BEST PRACTICE: BITUMEN-EMULSION AND FOAMED BITUMEN MATERIALS LABORATORY PROCESSING

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ABSTRACT

Although accelerated laboratory curing of bitumen-emulsion and foamed bitumen treated materials is undertaken widely, there is not an accepted standard procedure.

A major contributing factor to this situation is undoubtedly the complex composition of these materials, which can include both active and inactive fillers such as lime, cement, fly ash, etc., as well as the bituminous binder and parent material. The complexities of the various chemical reactions and interactions that will occur during the treatment process are poorly understood at best.

While an accelerated curing regime should not alter these fundamental processes from those that would occur in field conditions, given the variations in composition of these treated materials in terms of specific composition and quantities, there is concern that the influence of accelerated curing is not fully understood. Consequently there is a significant possibility that laboratory cured specimens have strength or other characteristics that are dissimilar to the field materials that they supposedly represent.

This paper, based on a review of past practice and fundamental behaviour, identifies what are regarded as most appropriate laboratory procedures for these types of treated materials to ensure that laboratory testing should reliably characterise field properties.

1. BACKGROUND AND INTRODUCTION

The technique of applying small quantities of diluted bitumen-emulsion to unbound roadbase materials in South Africa developed recognition some 30 years ago, primarily as an aid in achieving specified densities when this was otherwise difficult or not possible with the untreated material (Marais & Tait, 1989; Bergh, 2005). Anionic emulsion was adopted at that time as being relatively slow breaking, in order to avoid potential problems of the emulsified bitumen reverting to its normal bitumen type too quickly. Early experience established that more rapid breaking could make any of the mixing, placing and compaction processes unworkable. In some cases, however, it was also found that the emulsion did not break sufficiently quickly and this led to a small amount of cement being introduced to promote the breaking process.

Although initially used therefore as a short term construction aid, subsequent qualitative observations from roads constructed using bitumen-emulsion treatment of the base indicated that the longer term performance was also considerably enhanced.

Rutting, ravelling and cracking (the most common distress types normally associated with unbound, bitumen-bound and cement-bound roadbases, and consequently providing the point of reference) were generally far less significant to non-existent compared with what

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might have been expected if the same parent material had been used in any of these conventional applications.

Quantitative monitoring confirmed that the bitumen-emulsion treated roadbases did in fact have improved engineering properties compared with the untreated parent material (primarily increased stiffness and strength characteristics), which would clearly contribute to the performance enhancement. More important, it was found that the changes in these material properties continued over time, and early work suggested that this could take place over 6 months to 2 years before a final cured state and constant engineering properties would be achieved (Marais & Tait, 1989).

Thus it appeared that, from what had originally started as a construction expedient, a new and very promising technique for improved roadbase performance had been found.

Sabita (South African Bitumen Association), recognising the potential of this approach, sponsored various studies on the application of bitumen-emulsion to roadbase construction from the 1980s culminating in guidelines for industry in order to promote more widespread usage (Sabita, 1993, 1999).

More recently, with the burgeoning need for cost-effective methods of pavement rehabilitation, the technique of foaming bitumen has been developed in conjunction with purpose-built recycling milling machines primarily to effect *in situ* treatment of existing pavement layers. In South Africa the approach draws heavily on the bitumen-emulsion technique, in terms of residual bitumen application rates and possible inclusion of cement or other active filler.

Considerable research effort has gone into foamed bitumen treatment since the mid-1990s in South Africa, and industry guidelines on current best practice were released in 2002 (Asphalt Academy, 2002). This document, mainly sponsored by Gauteng Department of Public Transport, Roads and Works (Gautrans) and supported by Sabita, has also provided an impetus for unifying and updating the earlier guidelines for bitumen-emulsion applications. A draft version is under review pending clarification of certain critical areas that are as yet insufficiently addressed from our current knowledge base. Some additional work is therefore being undertaken to augment the knowledge base in those areas for both bitumen-emulsion and foamed bitumen applications.

The study that forms the basis for this paper (Kekwick, 2004) arose from the specific need to provide guidance on laboratory curing methods most appropriate to evaluating the potential use of bitumen-emulsion or foamed bitumen for a given parent material. The objective of this project was to identify the most appropriate curing method(s) to ensure that laboratory testing should reliably characterise the engineering properties of the treated material.

While the previous guidelines gave laboratory curing recommendations, it had become clear that these did not provide a consistent basis for evaluating the treated material so that practitioners were finding disparities between laboratory testing and subsequent field performance.

A major contributing factor to this situation is undoubtedly the complex composition of these materials, which can include both active and inactive fillers such as lime, cement, fly ash, etc., as well as the bituminous binder and parent material. The complexity of the various chemical reactions and interactions that occur during the treatment process is

poorly understood at best, and there is continuing debate on the exact processes that lead to the observed long-term changes in engineering properties.

The main concern was that the influence of accelerated curing on these processes is not known. Consequently there was a significant possibility that laboratory cured specimens have strength or other characteristics that are dissimilar to the field materials that they supposedly represent.

The study, in addressing the issue of laboratory curing, found it essential to place curing in the broader context of meaningful laboratory evaluation of these types of materials.

It should be noted from the outset that the findings and recommendations are specifically for typical applications in South Africa. These mixes can be broadly described as having residual bitumen contents of 1 to 2% by mass, and will often include a cement addition of up to 1%.

This approach can be considered uniquely South African, based on the earliest usage of bitumen-emulsion for roadbase construction in this country as outlined in the foregoing, and there is now wider interest largely arising from increasing international exposure. In contrast, broader international practice with bitumen-emulsions in road construction has tended to remain focussed on surfacings (including spray applications, surface dressings, slurry seals and surface courses) having relatively high residual bitumen contents and for which medium- to fast-breaking cationic emulsion is widely used.

