Effects of Active Filler Selection on Foamed Bitumen Mixture in Western Australia

Yue Huan[1, a], Peerapong Jitsangiam[2, b] and Hamid Nikraz[3, c]

[1]PhD candidate, Department of Civil Engineering, Curtin University, P.O. Box U1987, Perth, WA,
Australia 6845; PH (61) 8 9266-7718; FAX (61) 9266-2681
[2]Lecturer, Department of Civil Engineering, Curtin University, P.O. Box U1987, Perth, WA,
Australia 6845; PH (61) 8 9266-4527; FAX (61) 9266-2681
[3]Professor, Department of Civil Engineering, Curtin University, P.O. Box U1987, Perth, WA,
Australia 6845; PH (61) 8 9266-7609; FAX (61) 9266-2681
[a]email: yue.huan@postgrad.curtin.edu.au, [b]email: p.jitsangiam@curtin.edu.au,
[c]email: h.nikraz@curtin.edu.au

Key words: Cold in-place recycling, foamed bitumen, active filler, indirect tensile resilient modulus, indirect tensile strength, unconfined compressive strength

Abstract

This study investigated the effects of different active filler types and contents on the mechanical properties of foamed bitumen treated materials under laboratory conditions. Four different active fillers were tested namely Portland cement, hydrated lime, quicklime and fly ash, at varying concentration of 0%, 1%, 3% and 5%. To evaluate the effects of the additional active fillers, samples were prepared under laboratory conditions and tested using indirect tensile strength, indirect tensile resilient modulus and unconfined compressive strength tests. Based upon our findings, all active filler types except fly ash contributed in improving the strength of foamed bitumen mixtures at different levels. Cement, regardless of adding contents, always provided the highest mechanical performance compared with the other two counterparts: hydrated lime and quicklime. Fly ash was deliberated to be precluded because fly ash on its own did not affect any mechanical strength of foamed bitumen mixes instead it acted as a mineral filler to modify aggregate gradation. The addition of active filler content should be limited within 3% in terms of strength gain and potential cracking prevent when mixing with 4% foamed bitumen content and locally sourced raw materials for base course.

Introduction

Cold in-place recycling (CIPR) has grown significantly over the past few years as a favoured method to rehabilitate existing pavements without removal from site. Many techniques have been involved in this rehabilitation method, one of them being cold-recycling with foamed bitumen. To date, foamed bitumen is not a new concept for many departments of transportation and road agencies in the world since it was initially proposed by Csanyi in the mid-1950s at Iowa State University in North America [1]. Subsequently, the year 1968 witnessed a great modification of the original process that enabled foamed bitumen to be practically and widely implemented in the field, with Mobil Oil Australia replacing steam with cold water. Basically, when hot bitumen (around 160℃ to 180℃) comes in contact with pressured cold water and air, the foam forms and bitumen spontaneously expands to 10-15 times of its original volume, offering an excellent opportunity to well coat moist and cold aggregate particles. Due to the intrinsic flexibility with relatively high stiffness of the treated material produced from this technique, it seems to be an ideal material for flexible pavements and this technique did have a renaissance in the past few decades. Research has also been conducted in many laboratories to find out an ideal composition to produce the best mechanical properties and long-term performances of foamed bitumen mixes.

The benefits of adding different types of active fillers (cement, lime, fly ash) into foamed bitumen mixes were well documented and recognised, such as adjusting the fine fraction of the aggregate gradation, improving adhesion of the bitumen to the aggregate, assisting in dispersion of bitumen, reducing the moisture sensitivity and improving early mechanical strength [2]. The foregoing effort had been continuingly put into the selection of active filler type and content. The supplying function of active fillers in gradation was confirmed when insufficient fines content was observed and it was suggested that 2% by mass of dry aggregate of cementitious additives should be the maximum value for foamed bitumen mix in order to prevent shrinkage cracks [3]. Compared with the cases of inclusion of inactive filler and exclusion of active filler, an apparent increasing of indirect tensile strength values was investigated when foamed bitumen mixes were treated by any type of cementitious filler [4]. Both cement and lime contributed a rather significant increase in the mechanical strengths of foamed bitumen mixes when determined by indirect tensile strength and Marshall Stability test. It also pointed out that the total amount of active filler should be limited under a low value, possibly 1.5% by mass of dry aggregate or a brittle state instead of flexibility was likely to occur and be associated with deformation and cracking [5]. The cement content was then confirmed in a South African guideline that the maximum value should be 1% and not exceed to the bitumen content [2].The mechanical properties of foamed bitumen mixes when incorporating with different active filler types (Portland cement, cement kiln dust, lime and fly ash) under different curing stages were also determined by tri-axial resilient modulus and tri-axial permanent deformation test in addition to indirect tensile strength. It was noted that cement improves the indirect tensile strength and resilient modulus to a higher degree than hydrated lime whilst fly ash does not affect the mechanical properties of the foamed bitumen mix but rather works as a mineral filler of the aggregate gradation [6]. The reason that lime is more preferable in Australia is because Australian rehabilitation works are mostly base course work where lime has exhibited good performance [7]. Despite previous achievements, limited information was still available concerning the effects of different types of active fillers on the mechanical properties of foamed bitumen mixes and the best performing active filler in Western Australia.

