
Predictions, 40 mm inlay: (concrete base)	SMA:	2 msa to 30 mm top-down, 19 msa to failure
	Polymer modified:	5 msa to 30 mm top-down, 20.5 msa to failure
	Gipave:	6 msa to 30 mm top-down, 25 msa to failure
Predictions, 100 mm inlay: (concrete base)	SMA:	6 msa to 30 mm top-down, 148 msa to failure
	Polymer modified:	13 msa to 30 mm top-down, 390 msa to failure
	Gipave:	26 msa to 30 mm top-down, 594 msa to failure
Predictions, 40 mm inlay: (granular base)	SMA/AC:	0.058 msa
	Polymer modified:	0.059 msa

	Gipave:	0.06 msa
Predictions, 100 mm inlay: (granular base)	SMA/AC:	0.33 msa
	Polymer modified:	0.87 msa
	Gipave:	1.02 msa

Comment: Over a concrete base, cracking is predominately top-down reflective cracking, which means asphalt properties have a significant effect on damage rate. The lives to failure are highly theoretical and do not account for thermally driven crack growth. Over an old asphalt / granular base, bottom-up cracking dominates but there is a significant effect from the different materials since they form a large proportion or all of the bound pavement layers.

5.4 Florence Road

Core information: ca. 50 mm asphalt

Design assumptions: asphalt modulus = 2500 MPa (poor visual appearance)
unbound base/subbase modulus = 250 MPa, say 250mm thick
unbound foundation modulus = 100 MPa

Predictions, 50 mm inlay:	SMA:	0.0097 msa
	Polymer modified:	0.025 msa
	Gipave:	0.026 msa

Comment: Bottom-up cracking dominates so again there is a significant effect due to differing asphalt properties.

6.0 CONCLUSION

As with use of polymer modification, the benefit of Gipave is seen when the layer in which it is used is a key contributor to the failure process. In the case of an inlay this means either where top-down cracking is significant or where the inlay thickness comprises most or all of the asphalt. Cases where top-down cracking is significant include thick pavements such as A226 Rochester Road or some reflective cracking cases such as parts of A227 Wrotham Road.

Compared to the example of polymer modification selected, the advantage of Gipave is predicted to be moderate, being most significant in the reflective cracking case (A227 Wrotham Road, concrete base) which included both a thin asphalt layer and a predominately top-down failure mode.

REFERENCE

Thom, N.H., “A Simplified Computer Model for Grid Reinforced Asphalt Overlays” Proceedings of the 4th International RILEM Conference on Reflective Cracking in Pavements, Ottawa, 2000, pp 37-46.

APPENDIX A

Pavement Design using Gipave

Report to Amey by N H Thom, University of Nottingham

8th June 2021

Abstract

Evidence for the properties of asphalt layers including Gipave additive at 5% of binder content has been abstracted from reports on a site trial in Italy, another trial in Oxfordshire, and from fatigue data supplied by Conway. Both insitu and laboratory data have been considered. This evidence has led to the proposal that Stone Mastic Asphalt (SMA) surface and binder course materials, without and with Gipave additive, should be assigned 20C stiffness moduli for design of 4000 and 4600 MPa respectively. Furthermore, the evidence suggests a factor of improvement on fatigue life at a given level of strain of about 2.7.

These design inputs have been applied in a design spreadsheet known as OLCRACK, which predicts the development of both top-down and bottom-up cracking. Two cases have been identified where Gipave is likely to provide significant benefit. The first is the case of SMA surface and binder course over a hydraulically-bound (e.g. cemented) or cold-mix asphalt base; the second is a thick asphalt pavement (i.e. at least 300mm) including SMA surface and binder course. In both these cases the benefit derived from Gipave additive in terms of life extension prior to significant maintenance is predicted to be a factor of 2.5 to 3.

1. Scope

This mini-report outlines predicted benefits to be derived from using Gipave in surface course and binder course layers, based on data made available through Amey and utilising a pavement performance prediction technique developed at the University of Nottingham. It does not cover rut resistance, where Gipave is acknowledged to give excellent performance, but concentrates on cracking and associated surface distress.