2. CURRENT LABORATORY CURING PRACTICES

The two most recent national guidelines for bitumen-emulsion and foamed bitumen treatments (Sabita, 1999 & Asphalt Academy, 2002 respectively) can be regarded as *de facto* benchmarks for current local practice.

Two laboratory curing methods are recommended for bitumen-emulsion treated materials: curing in the moulds for 24 hours at ambient temperature, followed by 48 hours curing at 40°C (if optimum moisture content is less than 8 per cent), or 45 hours at 60°C (if the optimum moisture content is greater than 8 per cent). It also alternatively proposes that specimens can be cured for 7 days at ambient temperature (when cement has been added) or 28 days at ambient temperature (when no cement has been added).

For foamed bitumen treatments, the recommended curing regime is 24 hours in the mould and 72 hours at 40°C. In this case specimens are cured in plastic bags with the intention of simulating equilibrium moisture content on completion of curing, and it is anticipated that this will represent approximately 6 months site curing.

As noted in the introduction, there have been concerns that using these curing methods in evaluating materials for potential treatment do not, in some cases, provide results consistent with field observation of performance. In other words the link between laboratory test and field may be unreliable and therefore casts doubt on the initial selection process and subsequent mix design. This is clearly unacceptable to both clients and practitioners.

An indication of the lack of conformity regarding local laboratory curing practices can be gleaned from the recent Capsa'04 conference. While Bondietti *et al* (2004) followed the Sabita curing recommendations for bitumen-emulsion (1999), their study included a comparison with ambient curing, from which it was found that unconfined compression test (UCS) results from the accelerated curing regime differed from those using ambient curing.

In their study of the role of fillers in both bitumen-emulsion and foamed bitumen treated materials, Hodgkinson & Visser (2004) cured for 24 hours in the mould at ambient temperature, followed by 72 hours at 60°C. In an evaluation of which of these treatment types would be most appropriate for cold recycling a section of the N7, Jenkins *et al* (2004) adopted curing of 72 hours at 40°C in sealed plastic bags.

For their study into indirect tensile strength (ITS) and UCS test protocols for foamed bitumen treated materials, Houston & Long (2004) adopted various curing regimes, including 72 hours in the mould at 40°C, and 24 hours at ambient temperature followed by 48 hours in sealed plastic bags at 40°C.

Further afield, despite differences in specific usage, the situation is similarly unclear regarding laboratory curing of cold mix bituminous applications.

The objective of the fairly recent major European OPTEL project (Optimisation of slow-setting cationic bituminous emulsions for the construction and maintenance of roads, Potti *et al*, 2002) was "to deepen knowledge on the manufacture of emulsions and cold bituminous mixes so as to use it in a rational way within improved design methods".

In this case an underlying rationale was to look at the influence of both temperature and humidity on the rate of moisture departure from laboratory specimens. Moisture content change and compressive strength were monitored using three temperature/relative humidity combinations: 18°C/50%, 50°C/50% and 50°C/10%. It was reported that the findings raised further questions related to probable site behaviour, including the manner in which free water was held within the material, and the phenomena governing the increase in cohesion/strength especially as the minimum moisture content is approached.

On these last two issues, it was concluded that temperature and rheological behaviour of the bitumen would have an influence, thus leading to the finding that it is probably more realistic to accelerate water departure by humidity reduction rather than temperature increase.

While the curing study was just one component of the project as a whole, after 300 man-months effort over a three and a half year period involving seven industrial and academic partners, and drawing on the specialist knowledge of the consortium partners, no specific hard recommendations on curing were made and it was left open to the need for further work.

Significantly, this was concluded without any consideration of the probable additional complexities of incorporating active filler as is commonly the case in South Africa.

For practical purposes then, the OPTEL study duly confirms that there is no established standard European procedure for curing of bitumen-emulsion treated materials, and this is further corroborated by the comprehensive study of Brown and Needham (2000).

In this case the fundamentals of emulsion breaking and mixture curing when cement was incorporated were studied, thus being more aligned with South African practice, although a slow setting cationic emulsion was used. Curing and testing were undertaken at 20°C and 50% relative humidity after specimen extraction from the moulds after 16 hours.

Even at this relatively low temperature, presumably regarded as more representative of UK conditions, the stiffness moduli of all emulsion treated mixes increased steadily with time. For these high quality mixes the effect of cement inclusion was distinct with the stiffnesses, and rate of stiffness increase, being significantly higher with increase in

cement. More significantly, in the case of the cement-treated hot mix, there was no practical change in stiffness regardless of cement content.

Attempts to determine whether any standard laboratory curing practices were used in other countries, such as the United States/Canada or Australia/New Zealand, were equally conclusive in that there seemed no conformity.

The only claim found for a complete mix design system for cold mixes was in fact from Norway (Jostein, 2000), and in this case the laboratory curing regime (applied to both treatment types) would be 7 days (168 hours) oven drying at 40°C. An alternative in the event of lack of time (and subject to client approval) would be 72 hours at 60°C. However it would appear that these mixes would not include cement addition.

In the case of foamed bitumen, Jenkins (2000) provides a comprehensive overview of past curing methods adopted by various researchers between 1970 and 1994. An indication of the various approaches is listed below, together with the nominal field cure period considered to be represented if defined:

- 24 hours @ ambient in mould   for short term simulation
- 24 hours @ ambient in mould, 24 hours @ 40°C   ≡ 7 – 14 days
- 24 hours @ ambient in mould, 72 hours @ 40°C   ≡ 30 days
- 24 hours @ 38°C   ≡ 7 days
- 72 hours @ 23°C
- 72 hours @ 60°C   ≡ construction period + early life
- 72 hours @ 60°C   ≡ 23 to 200 days
- 72 hours @ 60°C   ≡ 1 year simulation
- 72 hours @ 60°C, 72 hours @ 24°C
- 240 hours (10 days) ambient, 50 hours @ 60°C

While effort has been made to relate the laboratory curing regime to field condition in these cases, it is still readily apparent and of great significance (particularly from the 72 hour/60°C regimes), that prevailing local field curing conditions differ greatly.

