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INITIAL INVESTIGATION ON THE USE OF OIL DRILL WASTE STABILIZED FOAMED BITUMEN AS PAVEMENT MATERIALS

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Abstract

This paper provides an overview in the use of foamed bitumen to stabilize oil drill waste soil. In this investigation, an attempting has been conducted in order to evaluate the stiffness modulus of the stabilized soil. This was included the usage of limestone crushed aggregates, hydrated lime and Portland cement in order to see their effect on the mixture performance. The mix protocol and composition of the stabilized mixture have also been proposed to obtain the optimum performance. Oil drill waste can be stabilized using foamed bitumen. With considering their strength, this material can be used as pavement materials. The drill wastes contained clay and oils seem to prevent the mixtures from bonding as effectively to the foam as limestone crushed aggregates, it is suggested that the drill waste should be treated first by hydrated lime prior mixing with foam. To achieve a more effective coating between the foamed bitumen and the aggregate particles, it is suggested to mix the foamed bitumen only with the rock dust. The resultant mixture can then be stored for reasonable periods (sealed up to 3 months) before being mixed with drill waste, hydrated lime and, optionally, coarse aggregate and/or Portland cement.

Keywords: oil drill waste, soil, foamed bitumen, stabilization, stiffness modulus.

1. INTRODUCTION

Foamed bitumen has increasingly gained acceptance as an effective and economical stabilization agent for pavement materials. It can potentially be used as a binder of cold mix asphalt. A wide variety of aggregate types from conventional high quality graded materials, reclaimed asphalt to marginal materials including soil can be stabilized using foamed bitumen (Lee, 1981; Muthen, 1999 and Millar and Nothard, 2004).

Foamed bitumen can be generated by injecting hot bitumen with a small amount of water. For example, if 250g of hot bitumen injected using 2.5g to 25 g of cold water (1-10% of bitumen mass) normally results in foam with a maximum volume around 6 to 42 times that of the bitumen. The ratio between maximum foam volume achieved and the volume of original bitumen is termed the maximum expansion ratio (ERm). The ERm value is mainly dependent upon the amount of water added, namely the foaming water content (FWC). ERm increases with higher FWC. After reaching its maximum volume, the foam dissipates rapidly accompanied by steam gas escaping. The time that the foam takes to collapse to half of its maximum volume is called the half life (HL). In the above example, HL would normally be between 27 to 10 seconds. After a particular time (around 60 seconds), the foam volume reduces very slowly and asymptotically.

Foamed bitumen enables the coating of wet aggregate particles at ambient temperature to form foamed cold mix asphalt for pavement materials. As is common for cold-mix

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asphalts, the strength of this material at early life develops with loss of moisture (Jitareekul et al, 2007 and Sunarjono, 2007). In a pilot scale project (Nunn and Thom, 2002), foamed asphalt at very early life exhibited stiffness typical of unbound material. In the field, the mixture developed to gain satisfactorily high stiffness levels within 6 months.

2. OBJECTIVE OF THE RESEARCH

The main objective of this research is to investigate the possibility of the use of oil drill waste stabilized foamed bitumen mixture as pavement materials such as a local road access, car park, foot path etc. The investigation includes the mix protocol, the composition of material component that giving the optimum performance, and the stiffness of the mixture.

3. MATERIALS USED

3.1 Oil Drill Waste

Properties of oil drill waste can be seen in Table 1, whereas Figure 1 is photograph of this drill waste.

Table 1. Properties of oil drill waste

Property	Result
State	Heavy saturated mud
Colour	Heavy brown
Initial water content	30 %

Figure 1. Oil drill waste

3.2 Limestone Crushed Aggregate

Figure 2 shown the photograph of limestone crushed aggregates used in this investigation. This aggregate was collected and stored separately in six stockpiles according to the following sieves: 20 mm, 14 mm, 10 mm, 6 mm, dust and filler. The initial water content varied between 1 and 2 %. The aggregates were then dried prior use to obtained homogenous dry condition. The intake colour is light brown in the dry condition. Figure 3 shows the gradation of the aggregate used included the specification limit for foamed asphalt, design for 20mm and 10mm.

