Technical Paper

ISSN 1997-1400 Int. J. Pavement Res. Technol. 5(6):411-418

Effect of Binder Content and Active Filler Selection on Foamed Bitumen Mixtures: Western Australian Experience

Peerapong Jitsangiam[1+], Yue Huan[1], Komsun Siripun[1], Colin Leek[1], and Hamid Nikraz[1]

Abstract: Many factors affect the strength and durability of foamed bitumen treated materials, such as binder content, active filler type and content, aggregate composition and gradation, moisture content, compaction effort, and curing regime. This preliminary study investigates the effects of bitumen and active filler on standard mechanical test results. The results failed to demonstrate any consistent trend with bitumen content variation; however, four percent foamed bitumen appears an optimum value in some cases. The addition of cement always resulted in the highest mechanical performance, compared with the addition of hydrated lime and quicklime.

***Key words**: Active filler; Cold in situ recycling; Foamed bitumen; Mechanical testing methods; Pavement rehabilitation.*

Introduction

Premature failure of deteriorated road pavements, resulting from unreliably-predicted traffic demands and more heavily-trafficked axle group loading, is a severe problem encountered worldwide in road networks. This issue has resulted in the implementation of many different rehabilitation technologies to address road restoration, among which cold *in situ* recycling (CISR) has been widely accepted [1]. CISR is a common *in situ* stabilization process in which small quantities (1% to 4% by mass) of binders (i.e., cement as Portland and Blended cement, lime, foamed bitumen or bitumen emulsion and miscellaneous chemicals) are usually incorporated into reclaimed pavement materials at ambient temperature. This allows improved engineering properties without removal from the rehabilitation site. As a consequence of increased demand and the pursuit of more cost-effective and environmentally friendly methods, foamed bitumen stabilization, which presents outstanding performance among CISR techniques, has become a popular rehabilitation method.

Foamed bitumen was initially proposed by Csanyi in the mid-1950s at Iowa State University in North America [2]. The original process was modified in 1968 to enable foamed bitumen to be more easily implemented in the field, with Mobil Oil Australia replacing steam with cold water [3]. When hot bitumen (around 160℃ to 180℃) comes into contact with pressurized cold water and air, foam forms and the bitumen spontaneously expands to 10–15 times its original volume, coating the moist and cold aggregate particles. Due to the presence of bitumen—an intrinsically flexible product—in addition to an adequate quantity of cement or lime (inducing a relatively high stiffness to the parent materials), this seems to be an ideal material for flexible pavements. As a result, this technique has had a renaissance over the past few decades. However, due to the lack of a standardized mix design procedure, various factors such as binder content, active filler type and content, aggregate composition and gradation, moisture content, compaction effort, curing regime, and the like can affect the properties of the foamed bitumen mixture.

This preliminary study focuses on the effects of two binder media: bitumen and active filler. Two main objectives were identified, namely, a) to study the mechanical performance of foamed bitumen mixes with variable bitumen contents, and b) to compare and determine the effects of different active fillers on foamed bitumen mixes using mechanistic testing methods.

Previous research projects have endeavored to determine the optimum bitumen content for foamed bitumen mix design, but a consistent value has yet to be identified. Table 1 summarizes some previous research studies related to the determination of foamed bitumen content.

Studies of the benefits of adding different types of active fillers (cement, lime, fly ash) in foamed bitumen mixes are available. Some examples include adjusting the fine fraction of the aggregate gradation, improving the adhesion of the bitumen to the aggregate, assisting in the dispersion of bitumen, reducing the moisture sensitivity, and improving early mechanical strength [13]. These processes have been consistently incorporated into the selection of active filler type and content. Lancaster *et al.* [14] first confirmed the supply function of active fillers when insufficient fines content is observed, and suggested that 2% by mass of dry aggregate of cementitious additives should be the maximum value in foamed bitumen mix in order to prevent shrinkage cracks.

Compared with cases of inclusion of inactive filler and exclusion of active filler, an apparent increase in indirect tensile strength was investigated, where foamed bitumen mixes were treated with any type of cementitious filler [15]. Kavussi and Hashemian [16] conducted indirect tensile strength tests and the Marshall Stability test to support the theory that both cement and lime contribute to a significant increase in the mechanical strength of foamed bitumen mixes. They also noted that the total amount of active filler should be limited to a low value, possibly 1.5% by mass of dry aggregate, otherwise a brittle instead of a flexible state was likely to occur, associated with deformation and cracking.

Halles and Thenoux [17] used indirect tensile strength tests, tri-axial resilient modulus, and tri-axial permanent deformation tests to determine the mechanical properties of foamed bitumen mixes

---

[1] Department of Civil Engineering, Curtin University, P.O. Box U1987, Perth, WA, Australia 9845.