3. WHERE ARE WE NOW?

The foregoing serves simply to inform that there is considerable confusion both here and overseas, even after several decades experience in this country with our unique bitumen-emulsion application to roadbases, and longer elsewhere (Europe, especially) with their particular road applications.

Clearly, part of the problem must be that the aim of the laboratory curing process is not consistently defined (if defined at all). Is it to simulate early life/construction conditions, longer-term (say 6 to 12 month) conditions, or the ultimate condition when engineering properties are constant (if such a condition exists)? And what would be the most meaningful choice?

However, laboratory curing is viewed as only one component in a far larger problem when attempting to develop any rational evaluation method for these particular types of cold mix materials.

Another part of the problem, hinted at earlier, stems from lack of any clear understanding of the processes involved when such small quantities of additives (primarily bitumen, as emulsion or foam, but possibly other active filler particularly cement) can have a

disproportionately large, and beneficial, effect. While it was originally attributed to increased densities, as was aimed for and achieved in the original applications, there is ostensibly other activity taking place that leads to the observed longer term improvements in engineering properties. Any appraisal of the well-documented actions/reactions of the individual component materials in isolation does not seem to tally with the observed behaviour.

While it is well understood that cement will contribute a longer term increase in strength and stiffness in conventional applications, the rate and degree of improvement do not seem to readily match observed changes in the bitumen-emulsion treated materials. It is also not clear whether the long-term changes in the field are comparable in cases where cement has not been incorporated.

It must also be emphasised that the inclusion of up to 1% cement, say, for a typical cold mix application but without any bitumen being added should be regarded as highly unlikely to provide any action remotely comparable with that observed from the cold mix application, and would certainly not be regarded as good practice.

Still another part of the problem is viewed as arising from the relatively small quantities of additives involved. Development of stabilisation techniques to improve road construction materials (primarily using bitumen or cement) has been based on relatively high additive quantities, say 4% by mass or more. The selection of these stabiliser quantities is governed by achieving certain key engineering properties in laboratory tests, essentially strength and durability requirements, intended to ensure long-term serviceability will be achieved and minimise the risk of premature failure.

When such additives are applied at these levels, firstly, it is relatively easy to achieve a homogeneous mix (for practical purposes) in the field and the laboratory. Better graded parent material will normally require the lower additive contents, and additive content tends to increase for poorer graded material to achieve target properties. Parent material in most current South African cold mix applications for roadbase construction is generally likely to be considered relatively poor (in terms of grading, as well as possibly other properties). As a result it will be recognised that mix homogeneity is likely to be far more difficult to achieve in such applications with low additive contents.

Secondly, it is intuitively recognised that the degree of compaction achieved is likely to have a significant influence on the intimacy of the binding agent with the parent material in available voids, and also on the structure of the binder matrix within the void space. With the higher binder contents associated with stabilisation applications, while these factors will have some influence, it can be assumed that reasonable consistency of void filling and matrix structure is obtained as reflected in consistency of test results. It can be conjectured that this would be attributable to a relatively large portion of the available voids being filled by the binder. However, in the cold mix applications under discussion, this will not be the case and it is considered very likely that binder matrix development will be relatively sensitive to variation in compaction.

Now it is well established that, apart from temperature and humidity, each of the following has some influence on the field curing rate:

- mix moisture content after compaction;
- specific surface area and void content after compaction (grading);
- type of aggregate (specifically mineralogy and porosity/absorption);
- type and quantity of bituminous material;

- type and quantity of active filler if used (usually cement and/or lime);
- compaction method;
- layer sealing and sub-surface drainage conditions.

It will be readily appreciated that these are the factors that will influence the development of the binder matrix: proximity of active matrix ingredients, attraction to and coating of parent material, inherent speed of reaction, and constraints to moisture movement. It will further be noted that each of these will be uniquely project specific.

If it is then acknowledged that, regardless of the exact nature of the internal processes involved, the particular bitumen cold mix applications used in South Africa have properties that change (improve) with time/prevailing condition, other factors likely to have tangible influence on behaviour and therefore any evaluation of these types of cold mix materials are likely to include:

- timing of the mixing processes (including sequence, timing and period for additive addition and mixing);
- conditions during the mixing process (including material temperature and moisture contents, as well as ambient temperature and humidity);
- compaction process (including timing relative to mixing, and the actual mode of compaction);
- test process (including timing relative to mixing/compaction and test method).

This last factor again merits further discussion. While tests such as UCS and ITS are used widely, they were developed (together with their standardisation) for conventional stabilised materials which, as noted above, are likely to be considerably less sensitive to the various factors that contribute to the difficulties of evaluating the materials under discussion.

Strength testing is just one aspect of evaluating a material's fitness for purpose. For conventional stabilised materials, in which engineering properties remain constant (for practical purposes) or for which there is an entrenched understanding of such change (specifically concrete), there are also well established relationships of strength with other key engineering properties such as stiffness and durability, and with subsequent performance in the particular field application. Generally then, standardised strength testing is used as a simple and robust indicator of the material's suitability for these cases.