2. Background Information

The sources of information made available include:

- a report on Gipave by Inerchimica
- fatigue test data from Conway
- raw test data on material from a trial in Oxfordshire supplied by Inerchimica

2.1 Modulus

The Inerchimica report gave indirect tensile test moduli (ITSMs) on laboratory prepared material, tested at 5, 20 and 40C. At 20C the moduli of asphalt concrete materials with and without the Gipave additive (at 5% by mass of binder) were 5711 and 7809 MPa, an increase of 37% due to the additive. However, laboratory compaction managed to achieve air voids of 2.3 and 2.5% respectively whereas the air voids achieved in a site trial were around 5.4%. It is suggested that this difference probably equates to about a 20% difference in modulus, in which case the values applying should reduce to about 4800 and 6600 MPa.

Material from the site trial was also compacted into gyratory specimens and the reported difference between untreated and treated materials was 11% for the binder course mix and 22% for the surface course. Additionally, Falling Weight Deflectometer (FWD) tests were carried out and insitu 20C moduli deduced as 3855 and 6424 MPa, a difference of 67%.

To complete the picture, the data from Oxfordshire gave 6721 and 7013 (difference 4%) for gyratory specimens and 4280 and 4568 MPa (difference 7%) for cores taken from roller-compacted slabs.

Two issues arise, the magnitude of the difference between treated and untreated asphalt and the absolute magnitude. It is suggested here that the FWD moduli, being derived indirectly, are probably least trustworthy, and so the 67% difference is discounted. The laboratory testing of site materials is likely to be more accurate regarding the difference, in which case the 11 and 22% from the initial report or the 4 and 7% from Oxfordshire should be considered. Clearly it is impossible to reach a definitive conclusion; however, it is proposed that a difference of 15% is a reasonable expectation.

Regarding the absolute magnitude, the very low voids achieved by gyratory compaction in the initial report would be associated with unrealistically high moduli, and the same is likely for the results reported for gyratory specimens made from the Oxfordshire material. It is suggested that the most trustworthy estimates are to be derived from the roller-compacted slabs from Oxfordshire and the initial trial site in Italy. Accepting a 15% difference between treated and untreated, it is suggested that 4000 and 4600 MPa are adopted as 20C moduli for design.

2.2 Fatigue resistance

Fatigue is expressed as a graph of applied strain against number of load applications to failure, plotted on logarithmic scales. The first point to make is that fatigue data is always scattered and so best-fit lines are always very uncertain, particularly the slope of the line in log-log space. The second point is that different tests produce different answers, and data is available for two test types, the Indirect Tensile Fatigue test (ITFT) and the 4-point bending test.

In general it is expected that fatigue 'characteristics' have a slope of about 0.25. In the data provided, the reported slopes vary from 0.172 (Oxfordshire material, 4-point bending) to 0.34 (Conway data, ITFT). In the initial report the slope is not quoted.

Since logarithmic scales are used, a shift in one characteristic relative to another can be expressed as a factor of improvement. In the initial report the shift quoted was about × 6 from tests on laboratory mixes but × 1.7 or × 4.2 (binder course and surface course) for material from the site trial. The Oxfordshire data showed little difference between untreated and treated materials.

The other relevant piece of information comes from the Indirect Tensile Strength (ITS), which is effectively equivalent to a point on the fatigue characteristic where N = 1 (failure in a single load application). The initial report gave factors of improvement (due to treatment) of 1.6 from laboratory mixes and 1.28 from the site trial material.

The recommendation here is to place greatest reliance on tests on site material and to force a slope of 0.25 on the characteristic. If treated in this way the Conway data suggests an intercept of about 2800 microstrain at N = 1. The Oxfordshire data is slightly poorer, but should arguably not be forced in this way since it is a different type of test. If the factor of 1.28 on ITS from Oxfordshire site material is accepted then the intercept for untreated material becomes about 2200 microstrain – and this is compatible with the author's experience for SMA mixes. The factor in terms of life to failure then becomes about 2.7, in the range found for material from the initial trial site.