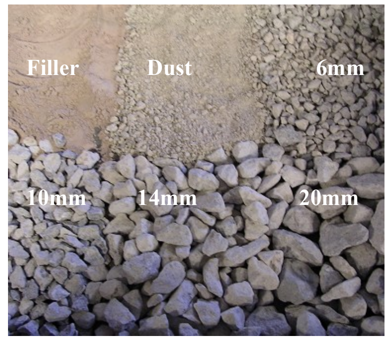

Figure 2. Limestone crushed aggregates

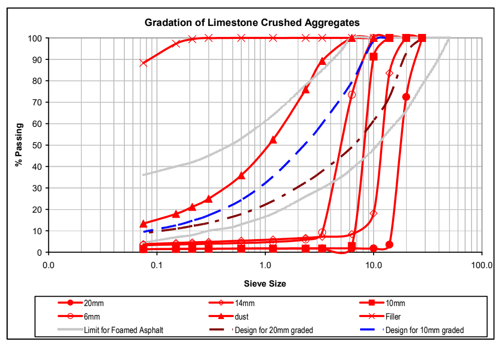

Figure 3. Gradation of Limestone Crushed Aggregate

3.3 Foamed Bitumen

In this investigation, penetration grade bitumen pen 15 and pen 50 were selected for the production of foamed bitumen. Basic properties of the bitumen including penetration, softening point, and viscosity was determined and the results are presented in Table 2.

Figure 4 presents the foamed bitumen characteristics at foaming temperature of 180 °C. It can be seen that if foaming water increase, the ERm increase and the HL tends to decrease. Wirtgen (2005) recommends a minimum expansion ratio of 8 times and half-life of 6 seconds. In this study, foaming water of 2.0% was selected to create the most stable foam. The corresponding maximum ER and HL values were 13.5 times and 7 s (for bitumen pen 50) and 11 times and 12 s (for bitumen pen 15).

Table 2. Basic properties of bitumen

Property	Pen 15	Pen 50
Penetration (0.01 mm)	15	49
Softening point (°C)	-	52.2
Specific gravity	-	1.024
Viscosity @ 180 °C (mPa s)	-	83

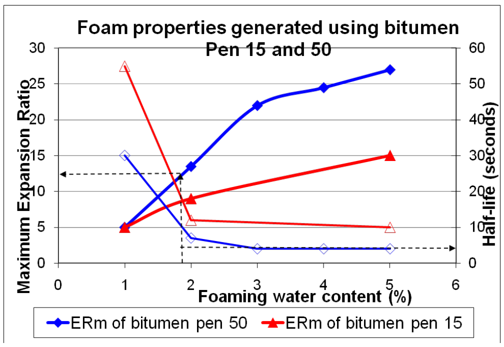

Figure 4. Foam characteristics of bitumen pen 15 and 50 at foaming temperature 180°C

4. WORK PROGRAM

All works were broken down into 20 batches (B-1 to B-20) with following purpose:

B-1 to B-7	to understand how the drill waste stabilised foamed bitumen mixture works and what the optimum mixture composition
B-8 to B-10	to evaluate the performance of limestone crushed dust (LCD)-foamed asphalt mixture which is used as a target of drill waste mixture.
B-11 to B-17	to evaluate the drill waste stabilised foamed bitumen performance in which foam is just sprayed onto limestone dust prior mix with drill waste and other materials (hydrated lime, cement and coarse aggregate)
B-18 to B-20	to evaluate the drill waste stabilised foamed bitumen performance which uses coarse aggregates (> 5mm)

5. RESULTS AND DISCUSSION

All blends were mixed with sprayed foam for approximate 1- 2 minutes. For hand mixing, the time was justified to achieve homogenous mixing.