What should not be ignored is that strength testing is inherently variable, whether in uniaxial compression or indirect tension for example, due in considerable part to the fact that the measured strength is largely governed by the weakest element of the material under test. While the degree of variability in strength testing has been found acceptable for conventional materials evaluations, there is little doubt that the variability for these specific cold mix bitumen treated materials (characterised by very low binder contents and properties that change with time/prevailing conditions) will be substantially greater. Consequently there is also the likelihood that interpretation of strength test results, based on limited numbers of specimens more appropriate to conventional materials, could be spurious and further contribute to difficulty in rational evaluation.

This would be in addition to any variability that may be incurred due to the influence of time at test: at early ages particularly, the difference in age of, say, 68 hours to 76 hours for a nominal three day test might give significant variation (e.g. for hypothetical specimens tested early or late in a working day, when manufactured in the middle of the day).

4. DISCUSSION

The basis for this study was concern that laboratory results inconsistent with field behaviour were being reported for bitumen-emulsion and foamed bitumen treated roadbase materials. This cast some doubt on the applicability of current laboratory curing regimes, and the objective of the study was to evaluate and recommend most appropriate accelerated laboratory curing methods. It became apparent, however, that there is a larger underlying problem: apparent not least due to the simple fact that even after years of monitoring, evaluation and in depth studies, such a concern is still to the fore.

Consequently the main thrust of the study became a quest for the reason (or reasons) that there was still uncertainty, from the pragmatic stance that the addition of familiar additives to commonplace aggregate should not result in unusual behaviour without rational explanation.

In reviewing the treatment process various factors were identified that, in the author's view, are likely to have some influence on the behaviour of the treated material as outlined in section 3. Variation, or inconsistency, in any of these variables could certainly contribute to difficulties in interpreting results especially if, as seems to be the present case, their possible influence is not considered.

In addition there seems to be fairly compelling evidence that, certainly in the case of the longer-established bitumen-emulsion treatment, the binding matrix formed is ostensibly greater than the sum of its components. This seems especially true if a small amount of cement is available, but it is not clear whether or not the absence of cement (or other active filler component, such as lime) still gives similar beneficial behaviour regarding long-term improvement in strength and stiffness.

In the author's view, it should simply be acknowledged that the mixes produced from the earliest days therefore inadvertently provided a "magic" recipe adopted for subsequent work, which has been used extensively in South Africa, and even adapted to foamed bitumen applications. Thus the binder matrix produced in the pioneering applications was, in effect, an amalgam that possessed properties from an engineering standpoint that are more desirable than the component materials alone. While this was unexpected and therefore fortuitous, it is also clear that the relative proportions of the bitumen-emulsion, cement and water (both in the emulsion and any free water in the mix) are important.

Over the years, the successful performance of these ETBs provided the impetus for successive attempts to develop rational methods for their wider application. This study provides continued witness to the fact that, for all the intensive research work that has taken place during the past 15 years or so, there are still inexplicable gaps in our knowledge of the fundamental behaviour.

This is viewed as attributable in part at least to practitioners having an inherent resistance to, or unawareness of, the possibility that the binding matrix might in fact be a complex hybrid combination that cannot be readily classified by either of our two conventional categories of bituminous or cementitious behaviour. It has been further complicated by factors such as those outlined earlier which, as indicated, are likely to have rather more influence on variability of these types of material than for conventional stabilised materials.

However, regardless of the exact process that takes place after mixing, the critical aspects regarding reliable characterisation of the treated material which must be taken into account in the laboratory are:

- engineering properties are not constant, and seemingly improve over time;
- numerous factors influence the degree and rate of change in properties, with prevailing temperature and internal moisture condition/external humidity being most critical;
- the addition of small amounts of cement (up to 1% by mass) to bitumen-emulsion treated materials seems reasonably common practice that arose initially from earliest applications when it was used as an aid to breaking of the emulsion;
- the practice of cement addition to foamed bitumen treated material seems to have carried over from the bitumen-emulsion;
- additive quantities are very low in comparison with traditional stabilisation norms.

Each of these factors carries potentially significant implication in terms of mixing, compacting, and evaluating the treated materials that laboratory processing must address.

It is also implicit that, in order to ensure that any laboratory testing is in fact meaningful, it should be based on samples that best represent field conditions. While it is impossible to replicate actual field conditions, it is nonetheless absolutely essential (initially, at least) to minimise any divergence and especially in those aspects likely to be of greatest significance on probable performance.

Once clearer understanding is developed that enables the influence of the various factors to be rationally quantified, then a true standardised laboratory process can be introduced. This will ensure that laboratory quantification of these treated material types is repeatable, reproducible, and allows selection of optimal mix design to provide required field performance with minimal (or known) risk of unforeseen failure.

At this stage, it is the author's belief that many of the possible factors that are likely to influence behaviour of these types of treated material have not been systematically quantified and this is contributing to the current situation of some confusion and, ostensibly, spurious performance being observed. Amongst these factors, laboratory curing is viewed as just one component that needs addressing.

In moving forward, and as proposed in the following section, a "back-to-basics" approach is advocated. This should provide a sound basis by which to assess the importance of the various factors outlined here, and on which to determine what governs the behaviour of these materials and how best to optimise them.

5. THE WAY AHEAD: RECOMMENDATIONS

This paper has drawn attention to a number of aspects in the evaluation of bituminous cold mix roadbase materials, as typically used in South Africa, which it is suggested are likely to be a factor in making rational assessment difficult if not addressed in a consistent and uniform manner.

These have been identified from consideration of fundamental processes that will occur in treatment of a parent material with small quantities of additives, and in the context of the known behaviour of these types of treated materials. Specifically this relates to the time-/prevailing condition-dependent changes in engineering properties that are well documented as taking place for bitumen-emulsion treated roadbases.