Materials

Aggregates

The host aggregate used in this laboratory study was a blend of 40% crushed rock base (CRB) and 60% crushed limestone (CLS) in accordance with the proportion in a real field trial implemented in City of Canning, Perth. After randomly sourcing the virgin aggregates from local quarries, they were directly transported to the laboratory of the Department of Civil Engineering, Curtin University. Both CRB and CLS were nominally graded at the maximum size of 19mm, conforming to Main Roads Western Australia (MRWA) Specification 501requirement.

Table 1 lists the main properties of this mixture. The particle size distribution and the relationship of optimum moisture content (OMC) and maximum dry density (MDD) were following the MRWA Test Method WA115.1 and WA 133.1, respectively. Fig.1 below shows the particle size distribution of the mixture complying with the grading zones for foamed bitumen outlined by Asphalt Academy.

Table 1 Mixture main properties

Sieve Size (mm)	Percentage Passing (%)	Ideal zone (mm)	Less suitable zone (mm)
19	100.0	66-99	99-100
13.2	98.1	67-87	87-100
9.5	93.1	49-74	74-100
4.75	78.4	35-56	56-95
2.36	67.8	25-42	42-78
1.18	56.3	18-33	33-65

0.6	46.3	14-28	28-54
0.425	40.1	12-26	26-50
0.3	32.0	10-24	24-43
0.15	15.3	7-17	17-30
0.075	8.6	4-10	10-20
OMC (%)	8.65		
MDD (kg/m^3)	2062		

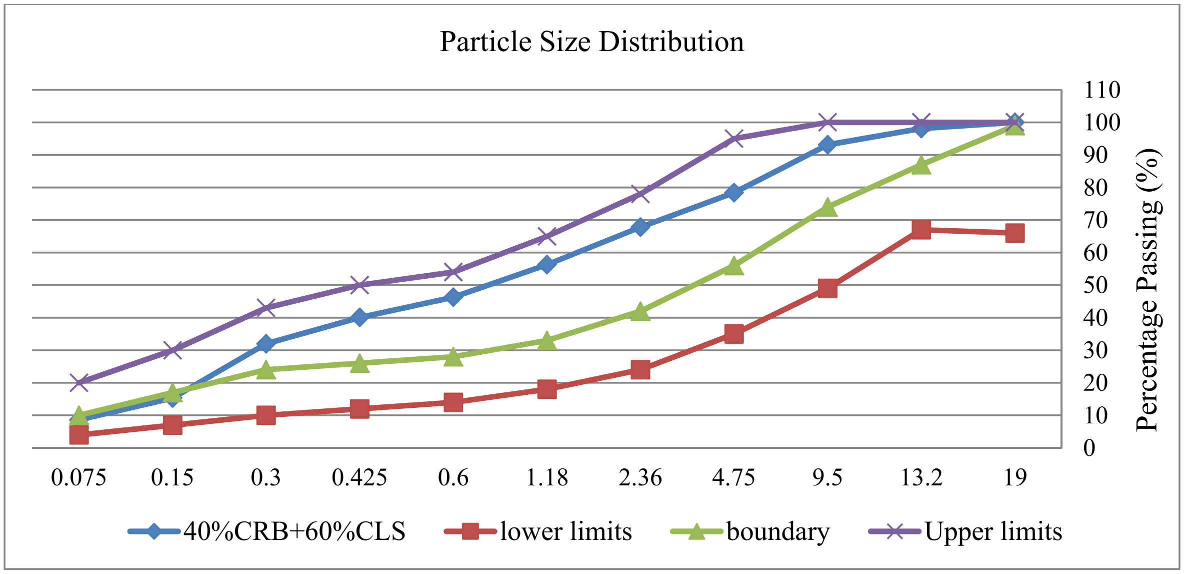

Fig. 1 Particle Size Distribution compared with Grading Zone introduced by Asphalt Academy

