ALAKONA CORPORATION

HAWAII

FOAMED BITUMEN MIX DESIGN REPORT

AUGUST 2008

PREPARED BY

LOUDON INTERNATIONAL

FOAMED BITUMEN MIX DESIGN REPORT

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ALAKONA CORPORATION – HONOLULU, HAWAII

ASSESSMENT OF FOAMED BITUMEN STABILISED MATERIALS

1. INTRODUCTION

As part of their effort to promote “Green Technology”, Alakona Corporation has recently purchased a Wirtgen KMA220, foamed bitumen stabilisation static plant. The KMA220 allows for materials and blend of materials of controlled quality and gradation to be stabilised with predetermined amounts of foamed bitumen to produce high quality bitumen stabilised material. This stabilised material can be stockpile for 1 to 2 months or used immediately to construct exceptional flexible pavement bases.

The use of bitumen stabilised bases are becoming more popular throughout the world. Previously the base materials were stabilised with emulsions but with the advent of the Wirtgen Recycling machinery, the use of foamed bitumen as a stabilizing agent has gained in popularity.

This report details the mix design procedure and mix design results carried out on various materials and blend of materials. The report also recommends optimal foamed bitumen and active filler contents together with Structural Coefficients for each of the stabilised materials tested.

2. DESCRIPTION OF WORK UNDERTAKEN

Alakona Corporation is making a concerted effort to produce stabilised base materials that can be used parking areas, residential roads to State highways.

One of the by-products of conventional road recycling (mill and replace) is the Reclaimed Asphalt Pavement (RAP). This product is normally freely available in abundant quantities and was therefore used in the test programme.

The other abundant material on the island is granular Coral. The mix designs tested both materials and also blends of the materials. For the 100% RAP mixes the added filler was varied to determine the effect of the fillers available. The initial mix designs were as listed below;

Design Set 1: 100% RAP with 3 types of fillers

- Mix Design 1 100% RAP + 1% cement
- Mix Design 2 100% RAP + 1% rock dust
- Mix Design 3 100% RAP + 1% coral dust

Design Set 2: Blends of RAP and granular Coral

- Mix Design 4 90% RAP + 10% Coral + 1% cement
- Mix Design 5 80% RAP + 20% Coral + 1% cement
- Mix Design 6 100% Coral + 1% cement

3. FOAMED BITUMEN MIX DESIGN PROCEDURES

Bulk samples of material from both the existing milled and crushed asphalt stockpile (RAP) and granular Coral stockpile were obtained. These samples were transported to the Alakona facility in Mapunapuna where the Wirtgen WLB10 laboratory foamed bitumen unit was located. The Wirtgen WLB10 unit a laboratory scale unit which produces foamed bitumen of similar quality to the larger recyclers. The unit is coupled with a pug-mill type mixer and together these units produce stabilised mixes of equal quality to that produced during recycling.

Laboratory tests were conducted on the RAP sample and the sieve analysis showed a lack of fine material (passing #200) for the RAP. This is a common phenomenon with RAP and generally 2-4% fines are normally available. RAP has an added advantage over natural granular materials in that the foamed bitumen has sufficient energy to heat and adhere to the existing bitumen in the RAP. Therefore with 100% RAP the 5% fines requirement can be waived. The fines content of the granular coral is well above the minimum 5% requirement.

The mix designs are carried out to determine the optimal application rate for foamed bitumen and the need for an active filler (cement). In addition, the strength achieved from stabilization is used as the primary indicator of effective stiffness (resilient modulus) for use in the structural design exercise. The mix designs were carried out in accordance with the procedures shown in Appendix A2 of the Wirtgen Cold Recycling Manual, 2nd Edition, 2004.

Base on the relative coarseness of the material, the guidelines in the 2nd Edition of the Wirtgen Cold Recycling Manual were followed in estimating the approximate percentage of foamed bitumen required to stabilise each material and the following ranges selected:

- 2.0%, 2.25% and 2.5% (by mass) to the RAP material;
- 2.25%, 2.5%, and 2.75% (by mass) for the RAP:Coral blends; and
- 3.0% (by mass) for the 100% Granular Coral.

All mix designs included 1% cement as an active filler. In addition to increasing the percentage dust (fraction passing the 0.075mm sieve), such active filler is critical for the proper dispersion of the foamed bitumen and improving the strength retained under saturated conditions. In addition the 100% RAP was tested with 1% rock dust and also 1% coral dust in lieu of the 1% cement.