All ITSM (Indirect Tensile Stiffness Modulus) testing were conducted referring to BS DD 213 (1993):

• Test temperature	: 20°C (with option 5°C and 40°C)
• Rise time	: 124 ± 4 ms
• Horizontal deformation	: 5 ± 2 μm (for diameter 100mm)
• Poisson's ratio	: 0.35

5.1 Work-1 (B-1 to B-7)

Figure 5 shows the investigation result of the composition between Drill Waste (DW) and Limestone Crushed Dust (LCD). There indicates that for specimens with composition DW: LCD = 1: 2, their stiffness was too low. This is because the material is too wet and also the nature properties of DW cannot be stabilised directly by foamed bitumen. Whilst the composition DW: LCD of 1:3 and 1:4 exhibit better performance and can be considered for further investigation.

Figure 6 shows effect of curing time on the stiffness of specimens. The specimens that have been tested after oven curing at 40°C for 3 days was cured more for another 40°C for 3 days. From this figure, it can be seen that effect of this additional curing was very significant. This means that for DW-foamed asphalt mixture that contain fine aggregates need longer curing time to allow most of the liquid and water evaporate. It can also be considered with apply oven curing at 60°C to accelerate the evaporation.

Figure 7 shows the effect of foamed bitumen content (FBC) on mix stiffness. The trend appears inconsistent due to mix protocol of these 3 specimen types is different. At FBC 3% the specimens performed lower stiffness than at FBC 2% and 3.5%. Specimens at FBC 2% and 3.5% exhibit comparable but the specimens at FBC 2% demonstrate more consistent. It is predicted that half-life (HL) work more effective at lower FBC and enhance the stiffness. In other hand, foamed bitumen does not work effectively when they are sprayed directly onto DW since the stiffness exhibit low.

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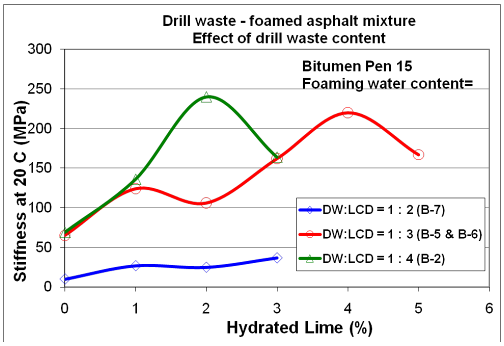

Figure 5. Effect of hydrated lime and mixture composition

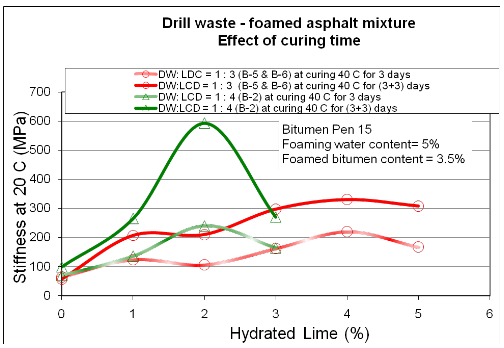

Figure 6. Effect of curing time at different mixture composition

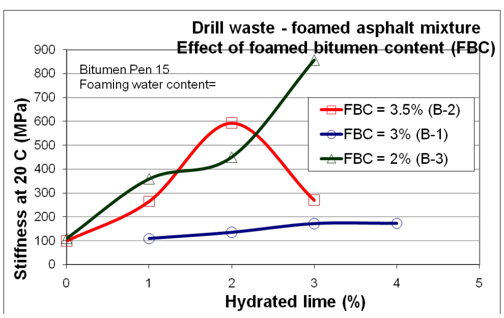

Figure 7. Effect foamed bitumen content (FBC)

5.2 Work-2 (B-8 to B-10)

The result of investigation work-2 was presented in Figure 8. This is the performance of limestone crushed dust (LCD)-foamed asphalt mixture. These specimens use 100% limestone aggregates, no DW included.

From Figure 8, the foam in the specimens with FBC 4.5% was dispersed but the effect of foam is masked by the effect of the LCD, hence in Figure 8, the specimens do not appear as bituminous materials. In all cases the specimens were light brown in colour and very dry appearance indicating inadequate quantity of foamed bitumen. The stiffness of cured samples in Figure 8 does not appear to change with changing test temperature which indicates that the binder is not effective in controlling mix stiffness, i.e. binder is not continuous phase.