While such changes are also reported for foamed bitumen treated materials, the situation is not as clear since the service track record is considerably shorter, and there is doubt that the underlying processes can be similar. This, however, once again highlights the fact

that there are gaps in our knowledge base at this time, and emphasises the need to carefully address and quantify the influence of those components identified here.

Table 1 attempts to summarise the key elements that are regarded as likely to have particular impact in any laboratory evaluation, categorised under mixing, compaction, curing, and testing (designated "Primary Activity"). The "Aspect" designation identifies the specific part of the activity, with the "Initial Objective" indicating what is viewed as the immediate/fundamental need. The last two columns ("Comment" and "Scope for further work") give a cursory overview of the rationale and future thrusts.

For practical purposes any evaluation will hinge on the method of assessment (testing) and, although there are important recommendations regarding compaction and curing methods, it is the testing component that is the most significant. Consequently this paper concludes with more detailed discussion of the proposed approach.

Table 1: Summary of identified needs for key elements in the evaluation of bituminous cold mix treated roadbase materials

Primary Activity	Aspect	Initial Objective	Comment	Scope for further work
Mixing	Materials	To ensure materials used in the laboratory are directly comparable with those in the field.	Grade, quality and application mode of additives. Special attention to classification, moisture condition and grading of parent material. In particular, no removal of large size fractions unless considered unrepresentative of typical field condition.	Optimisation of additive types, esp. type, grade and dilution of bitumen-emulsion (eg, anionic/cationic, slow setting/medium setting), and active filler (eg, cement class, strength, lime usage, etc). Efficacy of treatment approach for different types of parent material.
	Process	To replicate the timing of additive addition to represent most likely prevailing field conditions.	Timing of active filler inclusion relative to bituminous additive (emulsion or foam) addition likely to have significant influence on binder matrix development.	Optimisation of timing of mixing process for most beneficial results.
	Conditions	To best replicate the internal moisture, external humidity and temperature of most likely prevailing field conditions.	Each of these factors is known to influence the rate and extent of change in engineering property development, and by inference the action/reaction taking place in the binder matrix.	Quantification of the specific influence of moisture, humidity and temperature on matrix and material properties.
Compaction	Method	To simulate probable field compaction and final density.	Size and distribution of voids is viewed as critical to binder matrix development and subsequent engineering properties. Standard impact hammer compaction methods are seen as inappropriate for these types of materials, and quite unlikely to achieve a compacted condition approximating field condition. A combination of vibration and load will normally better approximate field compaction, and laboratory application of a vibrating hammer (eg, Kango type) to achieve refusal density is recommended.	Comparison of laboratory compaction methods with field to determine most appropriate method for standard laboratory processing.
Curing	Method	To simulate probable field curing condition for direct comparison of laboratory and field results, thus developing a sound initial basis for laboratory/field correlation.	Ambient curing of laboratory samples in conditions similar to the field application is the only way to ensure reasonable direct correlation initially, and allow rational interpretation of results.	Determination of laboratory accelerated curing regime that gives most reliable and consistent correlation with ambient/field curing, therefore providing a sound basis for comparison of alternative mixes.
Testing	Method	To determine fundamental engineering properties (ie, stiffness and strength) in a reliable method using simple, widely available laboratory equipment*. To systematically monitor time at test (within the nearest hour for early testing especially).	Material stiffness (ie, "elastic" modulus) is fundamental to the layer behaviour in pavements under traffic loading. Strength (as limiting stress or strain) is used as an indicator to confirm likely satisfactory long-term performance. Derivation of stress-strain response (from load-displacement) on a routine evaluation basis using readily available equipment will rapidly enhance our knowledge base. It will specifically provide a more rational basis for pavement design. Correlation of laboratory response with field measurement of nominal layer stiffness (derived from surface deflection bowl) will provide an invaluable basis for pavement design. An initial approach recommended for pavement design would be to acknowledge that these materials are primarily modified aggregates, and base pavement design on the nominal stiffness modulus of the parent aggregate. Since these material types (as typically used in South Africa) have engineering properties that only seem to improve, this would provide a conservative basis that can be refined as more data become available.	Determination of stiffness and strength changes over time in prevailing conditions for a wide range of material types, from laboratory and field monitoring, is regarded as the ultimate key in enabling reliable pavement design and providing mix design criteria. Once standardisation or conformity in the other aspects mentioned above is reached, this then will be the basis of our knowledge base. It will be the main thrust then for developing reliable performance models that should ideally accommodate parent material type, grading (or packing potential), additive types and relative proportions, nominal ambient conditions, etc, etc. It should cover use of simpler indicator tests for determining key characteristics. Scope for further work is significant.

* Note: see text for recommendation.

The bitumen-emulsion and foamed bitumen treated materials should be viewed, initially at least, as improved aggregate rather than a stabilised material. This acknowledges the nature of these bituminous cold mix materials as adopted in South Africa, the relatively slow improvement in engineering properties with time, and the fact that all available evidence indicates that any improvements in engineering properties are only beneficial in terms of performance.

For pavement design, provided the material has adequate inherent strength to resist crushing or breakdown under traffic loading, and is sufficiently well compacted to minimise further significant compaction under traffic, its successful application stems from its ability to spread the traffic load. This is a direct function of its stiffness and consequently its ability to attenuate the effects of traffic load stresses with depth.

The pavement design process is then used to determine the layer thickness required that will ensure that stresses transmitted will not cause overstressing or unacceptable deterioration to the underlying layer(s).

While it is normal in routine laboratory testing to use some measure of strength (or ultimate strain) for materials evaluation and acceptance, it must be recognised that this does not characterise a material: it is simply an indicator that, over the years, has been correlated with performance of the material in the particular application. It does, of course, also imply certain expectation that other key engineering properties (particularly stiffness and durability) are satisfactory.