Six 10cm diameter briquettes were manufactured from each mix of foamed bitumen stabilised material by applying standard “Marshall” compaction effort. The briquettes were then placed in an oven at 40°C for three days (72 hours) to cure (remove all moisture).

The briquettes were then tested for dry and soaked Indirect Tensile Strength (ITS). The soaked ITS strength and retained strength was used as the criterion for selecting the optimum bitumen content for each mix.

The full test method is shown in Appendix B to this report.

4. ASSESSMENT OF STABILISED MATERIALS

4.1 Design Set 1

The intention with this set of designs was to test the sensitivity of the 100% RAP material to different available fillers.

A summary of the results of these tests are shown in Table 1 below.

Table 1: Summary of Mix Designs with 100% RAP									
Design Number	Mix Design 1			Mix Design 2			Mix Design 3		
Percent Foamed Bitumen	2.0	2.25	2.5	2.0	2.25	2.5	2.0	2.25	2.5
Percent and Type of Filler	1% Cement			1% Rock Dust			1% Coral Dust		
ITS_{DRY} (kPa)	347	353	347	315	322	304	302	390	293
ITS_{SOAKED} (kPa)	244	231	252	73	107	102	75	121	103
Retained ITS	70	65	73	23	33	34	25	31	35
Bulk Density (kg/m^3)	2183	2116	2187	2203	2239	2178	2152	2229	2143

The results in Table 1 indicate that the rock dust and coral dust do not assist with improving the soaked strengths of the RAP material. The ITS_{DRY} strengths for all designs are virtually the same indicating once again that the cement is not acting as a cementing agent but as a dispersing agent.

The following stabiliser percentages are recommended for the 100% RAP material;

- minimum **2% foamed bitumen;** and
- maximum **1% cement.**

The Structural Layer Coefficient, as determined in accordance with Figure A3.2 in the 2nd Edition of the Wirtgen Cold Recycling Manual, for the foamed bitumen stabilised RAP material is **0.28 per inch.**

The Structural Layer Coefficient can be increased by improving the gradation of the crushed RAP. An increase of finer material #200 to #4 should improve the compaction properties of the material thereby reducing the void content which in turn will render the compacted material less susceptible to moisture ingress.

The recommended compaction of the foamed bitumen stabilised RAP is;

- 100% of modified AASHTO for lightly trafficked areas; and
- 102% of modified AASHTO for heavily trafficked areas.

4.2 Design Set 2

These designs were carried out to assess the performance of RAP blended with varying percentages of natural granular Coral. All tests were carried out with 1% cement as the dispersing agent.

A summary of the results of these tests are shown in Table 2 below.

Table 2: Summary of Mix Designs with RAP and Coral Blends									
Design Number	Mix Design 4			Mix Design 5			Mix Design 6		
Material Blend	90% RAP : 10% Coral			80% RAP : 20% Coral			100% Coral		
Percent Foamed Bitumen	2.25	2.5	2.75	2.25	2.5	2.75	2.5	2.75	3.0
Percent and Type of Filler	1% Cement			1% Cement			1% Cement		
ITS_{DRY} (kPa)	319	406	407	369	375	308			509
ITS_{SOAKED} (kPa)	255	340	321	205	277	238			239
Retained ITS	80	84	79	55	74	77			47
Bulk Density (kg/m^3)	2169	2190	2187	2107	2171	2161			2942

The 90% RAP : 10% Coral illustrates the improvement in strength with an improvement in the gradation of the material but using Coral to improve the gradation increases the optimum foamed bitumen content.

Increasing the Coral content to 20% again reduces the soaked strength to that of the 100% RAP due to the increased uncoated granular content.

At 100% Coral the dry strength is well above that of the RAP:Coral blends but the soaked strength is similar to those achieved with the blends. The increased dry strength could be attributed to a possible cementing action due to the plasticity of the material.
Based on the above results the following recommendations can be made;

- For more important roads, municipal and state roads with high volumes of heavy traffic, the Coral content should be limited to 10% and the recommended stabiliser contents are **2.5% foamed bitumen + 1% cement.**

- For less important roads, cumulative traffic less than 1 million ESAL's, the Coral content can be increased with the following recommended stabiliser contents;

    1. Coral content up to 20% - **2.5% foamed bitumen + 1% cement**
    2. Coral content up to 100% - **3.0% foamed bitumen + 1% cement**
       (mix designs should be done at 50% RAP : 50% Coral and 25% RAP : 75% Coral to check if the bitumen requirement can be lowered, if these blends are to be used).