Therefore the specimens with same gradation was attempted to be mixed with 10% foam content but the mixture was impossible to mix and hence optimum foam content was arrived at 7% bitumen content. At 7% the mixture stiffness was a function of test temperature as shown in Figure 8 which shows continuity of binder in the aggregate matrix. Furthermore, the stiffness values were improved compared to Figure 5, Figure 6 and Figure 7.

From this work, it can be noted that DW stabilised foamed bitumen should be improved with minimum stiffness (temperature test of 20°C) around 1000 MPa (as result of B-8). The target of the DW mixture strength may as high as 2500 MPa (as result of B-10).

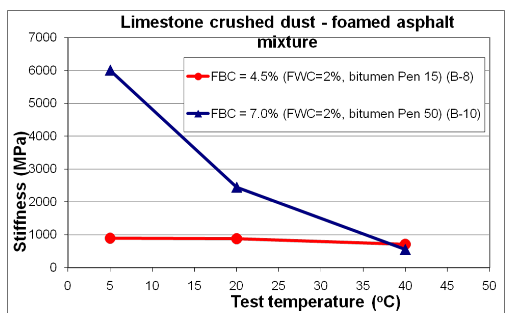

Figure 8. Performance of limestone crushed dust (LCD)-foamed asphalt mixture

5.3 Discussion of Work-1 and Work-2 Results

Because the Drill waste contains oil and clay, the waste cannot absorb foamed bitumen as well as limestone crushed dust. Evidence: visually all the specimens in Work-1 (Figure 5, Figure 6 and Figure 7) have a darker / blacker colour/appearance than specimens with FBC 4.5% in Work-2 (Figure 8), which means the foamed bitumen can be seen in specimens of Figure 5, Figure 6 and Figure 7 but not in Figure 8.

When 5% foamed bitumen was sprayed to blending with composition DW: LCD= 1:4, the mixtures became too difficult to mix and too stiff, and then more LCD had to be added to produce mixture with reduced bitumen content (3%) shown in Figure 7. Additionally, specimens in Work-1 suffer from bleeding following compaction and during the oven curing process. This is not the case for specimens in Work-2.

In conclusion, the drill waste cannot be combined directly with foamed bitumen, it is better to add hydrated lime to the drill waste (thus converting the drill waste into a dry powder which behaves similar to the filler in Work-2) prior to adding the foam.

In Work-1 all specimens (except B-6) the hydrated lime was added after the pre-wetting water and foam were introduced into the mix.

In general from Work-1, it is evident that increasing the proportion of crushed sand to drill waste will produce cured specimens with higher ITSM values.

Blending drill waste to dust in the ratio of 1:2 (B-7 in Figure 5) generates very low ITSM results (all < 50MPa). Increasing the waste to dust ratio to 1:3 improves the stiffness but the values still low (<350MPa) (Figure 5). Also adding lime up to 5% has not improved the ITSM values significantly.

Curing specimens at 3 days (40^{o}C) was found not to be sufficient to fully dry the specimens. An additional 3 days curing at 40^{o}C were introduced (total = 6 days at 40^{o}C) to ensure better drying.

Increasing the drill waste to dust ratio even further to 1:4 (i.e. reducing the ratio of drill waste) causes an increase in ITSM up to nearly 800MPa (at HL 3% and FBC 2%) as shown in Figure 7 (B-3).

Compared to the rest of the mixes of B-1, the mixtures produced low ITSM results (<130 MPa at 40^{o}C for 3 days) which can be explained by mixing procedure of B-1 (the initial 5% foam was introduced on to a smaller amount of crushed sand and then the remainder of the sand was added, which meant that binder dispersion was not correct).