As touched on earlier, it should also be recognised that ultimate strength/strain values can (and invariably will) be far more variable for most materials, and especially for these treated materials, than stiffness. Conventionally defined by the nominal linear portion, or initial tangent modulus of a stress-strain response, stiffness is a composite property that will derive primarily from the parent material and binder matrix. Ultimate strength/strain will be governed by the weakest element of the specimen which is inherently a more variable property.

For these types of treated material, in which key properties such as stiffness and strength change with time/prevailing conditions, and for which any correlation of these two distinct properties is likely to be influenced by various of the factors discussed earlier, it is evident that any attempt to characterise using just, say, a strength indicator is unlikely to be conclusive or reliable.

The "back-to-basics" approach proposed is therefore aimed at determining laboratory indications of both the fundamental engineering characteristics of stiffness and strength on a routine basis that will rapidly enhance our knowledge base. Primary amongst the needs will be better understanding of how these properties are influenced by prevailing conditions, and to enable direct correlations with field indications of stiffness and strength development.

The laboratory testing will consequently require some determination of stress/strain response (from load/displacement), allowing determination of a stiffness value, as well as strength/strain parameters that may include ultimate (failure) values.

"Back-to-basics" is founded on the fundamental understanding that satisfactory long-term performance of pavement layer materials can only be approached if induced stresses (and strains) principally from traffic loading are kept well within the nominal elastic portion of the

stress-strain response. The extent of the initial nominally linear portion of the stress-strain response, by which the stiffness is characterised, is therefore also important.

For these types of material it seems apparent that both the stiffness and the extent of the linear portion, defined by a stress and corresponding strain value representing the end of the linear "elastic" portion, increase with time/prevailing condition which undoubtedly contributes to the longevity observed. The laboratory test will therefore enable these values to be monitored and the effects of various factors on the behaviour to be determined. It is considered that these stress/strain values should provide more reliable criteria for characterisation than ultimate strength (or strain) values.

In trying to identify suitable equipment that is, or could be, widely available for stiffness testing it became evident that the test frame used for CBR tests is most likely candidate: it provides for the application of sufficient load and measurement of displacement, and is available in virtually all materials testing laboratories. In addition, an inherent requirement of the proposed test is that as much of the specimen as possible should contribute to the test result, in order to get a more representative response and minimise fundamental variability. This points clearly to uniaxial compression testing of unconfined specimens, in which the stress-strain response is determined from applied load and displacement.

It is consequently proposed that specimens should be formed in the CBR mould (diameter 152.4 mm) and to the maximum thickness of 152.4 mm, using the proposed method of compaction (Table 1). This thickness is, of course, typical of constructed layer thickness. Specimens will be extruded just prior to test and tested unconfined, using a 152.4 mm diameter load platen. Loading would then also be applied in the same direction, relative to the compaction, as the field traffic loading.

The use of this specimen size would be considered to provide a sufficiently large sample size to be representative and also reduce possible effects of inherent variability. It is also seen as allowing for the full material grading, without artificially influencing compactibility by taking out or further breaking down, for example, particles above 19 mm. At worst, it would be recommended that only the occasional particles above, say, 50 mm should be removed prior to compaction.

By using the CBR test frame, it is further proposed that the same standard loading rate (1.27 mm/minute) be adopted to simplify the test process. The stiffness value deduced from the load/displacement response should allow reliable linear correlation with, for example, layer stiffness from field measurements or cores. Correlation of strength parameters should be similarly robust.

The main drawback foreseen, especially where test frames are computer controlled and incorporate load cells and LVDTs, is the probable need to take readings at a higher rate than used for conventional CBR testing (every 0.635 mm). This sampling rate may or may not be readily changed depending on the software. Ideally a full load/displacement response would be required in order to characterise the initial tangent modulus, but it would be anticipated that readings would be required approximately at least every 5 seconds or 0.1 mm displacement during the first minute. Manually it should be possible to take measurements with coordination of load and displacement readings from respective dial gauges.

Subsequent determination of nominal stiffness value would require manual interpretation of the load-displacement response, and a template approach as illustrated in Figure 1 would be recommended. Values of limiting stresses and strains would again require

manual interpretation, and simple calculation from the appropriate load and displacement values.

In any laboratory testing that follows the proposed approach it is also advocated that, prior to specimen extrusion for the unconfined compression test, measurement of CBR be taken (only to a penetration of 2.54 mm) as a simple indicator test. While this is not a direct measurement of stiffness or strength, and is unlikely to provide a unique linear correlation with these properties since these are likely to be material and application specific, it would provide additional insight and possibly aid in developing a simpler evaluation method.