The Structural Layer Coefficient, as determined in accordance with Figure A3.2 in the 2nd Edition of the Wirtgen Cold Recycling Manual, for the foamed bitumen stabilised material blends are

- 90% RAP : 10% Coral blend **0.3 per inch;** and

- Higher percentages of Coral **0.27 per inch.**

Although the 100% Coral has a high dry strength, the retained strengths are well below what would be recommended for a region like Hawaii. Based on the soaked strength the dry strength has to be 320 kPa or less to achieve the recommended retained strength of 75%. Therefore the value of 320 kPa was used to estimate the Structural Layer Coefficient.

The recommended compaction of the foamed bitumen stabilised 90% RAP : 10% Coral is;

- 100% of modified AASHTO for lightly trafficked areas; and
- 102% of modified AASHTO for heavily trafficked areas.

and for the higher percentages of Coral

- 98% of modified AASHTO for lightly trafficked areas; and
- 100% of modified AASHTO for heavily trafficked areas.

5. SUMMARY OF RECOMMENDATIONS

The recommended stabilizer percentages and compaction requirements are summarized in Table 3 below.

Table 3: Summary of Requirements

MATERIAL	STABILIZER REQUIREMENTS		MATERIAL REQUIREMENTS	
	Percent Foamed Bitumen	Percent Cement	Minimum Compaction	Minimum ITS_{DRY}
100% RAP	2.0	1.0	102	280
90% RAP : 10% Coral	2.5	1.0	100	320
80% RAP : 20% Coral	2.5	1.0	100	280
100% Coral	3.0	1.0	98	250

K. SHUNMUGAM
LOUDON INTERNATIONAL

Boudon International	KMA using RAP Stockpile	FOAMED BITUMEN MIX DESIGN REPORT

Sample Number : ..... Date 04-Aug-08

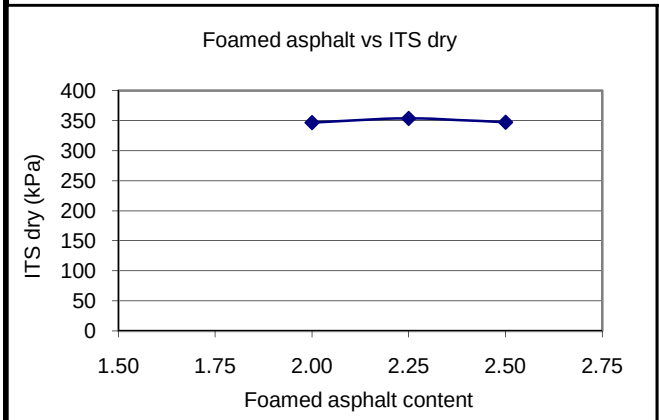
Material to be foamed	Aggregates	Bitumen	Filler
Location / Source:	Ex Stockpile		
Description	RAP		Cement