[+] Corresponding Author E-mail: p.jitsangiam@curtin.edu.au

Note: Submitted August 17, 2011; Revised June 25, 2012; Accepted July 27, 2012.

Table 1. Summary of Previous Research Studies Related to the Determination of Bitumen Content.

Research Projects	Research Methodology	Findings	References
A relationship Exists between Bitumen Content and Aggregate Gradation, Especially the Fines Contents Controlling at 4.75mm Sieve Passing and 0.075mm Sieve Passing	Guidelines can be Used to Select the Appropriate Bitumen Content when the Gradation Envelope of the Host Material is Given	Host Material with Higher Fine Contents Requires Higher Bitumen Content. Normally the Bitumen Content Range is from 3% to 5%	Ruckel *et al.* (1983); Muthen (1998); Nataatmadja (2001); [3–5]
	Target Bitumen Content can Possibly be Determined by Fines Content in Host Material	5% Fines Requires 3.5% Foamed Bitumen, while 5% Foamed Bitumen was Suitable for Aggregate with 20% Fines	Akeroyd (1989) [6]
Foamed Bitumen Content can be Determined by Mechanical Performance Testing	Six Hveem Testing Procedures: Resistance Value Test, Relative Stability Test, Cohesion Test, Free Swell Test, Unconfined Compressive Strength Test and Californian Permeability Test	Bitumen Content (in the Range of 1.5 to 3.5%) Could Protect Well-graded Materials Against Environmental Disruption	Bowering (1970) [7]
Sufficient Bitumen Content to Display Structural Properties	Five Tests Based on California Division of Highways Test Procedures: Modified Resistance Value; Modified Relative Stability; Cohesion; Free Swell and Permeability; Unconfined Compressive Strength	The Minimum Required Level for Foamed Bitumen Content is 1.5%	Bowering and Martin (1976)
Bitumen Contents on Eight Different Gradation Materials	Hveem, Hubbard-Field and Iowa K-test Methods	No Positive Value Observed to Determine the Optimum Bitumen Content, with the Exception of 4% Bitumen Content Providing an Excellent Marshall Stability Test Benchmark for all Treated Materials	Lee (1981) [9]
The Influence of Bitumen Content on Different Curing Times and Moisture Sensitivity	Marshall Stability Test	0.5% Bitumen Content Provided the Optimum Stability Under Two Different Curing Times, and 1% Bitumen Content Presented the Best Water Sensitivity Performance when Treating with Recycled Asphalt Pavement	Brennen *et al.* (1983) [10]
Optimum Bitumen Content	Retained Indirect Tensile Strength	2% Foamed Bitumen Content was Determined as Maximum Value	Mohammad *et al.* (2003) [11]
Typical Bitumen Content	Visually Inspected by Observing Coating Quality	3%–6% Bitumen Content is Typical. Higher Bitumen Content Resulting in a Thick Film would Simply Lubricate the Aggregate Particles, Whilst Lower Bitumen Content Resulting in Insufficient Coating would Decrease Mixture Stability and Water Susceptibility	Roberts *et al.* (1984) [12]

incorporated with different active filler types under different curing stages. It was noted that cement improves the indirect tensile strength and resilient modulus of the foamed bitumen mix to a higher degree than hydrated lime, while fly ash does not affect the mechanical properties but rather works as a mineral filler of the aggregate gradation. Vorobieff and Preston [18] presented to the NZIHT that lime is more preferable for use in Australia, as Australian rehabilitation works are mostly base course works where lime shows good performance.

Limited information is available in Western Australia concerning the effect and best performance of different types of active fillers on the mechanical properties of foamed bitumen mixes.

Materials and Laboratory Testing Methods

Materials

Aggregates

The virgin aggregates used in this laboratory study were blends of crushed rock base (CRB) and crushed limestone (CLS) from local quarries, in varying proportions. Both CRB and CLS were nominally graded at a maximum size of 19 mm, conforming to Mainroads Western Australia (MRWA) Specification 501 requirements. The four representative aggregate mixtures used in this study were:

- 100% crushed rock base and 0% crushed limestone (Mix A1);
- 75% crushed rock base and 25% crushed limestone (Mix A2);
- 50% crushed rock base and 50% crushed limestone (Mix A3);
- 25% crushed rock base and 75% crushed limestone (Mix A4).

Table 2. Aggregates Main Properties.