Overall, the discussion of Work-1 and Work-2 results imply that for optimum mix performance when using drill waste, the suggestions for further work are following:

- Use foam-dust (FD) system by means foam is only sprayed and mixed onto limestone crushed dust (LCD). Therefore the FD can be mixed later with other components.
- Introduce the hydrate lime (HL) to the drill waste prior to mix with the foam-dust.
- Cure specimen at higher temperature or longer time
- Investigate using more hydrated lime (HL)
- Investigate using ordinary Portland cement (OPC)
- Investigate using coarse aggregate (> 5mm)

5.4 Work-3 (B-11 to B-17)

All specimens were cured at 60^{o}C for 3 days prior performed ITSM testing. Testing was also carried out for all specimens after additional 3 days curing at same temperature.

Effect of adding hydrated lime (up to 9%), adding of cement (up to 3%) and foamed bitumen content (up to 9.6%) were discussed in this work. All results are presented in Figure 9, Figure 10 and Figure 11.

In Figure 9, curve of B-5 & B-6 (Work-1) and B-11 (Work-3) demonstrated the effect of HL on the specimens with composition DW: LCD = 1: 3 and FBC 3.5%. The stiffness values increase with increase of HL. It can be approached that for 1% incremental of HL, stiffness increases

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around 75 MPa. However when using higher FBC (5.2%) the stiffness tends to decrease. When using composition DW: LCD = 1: 4 at FBC 5.6%, the stiffness increase and comparable to specimens B-11. This means that adding HL causes increase their stiffness with dependent upon composition and FBC. However, it should be noted that all stiffness values was still less than 1000 MPa.

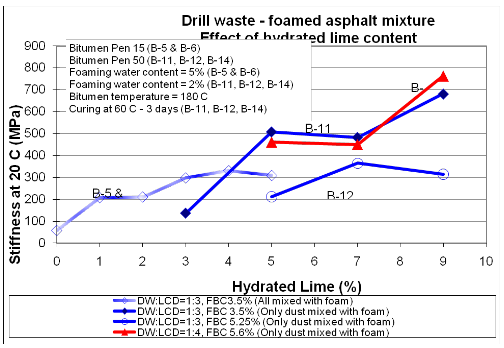

Figure 9. Effect of hydrated lime content at different mixture composition

Adding cement on specimens was purposed to increase their stiffness values and improve the performance at early life. Figure 10 shows the stiffness of cured specimens when cement was added up to 3%. From the figure, it is clear that cement has effect significantly. The cement effect varied with foam content. The highest value was 1350 MPa (B-15 at 3% cement). At higher foam content the increasing of stiffness tends to be less. The increasing rate of cement effect can be seen on specimens of B-14 & B-15. From the curve, increasing cement from 0 to 1% has higher rate (around 600 MPa) than from 1 to 3% (around 100 MPa per 1% cement). When these specimens were cured for another 3 days, their stiffness still increased. This means the stiffness still increase with extending time even it should consider effect of ageing.

Figure 11 shows effect of foamed bitumen content (FBC) on the stiffness of specimens with and without cement. It is clear that in the full range of FBC, the optimum value can be obtained. On the specimens without cement (B-14 & B-17), the optimum FBC was around 6-7 %, whereas for specimens with 2% cement (B-15 & B-16) the optimum FBC should be less than 6%.

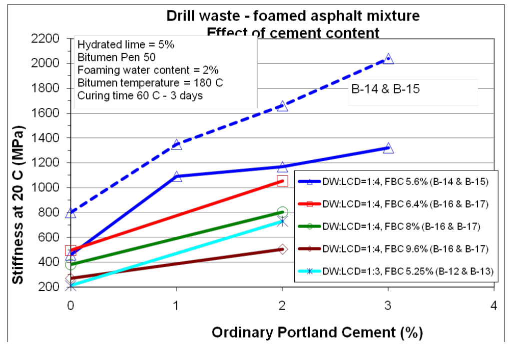

Figure 10. Effect of Ordinary Portland cement (OPC) at different mixture composition