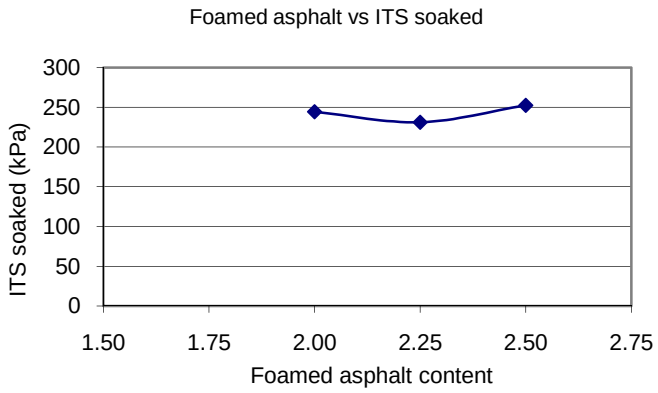
Foamed bitumen requirements

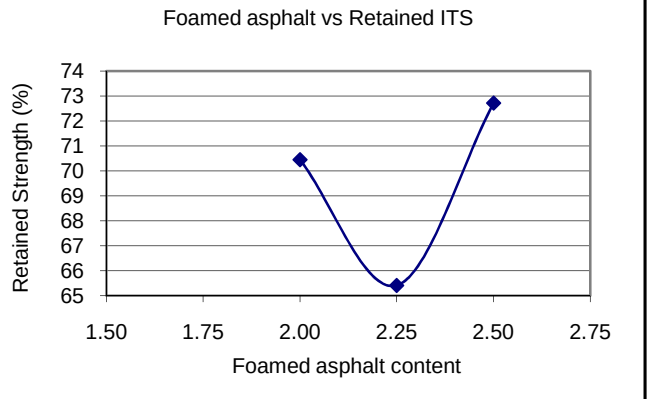
Percentage "foaming" water :	2.5	Temperature of bitumen:	160°C

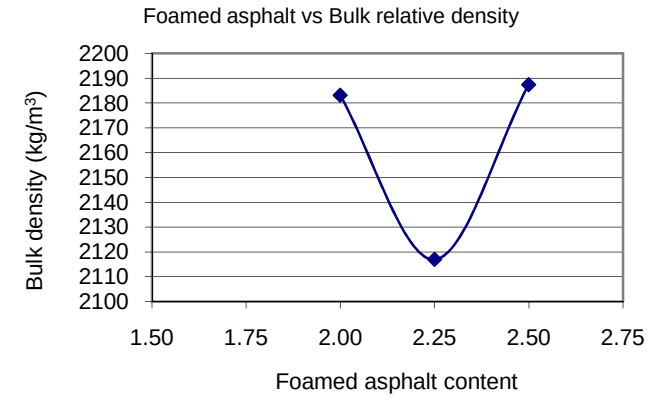
Foamed asphalt treated material characteristics

Foamed bitumen added :	2.00	2.25	2.50	
Type and Percentage Filler	1% Cement	1% Cement	1% Cement	
Diameter of specimen (mm)	101.0	101.0	101.0	
Height of specimen (mm) :	62.9	65.0	62.6	
Mass of specimen (g) :	1100.1	1102.8	1098.1	
Bulk density (kg/m^3):	2183.2	2116.9	2187.4	
ITS dry (kPa):	347	353	347	
ITS soaked (kPa):	244	231	252	
Retained ITS (%):	70	65	73	









Boudon International	KMA using RAP Stockpile	FOAMED BITUMEN MIX DESIGN REPORT

Sample Number : Mix 2 Date 04-Aug-08

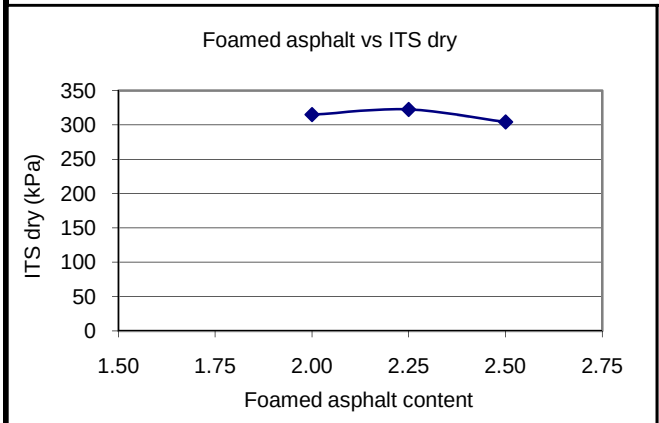
Material to be foamed	Aggregates	Bitumen	Filler
Location / Source:	Ex Stockpile		
Description	RAP		Rock Dust