3. Pavement Design

The inputs used for Gipave in pavement design are a modulus of 4600 MPa (at 20C), a fatigue intercept of 2800 microstrain and a slope of the fatigue characteristic of 0.25. The equivalent values taken for untreated material are 4000 MPa, 2200 microstrain and 0.25.

These inputs have been applied in the OLCRACK spreadsheet, which simulates the development of cracking in asphalt from both the surface and the underside of the asphalt layers. Since it is proposed to use Gipave in the surface course and binder course, it is the top-down cracking where benefit is to be expected. This in turn means that there will be little benefit in a pavement which is dominated by the development of bottom-up cracking, which would be a comparatively thin pavement but nevertheless including significant asphalt beneath the Gipave layer(s). Benefit is to be expected where the Gipave layers dominate – e.g. a pavement with 100% Gipave over a hydraulically-bound or cold-mix asphalt base – or where top-down cracking dominates, usually thick asphalt pavements. These therefore are the designs that will be pursued.

3.1 100% Gipave pavements

This type of pavement is only suitable if the base is relatively high-modulus but without discrete cracks that would then reflect to the surface. This can be achieved by use of a controlled strength hydraulically bound material, typically 2-3 MPa compressive strength, which then degrades under the roller to form a fragmented layer with very close cracks. It can also be achieved using cold-mix asphalt. A typical long-term modulus for such a layer would be 1000-1500 MPa.

In the following example, 100 mm of Gipave (or untreated SMA) overlies 150 mm of base with modulus 1500 MPa, a subbase of modulus 150 MPa (a common default assumption) and a subgrade of modulus 60 MPa (typical of around 5% CBR soil). Figure 1 traces the predicted development of cracking from the top and bottom of the asphalt.

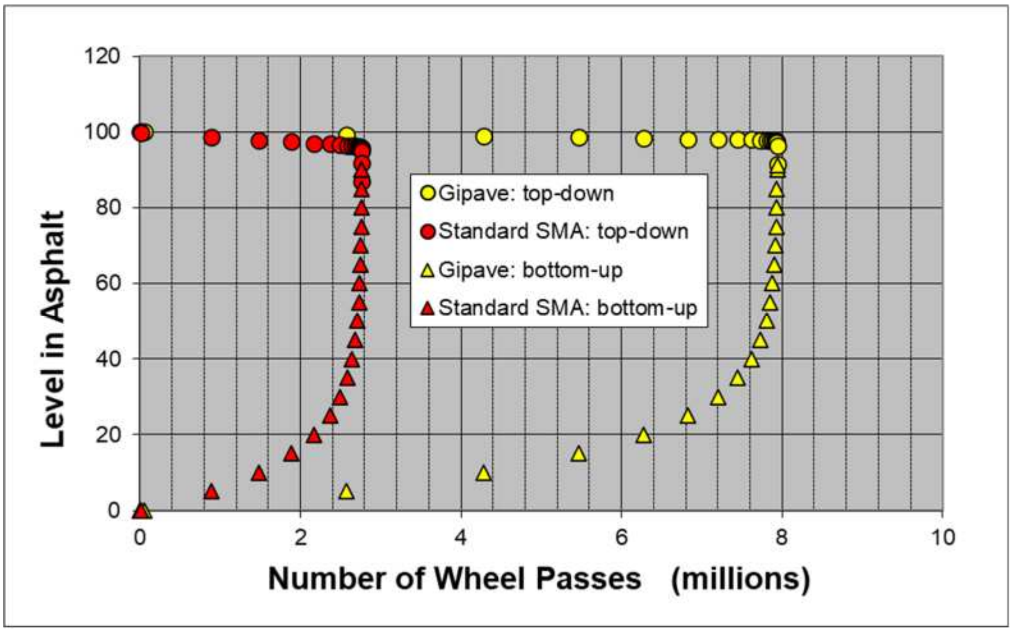

Figure 1. Predictions for thin asphalt pavement over stabilised base

The predicted extension on life before noticeable cracking occurs is from 2.8 to 8.0 msa, a factor of nearly × 3.