Even though the curve was not within the ideal zone and located in the less suitable zone, it was still believed to be suitable for this research. This was because the curve was not too far off from the ideal zone and the material could be simulating the conditions for light trafficked conditions [3]. For foamed bitumen operations, it was recommended that the minimum amount passing through the 0.075mm sieve size should be 5% and as can be seen from the table, the amount of fines in this material was 8.6% which was acceptable [8].

Foamed bitumen condition

The grade of bitumen used in this project was a standard Class 170 binder sourced from a local BP bitumen distributer. According to BP Australia Pty Ltd, the density of this type bitumen at 15℃ is 1040kg/m3 and viscosity at 60 and 135℃ are 170 and 0.4 Pa·s, respectively [9]. A laboratory scale foamed bitumen machine, Wirtgen WLB 10S, was used to produce the foamed bitumen and investigate foaming characteristics. The results showed that when 2.5% cold foaming water was injected to roughly 180℃hot bitumen, a foamed bitumen production with expansion rate of 12-15 times and half-life of 20s was yielded. This was considered good foam quality with the exclusion of foaming agent [10]. Four per cent bitumen content was nominated to be incorporated with host aggregate blend.

Active fillers

Four active fillers, namely Portland cement, hydrated lime, quicklime and fly ash were added to the aggregates with variant percentages by mass (0%, 1%, 3% and 5%). Table 2 lists some main physical and chemical properties of the chosen active fillers.

Table 2 Properties of active fillers

Properties	Portland Cement	Hydrated Lime	Quicklime	Fly Ash
Supplier	Cockburn Cement Limited, Australia	Cockburn Cement Limited, Australia	Cockburn Cement Limited, Australia	Callide power station, Australia
Appearance	Fine powder	white or off-white amorphous powder	Granular off-white amorphous powder	Grey powder
pH	12	12	12	7.1-7.2
Bulk Density (kg/m^3)	1000-1300	200-500	750-1000	-
Particle size (μm)	10-30% <7	95%<75	95%<600	-
Specific Gravity	2.5-3.2	2.1-2.3	3.2-3.4	-
Solubility	Slight, hardens on mixing with water	slightly	Sparingly soluble, reacts vigorously with water	slightly

Sample Preparation

Mixing process

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 a “dry mix” only ideally operated in laboratory conditions, was to prevent active filler particles form lumps when contacting with water and thereupon lose the designated purposes. Subsequently, a certain amount of water was added to achieve target moisture content raised to 100% of OMC of raw aggregates in this study. The mixes were then fabricated by spraying 4% of foamed bitumen by dry aggregate mass into the aggregates, producing approximately 15kg batches of foamed bitumen mixtures. A technique that was used to roughly investigate the binding quality of the treated material after mixing was introduced. When a small amount of loose mixed material was firmly squeezed on to the hand, a few black dots of bitumen sticking to the palm were seen as an indicator of good quality. Mixtures with no black dots of bitumen or visibly nubby bitumen were considered to be deficient.

Compaction

An automatic Marshall Compactor was then employed to fabricate six specimens for indirect tensile strength (ITS) and indirect tensile resilient modulus (ITM_R) tests. With this compaction condition of the Marshall Compactor, the specimens were compacted with 75 blows at one side in a mould 101(±1) mm in diameter and 76(±1) mm in height. Besides, a modified compaction method was utilised to prepare three samples for the unconfined compressive strength (UCS) test. In this process, a mould 100mm in diameter and 200mm in height was used in which materials were compacted 25 blows each for eight layers with a 4.9kg rammer at a 450mm drop height.