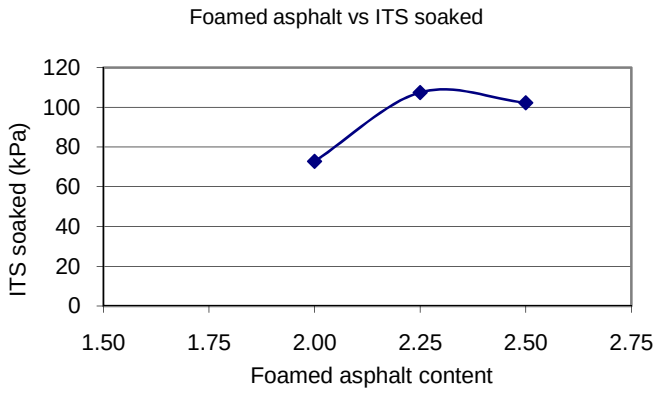
Foamed bitumen requirements

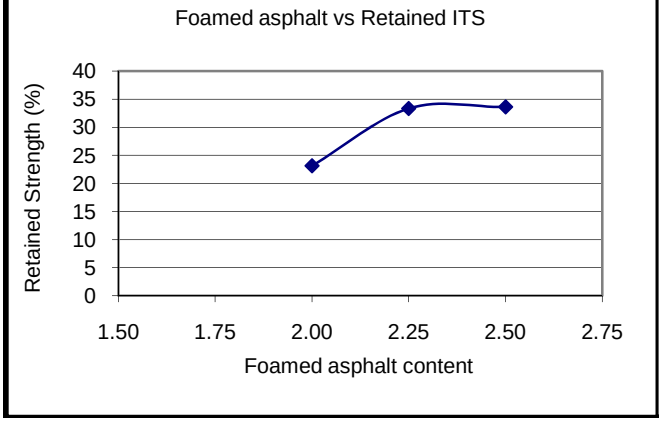
Percentage "foaming" water :	2.5	Temperature of bitumen:	160°C

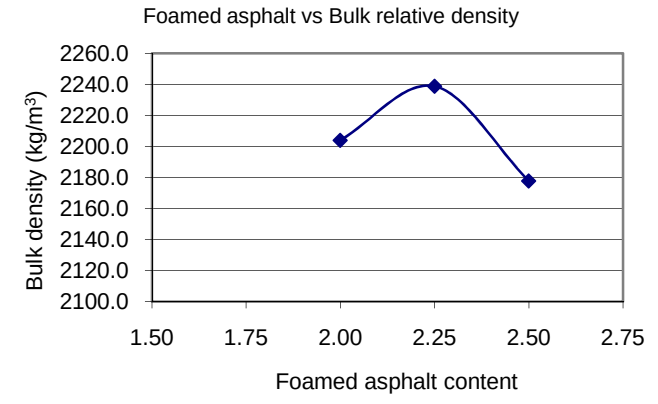
Foamed asphalt treated material characteristics

Foamed bitumen added :	2.00	2.25	2.50	
Type and Percentage Filler	1% Rock Dust	1% Rock Dust	1% Rock Dust	
Diameter of specimen (mm)	101.0	101.0	101.0	
Height of specimen (mm) :	62.3	60.8	63.2	
Mass of specimen (g) :	1100.8	1091.6	1103.4	
Bulk density (kg/m^3):	2203.9	2238.7	2177.7	
ITS dry (kPa):	315	322	304	
ITS soaked (kPa):	73	107	102	
Retained ITS (%):	23	33	34	









Boudon International	KMA using RAP Stockpile	FOAMED BITUMEN MIX DESIGN REPORT

Sample Number : ..... Date 04-Aug-08

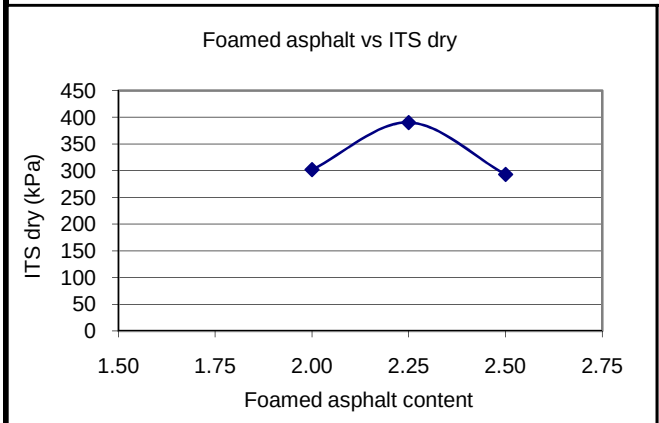
Material to be foamed	Aggregates	Bitumen	Filler
Location / Source:	Ex Stockpile		
Description	RAP		Coral Dust