E-value template for compression testing
(152.4 mm diameter specimen)
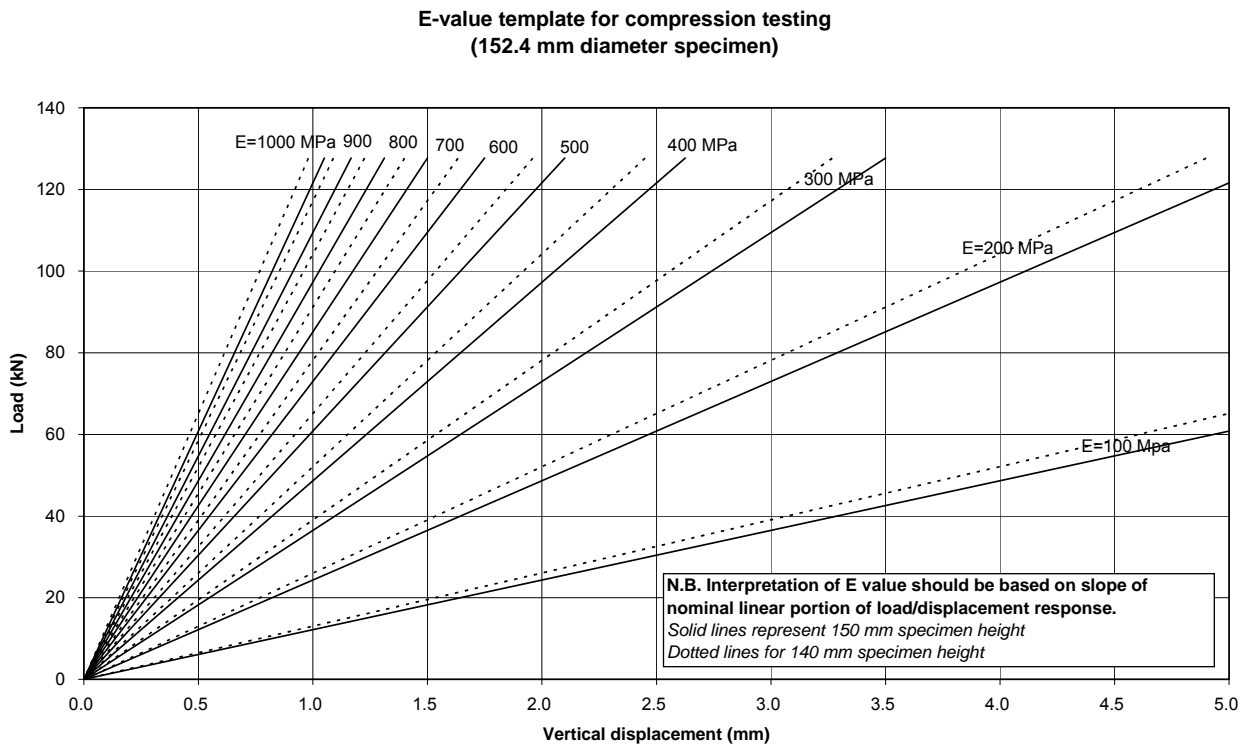
Figure 1: Example of template for interpretation of stiffness modulus value

The final recommendations, which could be viewed as most contentious, are twofold and must be kept within the context of these specific roadbase material applications. These are best broadly described as having residual bitumen contents of 1 to 2% by mass, and will often include a cement addition of up to 1%.

The first is based on the earlier observation that the beneficial performance of bitumen-emulsion treated roadbases seems disproportionate when compared with the individual additives and treatment levels, leading to the conclusion that the specific composition of the binder matrix must be a key factor.

In the interests of both attaining good performance and rapidly building the knowledge base, it is therefore recommended that a cement inclusion of 1% by mass be specified in all current applications.

It must be emphasised most strongly that the use of higher cement content is not advocated (certainly at this stage), not least because the long-term improvement in properties found for bitumen-emulsion treated bases is not associated with any of the characteristic problems of cement-treated or cement stabilised roadbase material (especially environment- or load-induced cracking, and subsequent deterioration).

Consequently simply increasing cement content, which is likely to induce this type of undesirable distress and unsatisfactory behaviour, should be avoided.

This recommendation is simply made as an expedient in best trying to emulate past successful applications. This quantity can be considered an amount sufficient to be mixed relatively uniformly, representative of present and past practice, and indisputably the most likely component that could contribute to long-term strength/stiffness improvement. Later study should be able to optimise the binder composition once a better understanding of the mechanism is developed.

The last main recommendation, again flagged in the earlier discussion, is based on the measurement and application of material stiffness as a fundamental property for pavement design purposes. In most simplistic terms, and on the assumption that exceeding a critical strength/strain is not a limiting factor, the stiffness of the pavement layer material will govern its application either as a main structural layer (base) or as a support layer such as the subbase. As essentially a modified aggregate material, the stiffness of a cold mix bituminous-treated material will initially be similar to the untreated parent material. If it does indeed gain stiffness and strength with time and subject to the prevailing conditions, then it would be expected to improve its traffic carrying capacity.

Rate of change of these properties with time will depend on ambient conditions applying, and it is almost inevitable that each application will have a unique engineering property development. This will be due to numerous factors, including region/climate, season, specific material type, additives, binder composition, etc, which will influence moisture dispersion, emulsion breaking, and binder matrix development.

The structural application of a cold mix bituminous-treated road base material in a pavement, similar to its unbound parent aggregate, will be governed primarily by its stiffness. Thus a good quality unbound aggregate with a relatively high layer stiffness (typically class G1 or G2) is suited to higher traffic and serviceability applications, whereas a lower quality (for example G3 or G4) would be satisfactory for lower traffic, lower serviceability applications.

Since the stiffness of the treated material in this case is subject to increase (at a rate that will depend on prevailing conditions), it is proposed that a design stiffness (and probably rate of stiffness development in the anticipated field conditions) be adopted as a mix design criterion.

The original discussion regarding accelerated laboratory curing highlighted the fact that the "target" condition (after curing) was not well defined. If the target is a laboratory stiffness value that relates to a field requirement, firstly a direct check on likely compliance can be obtained from laboratory testing of samples cured under ambient conditions. This will establish whether or not an acceptable stiffness value should be obtainable from a particular design mix and, if so, within what period.

A mix that may reach the target stiffness, but over a protracted period, would be regarded as less satisfactory compared with one that meets the target relatively quickly, say within one or two weeks which would be a realistic period in terms of the construction cycle.

In comparing two mixes that each meet a target stiffness within an acceptable period, it would then be realistic to select the one that seems to offer the better longer-term likelihood of continued improvement in stiffness and strength.

An appropriate laboratory accelerated curing regime can then be developed that best simulates the stiffness changes, but over a relatively short period.