Properties	Mix A1	Mix A2	Mix A3	Mix A4
Maximum Size	19 mm	19 mm	19 mm	19 mm
Particles Passing 4.75 mm Sieve Size	55.50%	65.40%	73.70%	80.50%
Fines passing 0.075 mm Sieve Size	9.20%	9.00%	9.70%	10.50%
Plastic Index	Nonplastic	Nonplastic	Nonplastic	Nonplastic
OMC	5.90%	6.48%	8.48%	8.90%
MDD	2370 kg/m^3	2251 kg/m^3	2081 kg/m^3	1989 kg/m^3

Table 3. Properties of Active Fillers

Properties	Portland Cement	Hydrated Lime	Quicklime
Supplier	Cockburn Cement Limited, Australia	Cockburn Cement Limited, Australia	Cockburn Cement Limited, Australia
Appearance	Fine Powder	White or Off-white Amorphous Powder	Granular Off-white Amorphous Powder
pH	12	12	12
Bulk Density (kg/m^3)	1000–1300	200–500	750–1000
Specific Gravity	2.5–3.2	2.1–2.3	3.2–3.4

Table 2 lists the main properties of aggregates with different CRB and CLS proportions. The measurement of particle size distribution and the relationship of optimum moisture content (OMC) and maximum dry density (MDD) followed MRWA Test Methods WA115.1 and WA 133.1, respectively [19].

Foamed Bitumen Condition

The bitumen used was a standard Class 170 binder. According to BP Australia Pty Ltd [20], the density of this type of bitumen at 15℃ is 1040 kg/m3, and viscosity at 60℃ and 135℃ is 170 and 0.4 Pa·s, respectively. A laboratory-scale foamed bitumen machine, Wirtgen WLB 10S, was used to produce the foamed bitumen. When 2.5% cold foaming water was incorporated with hot bitumen at roughly 180℃, a foamed bitumen product with an expansion rate of 12–15 times and a half-life of 20 s was yielded. It was deemed to be a good foam quality with the exclusion of the use of a foaming agent, with the foaming characteristic limits derived from the South African Asphalt Academy used as a reference [13]. Based on prior research concerning bitumen content, 3%, 4%, and 5% bitumen contents were used in accordance with the proportion proposed by Muthen (1998), where bitumen was injected into four different aggregate blends, producing corresponding foamed bitumen treated mixtures for further compaction [4].

Other than the variant bitumen contents used in the bitumen content research, only 4% bitumen content was considered in the selection of active filler. This is because the practical bitumen content used in field is always around 4% in Western Australia based on the author’s experience.

Active Fillers

In researching bitumen content, hydrated lime was added to the aggregates at 1% proportion by mass to constrain the influence of active fillers and further stabilize the aggregates. Three active fillers, namely Portland cement, hydrated lime, and quicklime, were then added to the aggregates with variable percentages by mass (0%, 1%, 3%, and 5%). Table 3 lists some major properties of these active fillers.

Sample Preparation

Mixing

The oven-dried aggregates were placed into a mixer (Wirtgen WLM30) with a nominated percentage and type of active filler for pre-mixing, until the active filler was homogeneously blended with the aggregates. This step, defined as “dry mix” and ideally carried out only in the laboratory, was to prevent active filler particles forming lumps when they came into contact with water (negating the purpose of the filler). Subsequently, a certain amount of water was added to achieve a target moisture content, which was chosen as 100% of the OMC of the raw aggregates in this study. The mixes were then fabricated by spraying different amounts of foamed bitumen into the aggregates, producing approximately 15 kg batches of foamed bitumen mixtures.

A technique was introduced to roughly estimate the binding quality of the treated material after mixing: when a small amount of loose mixed material was firmly squeezed by hand, a good consistency was observed if a few black dots of bitumen remained stuck on the palm of the hand. Mixtures were deemed to be deficient when there were either no black dots remaining, or the bitumen was visibly “nubby.”

Compaction

An automatic Marshall Compactor was employed to fabricate six specimens of each mix for indirect tensile strength (ITS) and indirect tensile resilient modulus (ITM$_R$) tests. The specimens were compacted with 75 blows to one side, in a mold 101±1 mm in diameter and 76±1 mm in height. A modified compaction method was also used to prepare three samples of each mix for an unconfined compressive strength (UCS) test. In this process, a mold of 100 mm diameter and 200 mm height was used, in which material was compacted with 25 blows each for eight layers, using a 4.9 kg rammer at a 450 mm drop height.

Fig. 1. Apparatus for ITM$_R$ Testing.

Curing

Ruckel et al. [3] concluded that the moisture content during the curing period had a major effect on the ultimate strength of the mix. Most previous curing methods have adopted the laboratory curing procedure proposed by Bowering [7], i.e., three days oven-curing at a temperature of 60℃ to simulate the driest or worst conditions encountered in field. However, recent studies indicate that a temperature of 60℃ contributes to the melting and aging of bitumen, and also interferes with or even stops the cement hydration process. This would significantly affect the resulting strength of the mixes [4, 21]. It seems likely that an accelerated oven-curing method would also not be able to simulate field conditions where cement is used as an active filler. Slow curing at room temperature in more natural conditions would probably provide a more realistic reflection of the effects of active fillers.