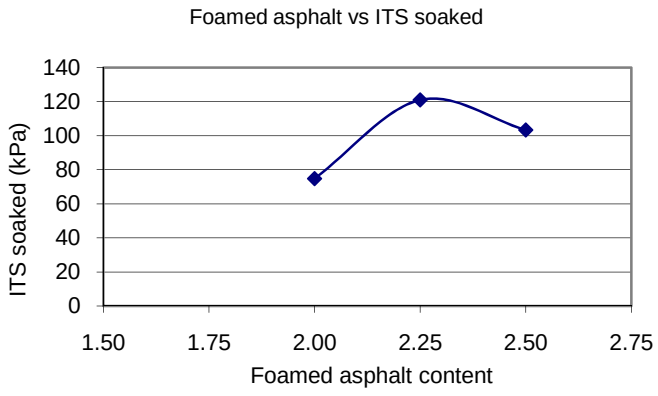
Foamed bitumen requirements

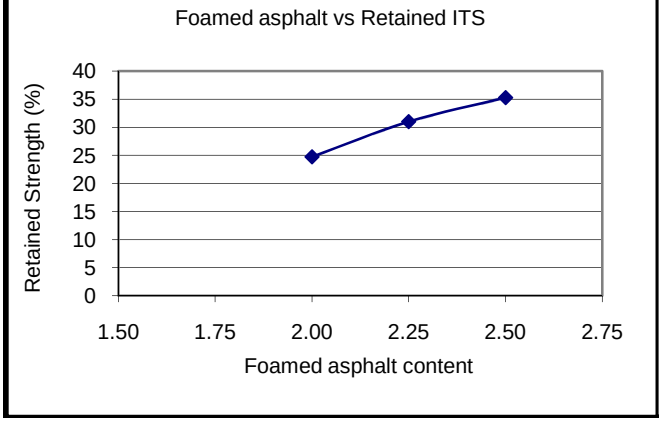
Percentage "foaming" water :	2.5	Temperature of bitumen:	160°C

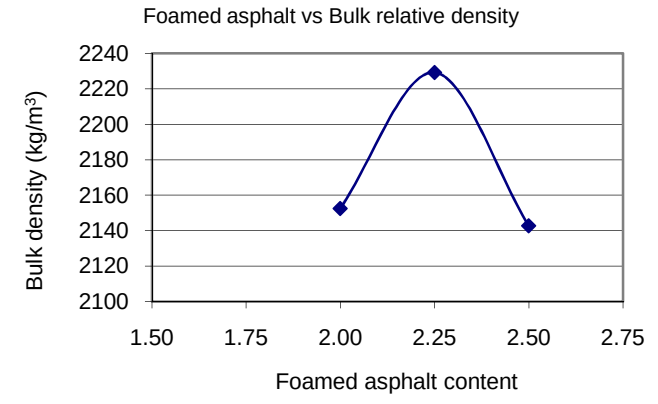
Foamed asphalt treated material characteristics

Foamed bitumen added :	2.00	2.25	2.50	
Type and Percentage Filler	1% Coral Dust	1% Coral Dust	1% Coral Dust	
Diameter of specimen (mm)	101.0	101.0	101.0	
Height of specimen (mm) :	64.0	61.7	64.4	
Mass of specimen (g) :	1103.9	1102.0	1105.3	
Bulk density (kg/m^3):	2152.5	2229.3	2142.8	
ITS dry (kPa):	302	390	293	
ITS soaked (kPa):	75	121	103	
Retained ITS (%):	25	31	35	









Loudon International	KMA using RAP Stockpile	FOAMED BITUMEN MIX DESIGN REPORT

Sample Number : ..... Date 01-Aug-08

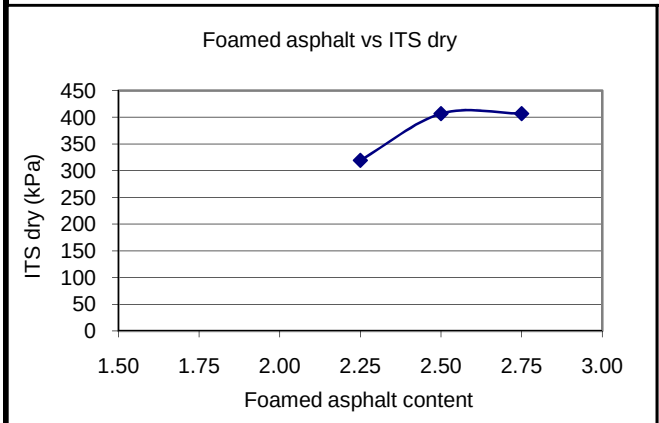
Material to be foamed	Aggregates	Bitumen	Filler
Location / Source:	Ex Stockpile	Tesoro	
Description	90%RAP + 10%Coral Gravel	PG 64-16	Cement