Curing

Curing is the process whereby foamed bitumen mix gradually gains strength over time accompanied by a reduction in the moisture content [11]. It was also found that the moisture content during the curing period had a major effect on the ultimate strength of the mix [12]. Most of the previous curing methods have adopted the laboratory curing procedure proposed by Bowering, i.e. 3 days oven curing at a temperature of 60℃ to simulate the driest or worst condition encountered in field [11]. However, recent studies indicate that the temperature at 60℃ contributes to the melting and aging of bitumen and also interferes or even stops the cement hydration process which would significantly affect the resulting strength of the mixes [8,13]. Therefore a concern was raised that accelerated oven curing method would not be able to simulate field conditions provided that cement is used as active filler. Instead slow nature curing at room temperature could more realistically reflect effects of active fillers. In this study, all specimens were allowed to be sealed in a plastic wrap and placed at room temperature for 7 days. On completion of curing, substantial moisture was still trapped in the wrap and there was therefore no need to re-introduce water to investigate moisture susceptibility. Hence a soaking process was not included in this research.

Testing Procedures

Three tests were performed at room temperature, each with a purpose to measure a different mechanical property of the specimens. Specifically, ITS measures the tensile strength and flexibility while ITM_R evaluates the maximum tensile stiffness as well as UCS measures the maximum compressive strength without confining pressure. These testing procedures were performed according to the guidelines set out in Australian Standards.

ITM_R testing

All Marshall samples are subjected to the ITM_R test first before commencing the ITS test. The ITM_R test is a non-destructive method that is used widely for the determination of stiffness modulus values is characterised using a repeated load tri-axial test apparatus in accordance with Australian Standard – AS 2891.13.1-1995. It should be noted here that the above standard is a resilient modulus testing standard initially designed for asphalt specimens but it is referred to here for foamed bitumen treated materials because no set standards for foamed bitumen mixes have been established. The rise time and estimate resilient modulus is therewith adjusted in order to avoid premature failure of the specimens during the test. The essentially standard target parameters kept constant throughout the testing are as follows in Table 3:

Table 3 Standard Target Parameter for ITM_R Testing

Loading Wave Shape	Haversine	Target Temperature (˚C)	25
Loading Pulse Width (ms)	90-110	Target Peak Strain (με)	50
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

ITS testing

ITS is determined using the Marshall Stability machine in accordance with Australian Standard - AS 1012.10-2000. In this test a cylindrical Marshall's specimen is diametrically loaded across the circular cross section. This loading applied continuously at a constant rate results in tensile deformation perpendicular to the direction of the loading, ultimately yielding a tensile fracture. A peak force is then recorded and used for the calculation of the ITS.

UCS testing

UCS testing, conformed to MRWA Test Method WA 143.1, was conducted using the GCTS STX-300 testing apparatus located in the Geomechanics Laboratory, Department of Civil Engineering, Curtin University. Samples are placed in latex specimen membranes to ensure protection of equipment and consideration is made to ensure that no confining pressure was applied during testing. Testing is commenced with an applied strain rate of 1.0mm/min until the maximum axial stress and strain values had been reached. To acquire an effective axial stress curve the testing continues until values had decreased to half that of the maximum value.

Quality Control

Each of the above tests utilised repeatable cylindrical shaped specimens fabricated with approximate moisture content and bulk density. Besides, the coefficient of variation (CV), which is the ratio of standard deviation to mean value, should be less than 10% to control the testing quality. However, only mean values are available for further analyses.

Results and Analysis

Indirect Tensile Resilient Modulus Test

What should be primarily highlighted here was that it was deliberate to preclude fly ash in the following analysis parts because fly ash on its own did not did not affect any mechanical strength of foamed bitumen mixes instead it acted as a mineral filler to modify aggregate gradation. After an initial investigation on the mechanical performance of fly ash treated mixtures, neither comparable results nor apparently improved performance was observed. Hence a time and material wasting concern was made to discard fly ash after initial tests and only three active fillers (cement, hydrated lime and quicklime) were continued in the experiment analysis thereafter.

As expected, cement always provided the highest resilient modulus than hydrated lime and quicklime, illustrated in Fig. 2. With the addition of 1% cement there was quite a significant increase in ITM_R values, approximately 250% more compared to 0% active filler, 1% hydrated lime and 1% quicklime. Comparatively speaking, the addition of 1% hydrated lime and 1% quicklime contributed to an approximately 5% increase in ITM_R values compared with mixture without active filler, which was only a mild degree on stiffness improvement. When the percentage came up to 3%, all of the active fillers accounted for obviously significant increase in resilient modulus, among which hydrated lime demonstrated the biggest improvement with nearly five times compared to 1% content. After 5% active filler was added, both hydrated lime and quicklime illustrated slight improvement whilst cement still played a major role in stiffness gaining with the ITM_R value was over 1000MPa. It was therefore manifested that during the hydration process that was attributed to stiffness improvement, cement owned a much stronger and more active reaction capacity than either hydrated lime or quicklime.