3.2 Thick asphalt pavements

In this case the occurrence of bottom-up cracking is neglected. They may still occur slowly but the pavement is in a so-called 'long-life' range, where it is impossible to be confident about exactly how long it will last, and indeed self-healing is possible under the weight of material above. The problem is therefore reduced to one of controlling surface damage. This is typically the situation on trunk roads and motorways.

The example selected is a pavement with 300 mm of asphalt (40 mm SMA/Gipave surface course, 60 mm SMA/Gipave binder course, 200 mm asphalt concrete base) overlying a competent subbase of modulus 500 MPa and a subgrade of 100 MPa modulus. Two scenarios have again been simulated, one with conventional untreated materials throughout, one with Gipave surface course and binder course. The duration of the analysis in terms of traffic is 100 msa, which might be very roughly equivalent to 20 years on a heavily trafficked road. Figure 2 presents the predictions.

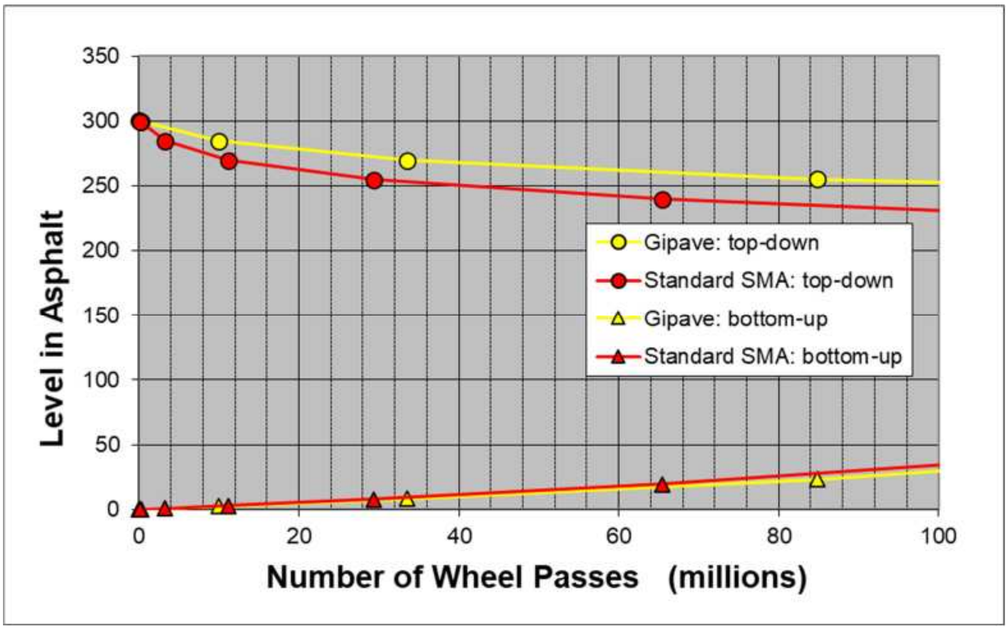

Figure 2. Predictions for thick asphalt pavement

The predicted bottom-up cracking is ignored. The benefit of Gipave is seen in the slower predicted development of top-down cracking. In the opinion of the author cracks will only become visible once they are predicted to extend about 30mm, and treatment might be considered at around 50mm predicted. The difference shown at 50mm depth in this case is from 40 msa to a little over 100 msa.

4. Conclusion

This mini-report has given two examples only to illustrate the potential effect of Gipave. They both show a significant improvement over unmodified SMA. It is considered that the assumptions made regarding the properties of materials are realistic based on the evidence, but it is also noted that these properties are not always achieved in practice.