For selection of "target" stiffness values, an obvious start point would be to adapt values that would be associated in pavement analysis with the unbound layer materials best representing the parent material. Immediate needs would then be to correlate the laboratory stiffness values derived from the unconfined compressive testing. Clearly, a laboratory study that parallels actual field construction, enabling direct comparison of, say, laboratory stiffness determination from cores (or laboratory specimens made during construction) with field values backcalculated from deflection testing of the layer made at the same time, would be ideal.

Proposed test periods for initial laboratory studies, in which the changes in engineering properties are monitored and stiffness comparisons of laboratory and field are made, are:

- 72 hours (± 1 hour), 168 hours (± 4 hours), 28 days, 14 weeks, 52 weeks for ambient curing;
- 24 hours (± 15 minutes), 72 hours (± 1 hour), and 168 hours (± 4 hours) for accelerated curing;

with timing based on time at final compaction in the mould. These periods are proposed as both practical and convenient for subsequent analysis, with the 14 and 52 week tests regarded as essential in developing our knowledge base at this stage. Exact time of test (along with the mixing and compaction times) should be recorded as a matter of routine and these parameters used in any time-based analysis.

From the previous review, selection of an accelerated curing regime is somewhat unclear. It would seem judicious to adopt the previously recommended accelerated curing regime for bitumen-emulsion treated roadbase materials as a reference point (Sabita, 1999). The author's recommendation for an alternative would, however, be 60ºC oven curing directly from compaction, the first 24 hours in the mould, then demoulded for subsequent curing and with no attempt to restrict moisture movement by either polythene bagging or any other method.

This approach has the perceived merit of using a temperature comparable with surface temperatures that can be commonly reached in South Africa in direct sunlight. Thus this cannot be considered excessive (even without clarity on the complex internal processes taking place during curing), yet should certainly accelerate overall development of stiffness and strength. During the first 24 hours, moisture movement is restricted by the mould to only upwards, which would certainly be the likely case for field applications during the first few days at least, whereas subsequently the specimen is allowed to dry (cure) as rapidly as possible in the curing conditions.

Another aspect that should be incorporated in any laboratory study, whether ambient or accelerated curing is used, is monitoring nominal moisture change from direct weighing of specimens (whether in or out of the mould) from compaction. Oven drying of sample material from tested specimens should also be undertaken as a matter of course. This will assist in developing our understanding of the influence of moisture content on measured properties.

In closing, it must be clearly understood that any "standard" accelerated curing regime, by definition, will lead to repeatable and reproducible results. In other words, no matter where

a compliance test is undertaken on the exact same materials mixed, compacted and cured identically, the result should be identical.

Since the properties of the material in any real application in the field will change in a distinctly non-standard way (according to the vagaries of the numerous factors outlined previously that are likely to have an influence), it will then be recognised that the main thrust has to be development of meaningful correlations to enable a standard test result to be interpreted realistically for the regional/climatic application. To emphasise this need it can be readily envisaged that an identical mix constructed in two wholly dissimilar regions, say very hot and arid compared with cold and wet, will respond in quite different ways and, very likely, behave and perform quite differently in a road. While not certain of the likely significance for the range of South African conditions, there is little doubt that this factor needs to be accommodated in future rational developments.

6. ACKNOWLEDGEMENTS

7. REFERENCES

[1] Asphalt Academy. Interim Technical Guideline: The design and use of foamed bitumen treated materials. Asphalt Academy, Technical Guideline TG2, Pretoria, 2002.

[2] Bergh, AO. Private communication. 2005.

[3] Bondietti, M, D Murphy, K. Jenkins and R. Burger. Research on the stabilisation of two different materials using bitumen emulsion and cement. CAPSA'04, Sun City, South Africa, September 2004.

[4] Brown, SF and D Needham. A study of cement modified bitumen emulsion mixtures. Paper to the 2000 Annual Meeting of the Association of Asphalt Paving Technologists.

[5] Hodgkinson, A and AT Visser. The role of fillers and cementitious binders when recycling with foamed bitumen or bitumen emulsion. CAPSA'04, Sun City, South Africa, September 2004.

[6] Houston, M and F Long. Corrrelations between different ITS and UCS test protocols for foamed bitumen treated materials. CAPSA'04, Sun City, South Africa, September 2004.

[7] Jenkins, K.J. Mix design considerations for cold and half-cold bituminous mixes with emphasis on foamed bitumen. Ph.D Thesis, University of Stellenbosch, South Africa, 2000.

[8] Jenkins, KJ, S Robroch, MG Henderson, J Wilkinson and AAA Molenaar. Advanced testing for cold recycling treatment selection on N7 near Cape Town. CAPSA'04, Sun City, South Africa, September 2004.

[9] Jostein, M. The use of cold bitumen stabilized base course mixes in Norway. Baltic Road Association, seminar session B2, 2000.

[10] Kekwick, SV. Accelerated Laboratory Curing of Bitumen-Emulsion and Foamed Bitumen Treated Specimens: Review of Current Practice. Gauteng Department of Public Transport, Roads and Works. CSIR Contract Report CR-2004/55, October 2004.

[11] Marais, CP and MI Tait. Pavements with bitument emulsion treated bases: proposed materialspecifications, mix design criteria and structural design procedures for southern African conditions. CAPSA'89, Swaziland, 1989.

[12] Potti, JJ, D Lesueur, and B Eckmann. Towards a rational mix design method for cold bituminous mixes. The Optel contribution. European Roads Review, Special Issue, RGRA2. 2002.

[13] South African Bitumen Association. ETB – The design and use of emulsion-treated bases. Sabita Manual 21, Cape Town, 1999.

[14] South African Bitumen Association. GEMS – The design and use of granular emulsion mixes. Sabita Manual 14, Cape Town, 1993.