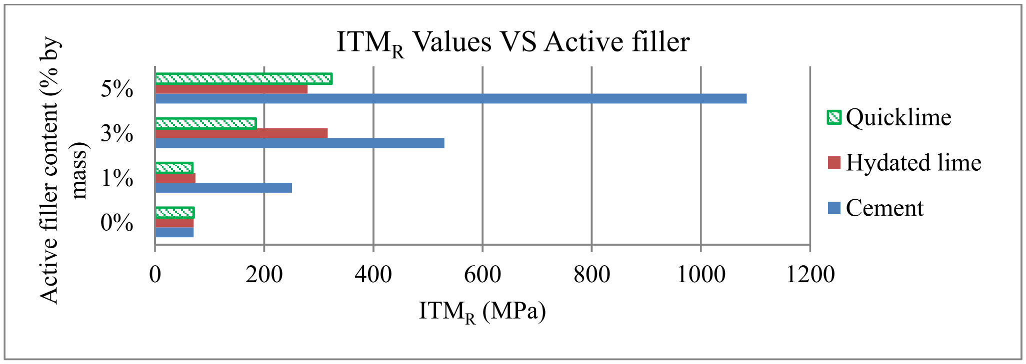

Fig. 2 ITM_R values for foamed bitumen materials with different active fillers

Indirect Tensile Strength Test

As can be seen from Fig. 3, all these three active fillers, regardless of the variant contents and types, contributed to the increase of tensile strength compared with mixes without active fillers. As the percentage of active fillers increased, so did the tensile strength, with cement always providing a significantly higher percentage increase compared with the other two counterparts: hydrated lime and quicklime. When comparison comes to the hydrated lime and quicklime, in the addition of 3% of active fillers, hydrated lime demonstrated a better tensile strength than quicklime but it was still very low compared to cement. When increasing the percentage to 5%, both fillers exhibited similar tensile strengths but again were very low compared to cement.

It was imperative to note that the addition of 5% of active fillers, proposed as an extreme case in this study, did exceed the amount suggested by previous research. Especially with cement, the treated samples became cementitious materials rather than foamed bitumen mixtures. Consequently, shrinkage cracking was likely to occur when the samples exhibited the cementitious properties even with a highest tensile strength, which should be avoidable in foamed bitumen treated materials.

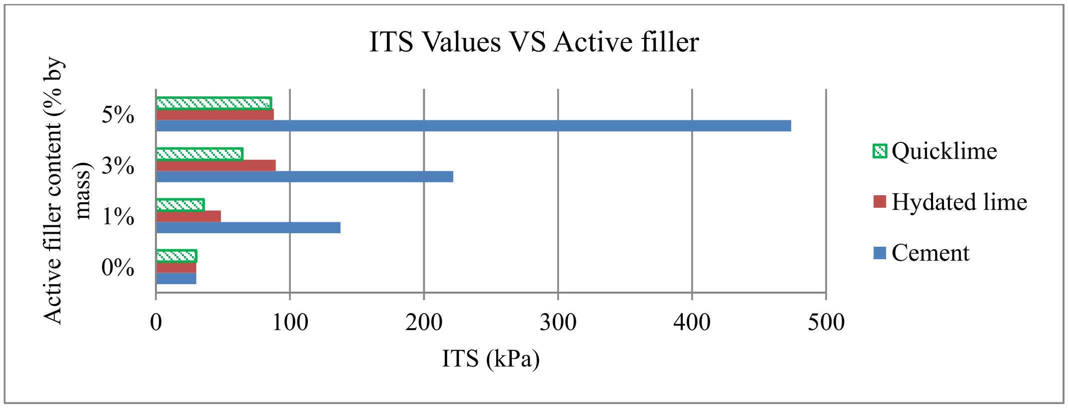

Fig. 3 ITS values for foamed bitumen materials with different active fillers

Unconfined compressive strength

From Fig. 4, it is evident that the strength of foamed bitumen treated mixtures increased with the addition of active fillers in different degrees. The increase in concentration contributed to a significant increase in compressive strength in some mixes like cement but not so much in hydrated lime and quicklime.