In this study, all specimens were sealed in plastic wrap and left for seven days at room temperature. Upon completion of curing, a substantial amount of moisture was still inside the wrap, causing some specimens to easily break apart in a very wet condition. When comparing the wet samples after curing with the wet condition of test samples from a normal soaking process (which replicates the worst condition of pavement materials soaking under water), it was decided not to include the soaking process in this study.

Testing Methods

Three tests were performed at room temperature: ITS gives a measurement of tensile strength and flexibility, ITM$_R$ evaluates the maximum tensile stiffness, and UCS measures the maximum compressive strength without confining pressure. In the current Austroads method, ITM$_R$ is the main criterion used to determine the binder content at the maximum resilient modulus; this is also adopted by Queensland Department of Transport and Main Roads [22]. The South African Guidelines recommend that ITS and UCS tests are suitable for bitumen content determination and secondary binder selection [13].

ITM$_R$ Testing

All test samples prepared using the Marshall compaction method were initially subjected to the ITM$_R$ test before commencing the ITS test. The ITM$_R$ test, a non-destructive method used widely to determine stiffness modulus values, is characterized by using a repeat load tri-axial test apparatus in accordance with Australian Standard – AS 2891.13.1-1995 [23]. Fig. 1 shows the apparatus used for this testing. This resilient modulus testing standard was initially designed for asphalt specimens, but was invoked here for use with foamed bitumen treated materials, as no set standards for foamed bitumen mixes have yet been established. The rise time and estimated resilient modulus were hence adjusted in order to avoid premature failure of the specimens during the test. The (essentially) standard target parameters were kept constant throughout the testing and are given in Table 4.

ITS Testing

ITS was determined using a Marshall Stability machine in accordance with Australian Standard - AS 1012.10-2000 [24]. In this test, a cylindrical specimen prepared using the Marshall compaction method is diametrically loaded across the circular cross section. Loading is applied continuously at a constant rate. The results yield a tensile deformation perpendicular to the direction of the loading, ultimately producing a tensile fracture. A peak force is then recorded and used for the calculation of the ITS.

UCS Testing

UCS testing, conforming to MRWA Test Method WA 143.1, was conducted using the GCTS STX-300 testing apparatus (Fig. 2) at Curtin University [25]. Samples were placed in latex specimen membranes to ensure the protection of the equipment, and allowances were made to ensure that no confining pressure was applied during testing. Testing commenced with an applied strain rate of 1.0 mm/min until the maximum axial stress and strain values had been reached. To acquire an effective axial stress curve, testing was continued until values had decreased to half of the maximum value.

Quality Control

Table 4. Standard Target Parameters for ITM$_R$ Testing

Loading Wave Shape	Haversine	Target Temperature (˚C)	25
Loading Pulse Width (ms)	90–110	Target Peak Strain (με)	30
Pulse Repetition Period (ms)	3000	Estimated Poisson Ratio	0.4
Preconditioning Pulse Count	5	Estimated Resilient Modulus (MPa)	200–1000
Test Pulse Count	5	10% to 90% Rise Time (ms)	40±2

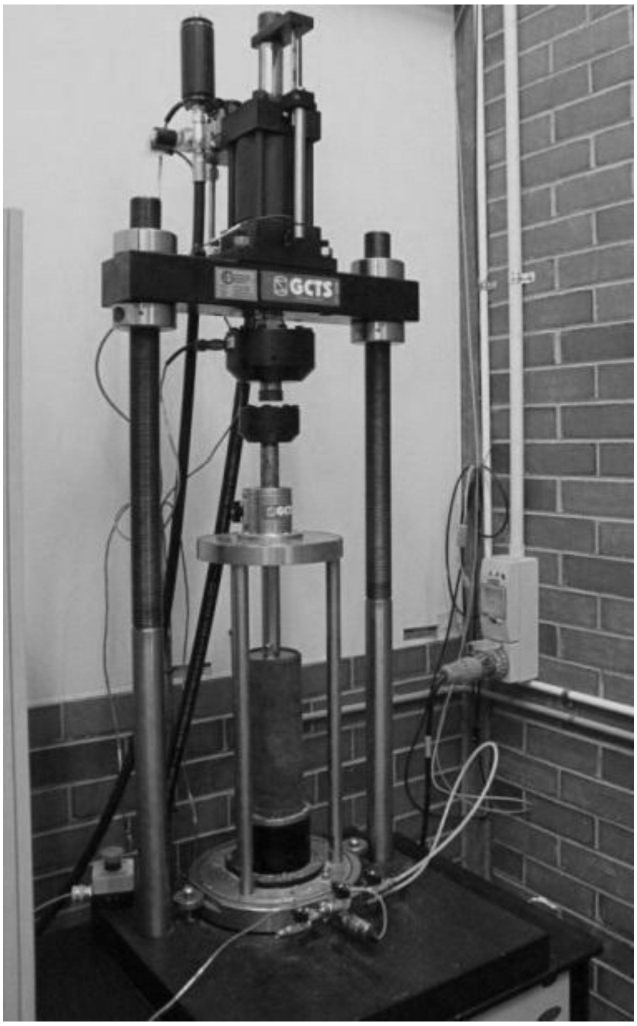

Fig.2. GCTS STX-300 Dynamic/stress-path Soil Tri-axial System for UCS Testing.