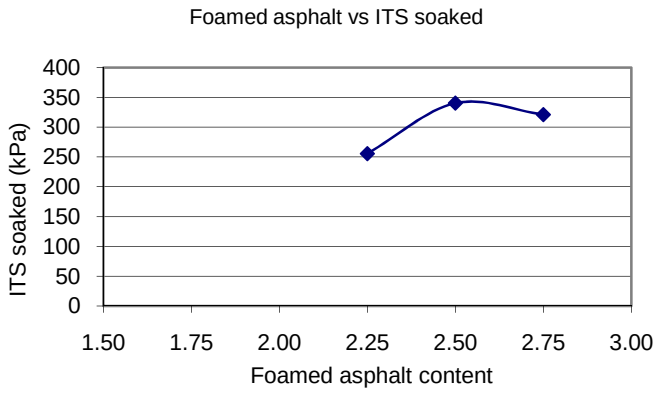
Foamed bitumen requirements

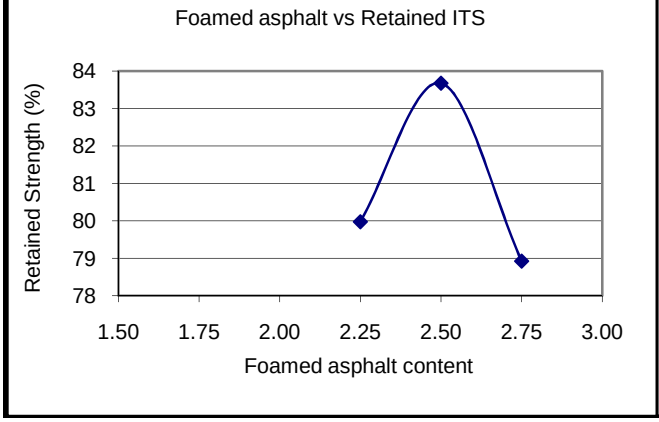
Percentage "foaming" water :	2.5	Temperature of bitumen:	160degC

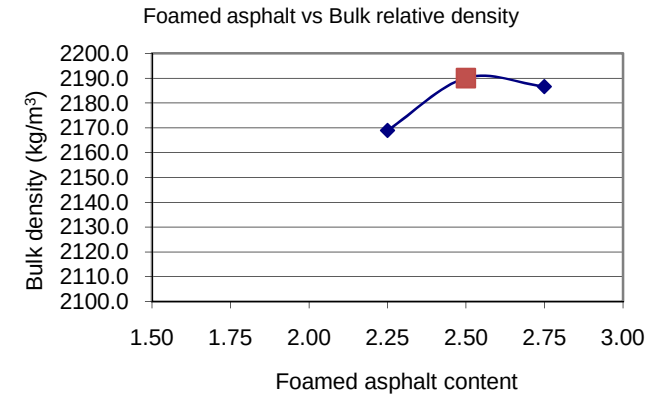
Foamed asphalt treated material characteristics

Foamed bitumen added :	2.25	2.50	2.75	
Type and Percentage Filler	1% Cement	1% Cement	1% Cement	
Diameter of specimen (inch)	101.0	101.0	101.0	
Height of specimen (inch) :	62.8	62.3	62.5	
Mass of specimen (lb) :	1092.3	1093.3	1094.6	
Bulk density (lb/ft^3):	2168.9	2190.1	2186.6	
ITS dry (kPa):	319	406	407	
ITS soaked (kPa):	255	340	321	
Retained ITS (%):	80	84	79	