With the addition of 1% cement the maximum compressive strength increased by approximately three times in comparison to the original samples with no active filler content. Also, as the concentration of cement was increased, a significant increase in compressive strength was observed. When the concentration was increased to 5%, it can be seen that strength increased by approximately 15 times. However, it is also imperative to note that the 5% concentration of cement was higher than the bitumen content (4%), the mixture therefore was behaving like a cementitious material rather than a foamed bitumen treated mixture, which was more prone to cracking in the long term service.

Hydrated lime and quicklime shared similar effects on the compressive strength of the treated mixtures. It was important to find out that unlike cement treated mixtures, the increasing percentage of adding hydrated lime and quicklime seemed less reactive to the foamed bitumen treated mixtures. As can be noticed, since 3% of either hydrated lime or quicklime was added, only two times improvement of UCS values was observed and no apparent improvement was obtained even 5% active filler was supplied. It could lead to a conclusion that with regarding to UCS, 3% of hydrated lime or quicklime was sufficient.

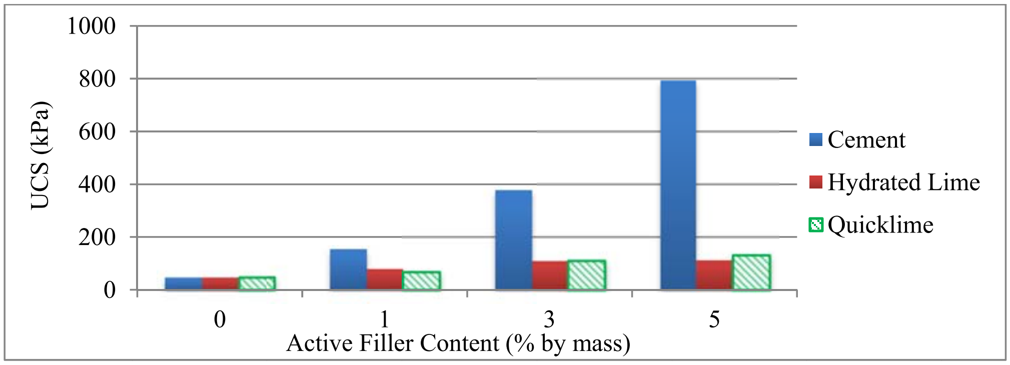

Fig. 4 UCS values for foamed bitumen materials with different active fillers

Conclusion

This study aimed to understand the mix parameters used in the production of foamed bitumen stabilised pavement in terms of mechanical strength and performance characteristics, considering one binder variable, active filler. Wirtgen bitumen foaming apparatus was utilised in this research to replicate pavement material produced in field application. Based upon the findings of this research the following conclusions have been drawn:

1) All active filler types except fly ash, contributed to the strength improvement of foamed bitumen mixtures at different levels.
2) A time and material wasting concern was made to discard fly ash after initial tests as fly ash on its own did not affect any mechanical strength of foamed bitumen mixes and instead it acted as mineral fillers to modify aggregate gradation.
3) Cement, regardless of adding contents, always provided the highest mechanical performance compared with the other two counterparts: hydrated lime and quicklime. It can be found that 3% cement was able to provide sufficient mechanical strengths in comparison to current base course performance. Although higher stiffness and strength can be obtained in relatively higher cement contents, a concern had been raised that when cement concentration was more than bitumen content, a cementitious properties was produced with the reduction of flexibility, thereby losing its designated purpose.
4) Hydrated lime and quicklime appeared to be less advantageous in comparison to cement but did contribute to the strength and stiffness improvement albeit at a lower degree than cement. No apparent strength improvement was found when adding content increasing from 3% to 5%.
5) It was feasible to equate the mechanical performance produced by 1% cement with 3% hydrated lime or quicklime, as derived from the results from this study.
6) It was difficult to quantify the optimum active filler content because it was highly dependent on the design criteria of the target performance for pavement construction. However, in this study, when mixing with 4% foamed bitumen content and locally sourced raw materials for base course, the addition of active filler content should be limited within 3% in terms of strength gain and potential cracking prevent.
7) In excessing of 3% cement content, 5% in this study was visually confirmed to transform foamed bitumen treated materials to become brittle and cementitious properties, which should be avoidable in foamed bitumen mix design. However, the reduction of flexibility in 5% of cement content needs to be experimental confirmation in further study.

Acknowledgement

Sincere and grateful thanks would be unreservedly expressed to the Curtin PRG for research assistance and facility support. The authors would also like to thank Mujtaba Hedayat, a final year student in Curtin University who assisted us to prepare and test the specimens.

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