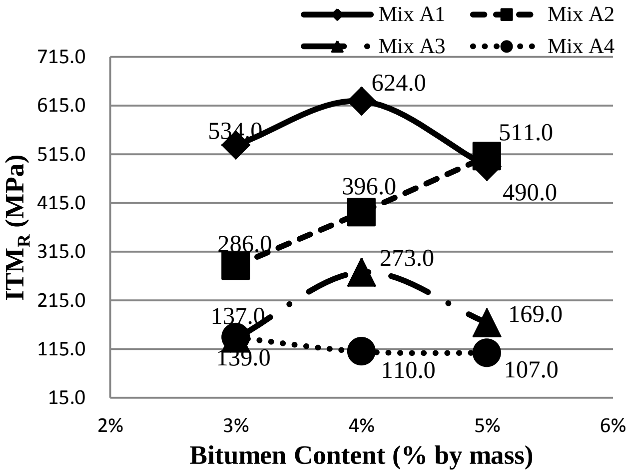

Fig. 3. ITM$_R$ Values for Foamed Bitumen Materials with Varying Bitumen Contents.

Each of the above tests used triplicate cylindrical shaped specimens with the same moisture content and maximum bulk density. Mean values were used in the subsequent analysis.

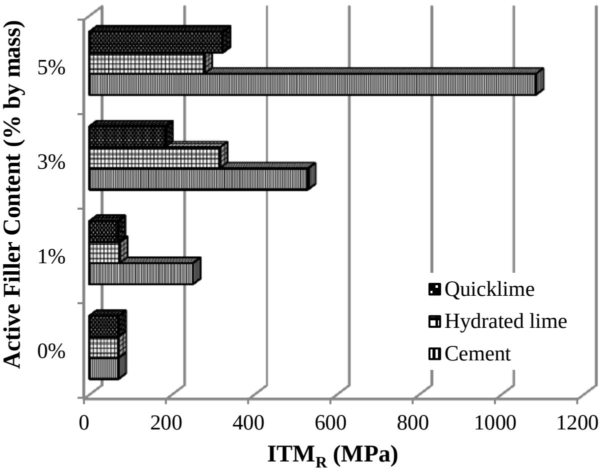

Fig. 4. ITM$_R$ Values for Foamed Bitumen Materials with Different Active Fillers.

Results and Analysis

Indirect Tensile Resilient Modulus Test

Bitumen Content

No clear trends were evident from the ITM$_R$ test results, as seen in Fig. 3. Mix A1 and Mix A3 typically achieved the highest resilient modulus at a bitumen content of 4%, with peak values at 624 MPa and 273 MPa, whereas Mix A2 and Mix A4 did not show clear trends for bitumen content requirements. However, ITM$_R$ values versus gradation clearly demonstrated that with an increasing percentage of introduced CLS, the peak ITM$_R$ values decreased correspondingly.

Active Filler Selection

As expected from previous research in the literature, cement always provided the highest resilient modulus of all the fillers tested, including hydrated lime and quicklime, as illustrated in Fig. 4. The addition of 1% cement created a significant increase in ITM$_R$ values--approximately 250% higher than with 0% active filler, 1% hydrated lime, or 1% quicklime. Comparatively, the addition of 1% hydrated lime and 1% quicklime contributed to an approximate 5% increase in ITM$_R$ values compared to the mixture without active filler, which showed only a mild degree of stiffness improvement. With an increase of up to 3%, all of the active fillers gave a significant increase in resilient modulus, with hydrated lime producing the biggest improvement—fivefold compared to the 1% content. With 5% active filler addition, both hydrated lime and quicklime provided a slight improvement, while cement still played a major role in stiffness gaining, with an ITM$_R$ value over 1,000 MPa. Cement displayed a much stronger and more active reaction capacity than either hydrated lime or quicklime.