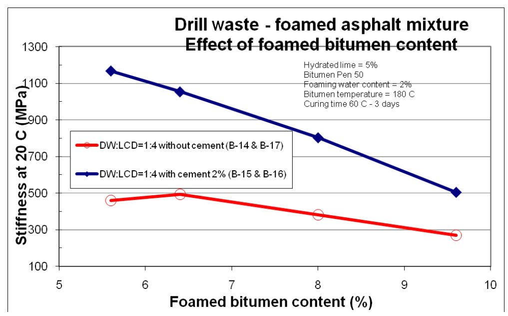

Figure 11. Effect of foamed bitumen content (FBC)

5.5 Work-4 (B-18 to B-20)

The work-4 was designed to evaluate DW stabilised foamed bitumen performance which uses coarse aggregates (> 5mm). In this work, FD (Foam-Dust) system was still adopted. The limestone crushed coarse aggregates (LCCA) were introduced together with DW and other materials. The results can be seen in Figure 12.

At the first work, a 20mm graded aggregate was used (B-18). The mixing protocol was similar to Work-3. A moist dust fraction was mixed first with foam. This FD material was then mixed with DW (drill waste), HL (hydrate lime), OPC (Ordinary Portland Cement) and LCCA. From figure, it can be seen that the stiffness was very low even they was cured longer. These values were as low as the specimens without coarse aggregates as shown in Figure 12 (B-14 and B-15). Two reasons were identified i.e. their grading was not appropriate and the foam that only dispersed on the dust fraction was not enough to bind the DW and big stones.

Then the nominal size of LCCA was reduced to become 10mm. As shown in Figure 12, the stiffness value dramatically increases up to 1200 MPa. When cement was added, their value also increases significantly up to 1650 MPa (OPC= 1%) and 1900 MPa (OPC= 2%). When these specimens were cured longer their stiffness little bit increase and better at higher cement content.

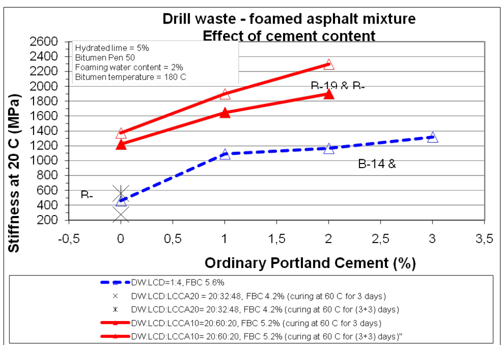

Figure 12. Effect of Ordinary Portland cement content

6. CONCLUSIONS

Based upon the results and observations in this investigation, with limited data, the following conclusions and recommendations can be drawn:

- Oil drill waste can be stabilised using foamed bitumen. With considering their strength, this material can be used as pavement materials.
- Due to the drill waste contains oil and clay that cause it cannot absorb foam as well as limestone crushed aggregate, it is suggested that the drill waste should be treated first by hydrated lime prior mixing with foam. The amount of hydrated lime can be adjusted by considering the wetness of the waste (in this study hydrated lime content of 5% was achieved a workable mixing).
- To get more effective coating between foam and particles, it is suggested to mix foam only on the aggregates. The mixing result can be stored for reasonable period (up to 3 months) or directly mixed with drill waste, hydrated lime and cement (optional).
- According to use coarse aggregate in drill waste – foamed asphalt mixture, it is recommended to use the well 10mm graded aggregate.
- There are 3 options in according the use of cement i.e. without or with cement (1 or 2%). This study does not recommend using 3% cement due to the foam material will be too rigid and has risk cracking. The content of cement and foam should be considered together in order to obtain the optimum mixture by means of the strength and flexibility.

So far, the following table are the optimum mixture performance.

Materials Alternative	Composition *1*	*2*	*3*
Portland cement	0 %	1 %	2 %
Drill waste	20 %	20 %	20 %
Limestone crushed dust (< 5mm)	51 %	50 %	49 %
Limestone coarse aggregate (5-10 mm)	20 %	20 %	20 %
Hydrated lime	4 %	4 %	4 %
Bitumen Pen 50 (foaming water content 2%)	5 %	5 %	5 %
Cured stiffness at 20°C (MPa)	1200	1600	2000

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