Indirect Tensile Strength Test

Bitumen Content

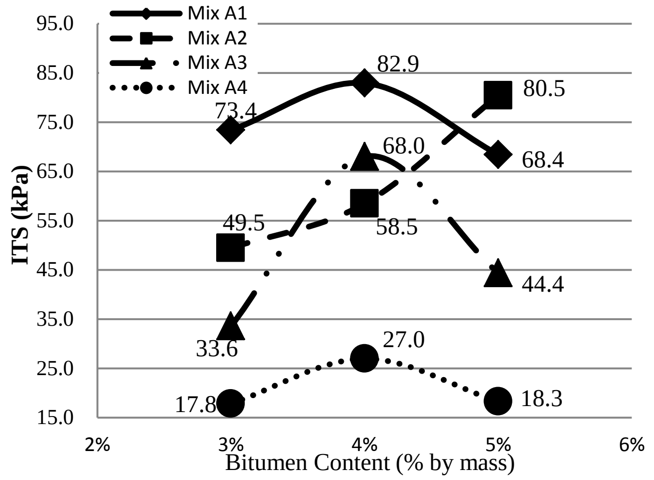

Fig. 5. ITS Values for Foamed Bitumen Materials with Different Bitumen Contents.

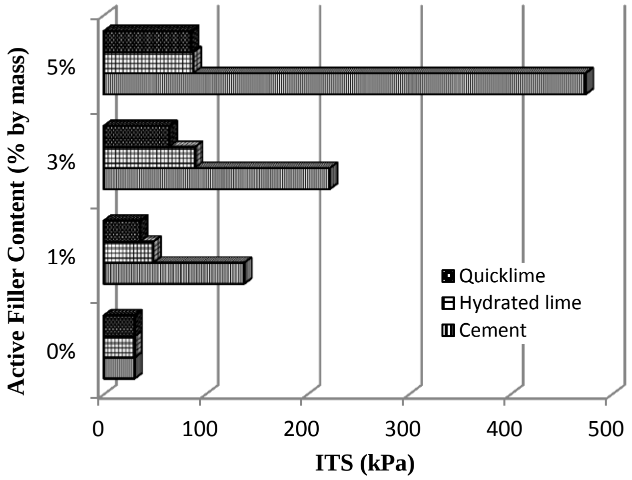

Fig. 6. ITS Values for Foamed Bitumen Materials with Different Active Fillers.

Fig. 5 show ITS values for foamed bitumen treated materials with different bitumen content. It is interesting to observe that apart from an increasing trend in Mix A2, the other three materials demonstrated roughly parabolic prevalent strength curves. They also showed an optimum strength at around 4% bitumen content. It may be inferred, from these results together with the ITM_R values, that with a fines content in the range of 9.0% to 11%, 4% bitumen content could exhibit the highest tensile strength. Similar to the ITM_R results, the ITS values of foamed bitumen mixes (incorporating the same bitumen content) decreased significantly with an increasing proportion of CLS.

Active Filler Selection

All three active fillers, regardless of the variant type and content, contributed to an increase in tensile strength compared to mixes without active fillers, as shown in Fig. 6. As the percentage of active filler increased, so did the tensile strength, with cement always providing a significantly higher percentage increase compared with the other two active fillers, hydrated lime and quicklime. When comparing hydrated lime and quicklime at 3% active filler addition, hydrated lime demonstrated better tensile strength than quicklime, but it was still very low compared to the strength of cement. Upon increasing to 5%, both fillers exhibited similar tensile strengths, but again were very low compared to cement.

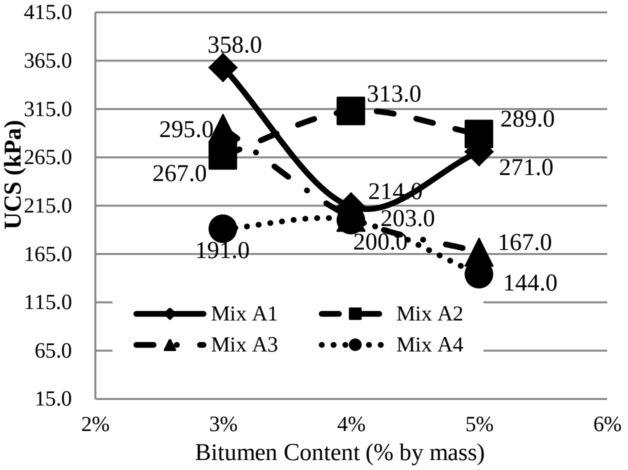

Fig. 7. UCS Values for Foamed Bitumen Materials with Different Bitumen Contents

The addition of 5% active filler, proposed as an extreme case in this study, far exceeds the amount suggested by Kavussi and Hashemian of 1.5% [16]. The cement-treated samples in particular became cementitious products rather than foamed bitumen mixtures. Consequently, shrinkage cracking is likely to occur when samples exhibit cementitious properties, even when they possess a higher tensile strength. This shrinkage problem for foamed bitumen stabilized material still needs more investigation for very high cement contents.

Unconfined Compressive Strength

Bitumen Content

Due to the ambiguity of the results, strong conclusions could not be drawn. Prevalent trends were not apparent, and the mixtures behaved uncharacteristically as the bitumen content varied. Fig. 7 presents curves for Mix A1 and Mix A3, and it is clear that the optimum bitumen content cannot be determined from a peak in the curves as expected. Instead of showing a peak at an intermediate proportion of bitumen content, these data demonstrated an unexpected decrease. It was also observed that Mix A2 exceeded the strength obtained by the equivalent Mix A1 counterpart, which was always lower in tensile strength test results. This reflected expectations from the author’s experience, demonstrating how the introduction of small proportions of CLS can be beneficial to compressive strength. For foamed bitumen stabilization to be effective, adequate fine particles must be distributed throughout the mixture to allow the bitumen to coat these particles and in turn form a mortar to bond the coarser particles together.

Active Filler Selection

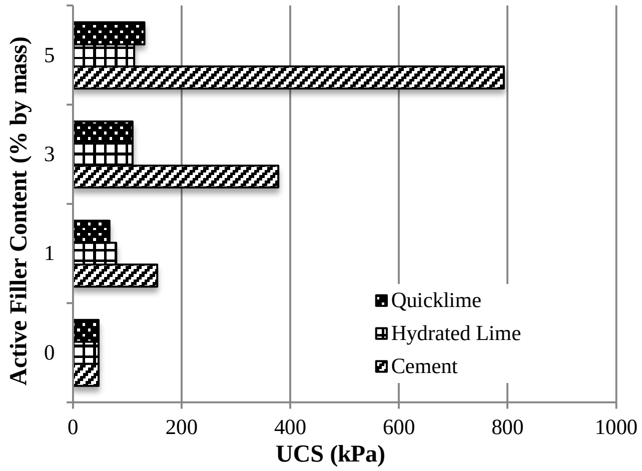

Fig. 8. UCS Values for Foamed Bitumen Materials with Different Active Fillers.

Fig. 8 shows that the strength of foamed bitumen treated mixtures increased with the addition of varying concentrations of active fillers. The increase in concentration contributed to a significant increase in the compressive strength of some mixes, like cement, but this was not as evident with the hydrated lime and quicklime.

With the addition of 1% cement, the maximum compressive strength of the mixture increased by approximately three times compared to the original samples with no active filler content. A significant increase in compressive strength was observed when the cement concentration increased to 5%--the mixture's strength increased by approximately 15 times. However, it is imperative to note that the 5% concentration of cement was higher than the bitumen content (4%). Therefore, the mixture was behaving more like a cementitious material than a foamed bitumen treated mixture, and would likely be more prone to cracking in the long-term [22].

Hydrated lime and quicklime were similar in their effects on the compressive strength of the treated mixtures. However, unlike the cement treated mixtures, increased percentages of added hydrated lime and quicklime seemed less reactive in the foamed bitumen treated mixtures. When 3% of either hydrated lime or quicklime was added, UCS values improved only twofold, and with 5% active filler, no apparent further improvement was obtained. This indicates that with regard to UCS, 3% hydrated lime or quicklime is sufficient.

Conclusions and Recommendations

Based upon the findings of this research, the following conclusions were made:

(1) The study of varying bitumen content generally failed to demonstrate any prevalent trends with bitumen content variation. These results conform with previous studies in which no clear trends or consistent values could be identified.

(2) Cement, regardless of the amount added, always provides the highest mechanical performance compared with hydrated lime and quicklime. Although higher stiffness and strength can be obtained with relatively higher cement content, a concern arises that when the cement content is higher than the bitumen content, cementitious properties will dominate, resulting in a reduction in flexibility and defeating the very purpose of the product.

(3) Hydrated lime and quicklime appear to be less advantageous in comparison to cement, but they do contribute to strength and stiffness improvement, albeit to a lower degree than cement.

(4) It is difficult to quantify an optimum active filler content, as this element is highly dependent on the design criteria regarding target performance for pavement construction. However, it is feasible to equate the mechanical performance produced by 1% cement to that produced by 3% hydrated lime or quicklime.

Acknowledgements

The authors would like to express their sincere thanks to the Curtin Pavement Research Group for generous support, facilities, and research assistance.

References

1. Jenkins, K.J. (2007). Foamed Bitumen Mixes = Shear Performance?, *The International Journal of Pavement Engineering*, 8(2), pp. 85–98.
2. Csanyi, L.H. (1957). Foamed Asphalt in Bituminous Paving Mixtures, *Highway Research Board Bulletin*, No.160, Vol. 10, Washington, DC, pp. 108–122.
3. Ruckel, P.J., Ascott, S.M., and Bowering, R.H. (1983). Foamed-Asphalt Paving Mixtures: Preparation of Design Mixes and Treatment of Test Specimens, Asphalt Materials, Mixtures, Construction, Moisture Effects and Sulfur., Washington, DC, USA, pp. 88–95.
4. Muthen, K.M. (1998). Foamed Asphalt Mixes - Mix Design Procedure, CSIR Transportek, South Africa.
5. Nataatmadja, A. (2001). Some Characteristics of Foamed Bitumen Mixes, *Transportation Research Record,* No. 1767(-1), pp. 120–125.
6. Akeroyd, F.M.L. (1989). Advances in Foamed Bitumen Technology, *Fifth Conference on Asphalt Pavements for Southern Africa*, pp. 1–4, Swaziland.
7. Bowering, R. H. (1970). Properties and Behaviour of Foamed Bitumen Mixtures for Road Building, *Proceedings of the 5th Australian Road Research Board Conference*, pp. 38–57, Canberra, Australia.
8. Bowering, R.H. and Martin, C.L. (1976). Foamed Bitumen Production and Application of Mixtures, Evaluation and Performance of Pavements, *Proceedings of the Association of Asphalt Paving Technologists*, 45, pp. 453–477.
9. Lee, D.Y. (1981). Treating Marginal Aggregates and Soils with Foamed Asphalt, *Proceedings of the Association of Asphalt Paving Technologists*, 50, pp. 211–250.
10. Brennen, M., Tia, M., Altschaeffl, A. G., and Wood, L. E. (1983). Laboratory Investigation of the Use of Foamed Asphalt for Recycled Bituminous Pavements, Asphalt Materials, Mixtures, Construction, Moisture Effects and Sulfur, Washington, DC, USA, pp. 80–87.

11. Mohammad, L.N., Abu-Farsakh, M.Y., Wu, Z., and Abadie, C. (2003). Louisiana Experience with Foamed Recycled Asphalt Pavement Base Materials, *Transportation Research Board 82nd Annual Meeting (CD-Rom)*, Washington, DC, USA.
12. Roberts, F.L., Engelbrecht, J.C., and Kennedy, T.W. (1984). Evaluation of Recycled Mixtures Using Foamed Asphalt, Asphalt Mixtures and Performance, Washington, DC., USA, pp. 77–85.
13. Asphalt Academy (2009). Technical Guideline: Bitumen Stabilised Materials. A guideline for the design and construction of bitumen emulsion and foamed bitumen stabilised materials, Pretoria, South Africa.
14. Lancaster, J., McArthur, L., and Warwick, R. (1994). VICROADS Experience with Foamed Bitumen Stabilisation, 17th ARRB Conference, Vol. 17. Part 3, pp. 193–211, Gold Coast, Queensland, Australia.
15. Hodgkinson, A. and Visser, A.T. (2004). The Role of Fillers and Cementitious Binders when Recycling with Foamed Bitumen or Bitumen Emulsion, *Proceeding of 8th Conference on Asphalt Pavements for Southern Africa*, Sun City, South Africa.
16. Kavussi, A. and Hashemian, L. (2004). The Effect of Lime and Cement in Foam Bitumen Mixes, *International RILEM Conference on the Use of Recycled Materials in Building and Structures*, pp. 76–83, RILEM Publications SARL.
17. Halles, F.A. and Thenoux, G.Z. (2009). Degree of Influence of Active Fillers on Properties of Recycled Mixes with Foamed Asphalt, *Transportation Research Record*, No. 2095(-1), pp. 127–135.
18. Vorobieff, G. and Preston, N. (2004). Bitumen Stabilisation - an Australian Perspective, NZIHT Stabilisation of Road Pavements seminar.
19. Main Roads Western Australia (2011). *Testing Methods (Soil)*, 2011.
20. BP Australia Pty Ltd (2008). Paving Grade Bitumen - Class 170, Class 320, Class 600, Road Construction and Maintenance Applications.
21. Saleh, M. (2004). New Zealand Experience with Foam Bitumen Stabilization, *Transportation Research Record*, No. 1868(-1), pp. 40–49.
22. Ramanujam, J., Jones, J., and Janosevic, M. (2009). Design, Construction and Performance of In-situ Foamed Bitumen Stabilised Pavements, *Queensland Roads Edition No. 7*, pp. 56–69.
23. Australian Standard (1995). Method 13.1: Determination of the resilient modulus of asphalt—Indirect tensile method, Methods of Sampling and Testing Asphalt, AS2891.13.1-1995.
24. Australian Standard (2000). Method 10: Determination of indirect tensile strength of concrete cylinders (‘Brazil’ or splitting test), Methods of Testing Concrete, AS 1012.10-2000.
25. Main Roads Western Australia (2011). Testing Method WA 143.1 – 2011: Determination of the unconfined compressive strength of laboratory compacted specimens, 2011.