Loudon International	KMA using RAP Stockpile	FOAMED BITUMEN MIX DESIGN REPORT

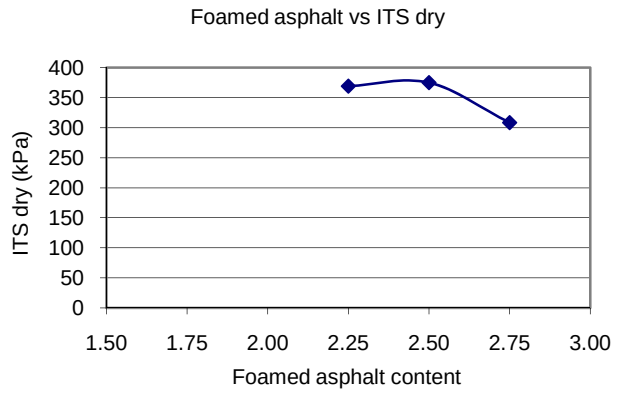
Sample Number : ..... Date 05-Aug-08

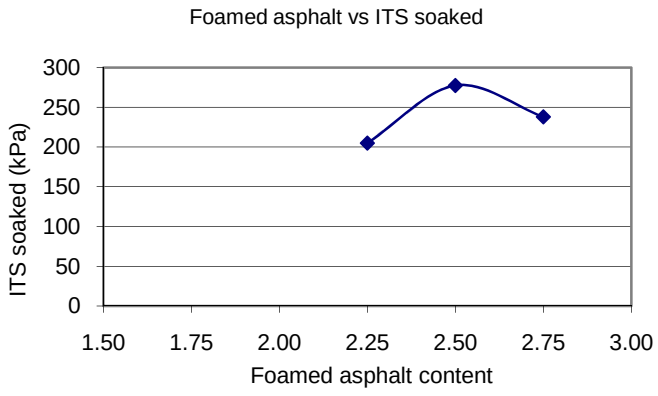
Material to be foamed	Aggregates	Bitumen	Filler
Location / Source:	Ex Stockpile	Tesoro	
Description	80%RAP + 20%Coral Gravel	PG 64-16	Cement

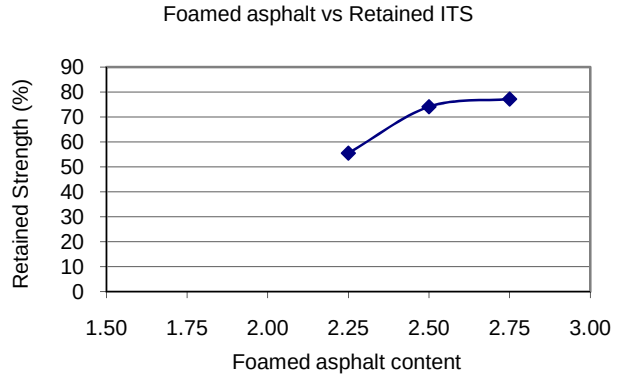
Foamed bitumen requirements

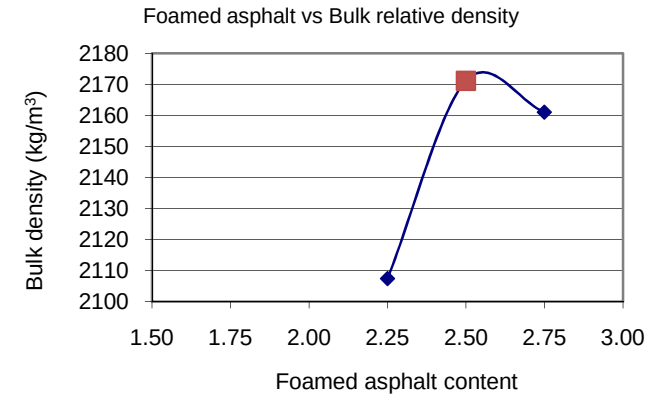
Percentage "foaming" water :	2.5	Temperature of bitumen:	160degC

Foamed asphalt treated material characteristics				100% Coral
Foamed bitumen added :	2.25	2.50	2.75	3.00
Type and Percentage Filler	1% Cement	1% Cement	1% Cement	1% Cement
Diameter of specimen (inch)	101.0	101.0	101.0	101.0
Height of specimen (inch) :	65.0	62.4	62.5	64.9
Mass of specimen (lb) :	1097.5	1086.6	1083.2	1062.7
Bulk density (lb/ft^3):	2107.4	2171.2	2161.0	2042.3
ITS dry (kPa):	369	375	308	509
ITS soaked (kPa):	205	277	238	239
Retained ITS (%):	55	74	77	47









	Loudon International	BITUMEN CALIBRATION	Test Method: Wirtgen Cold Recycling Manual

BITUMEN

Source :	Tesoro	Type:	PG64-16
Test temperature:	160 degC		

MACHINE SETTINGS

Pump calibration

Timer Setting	1	3	5
Reading 1	108	316	528
Reading 2	106	316	528
Reading 3	107	316	528
Average	107	316	528

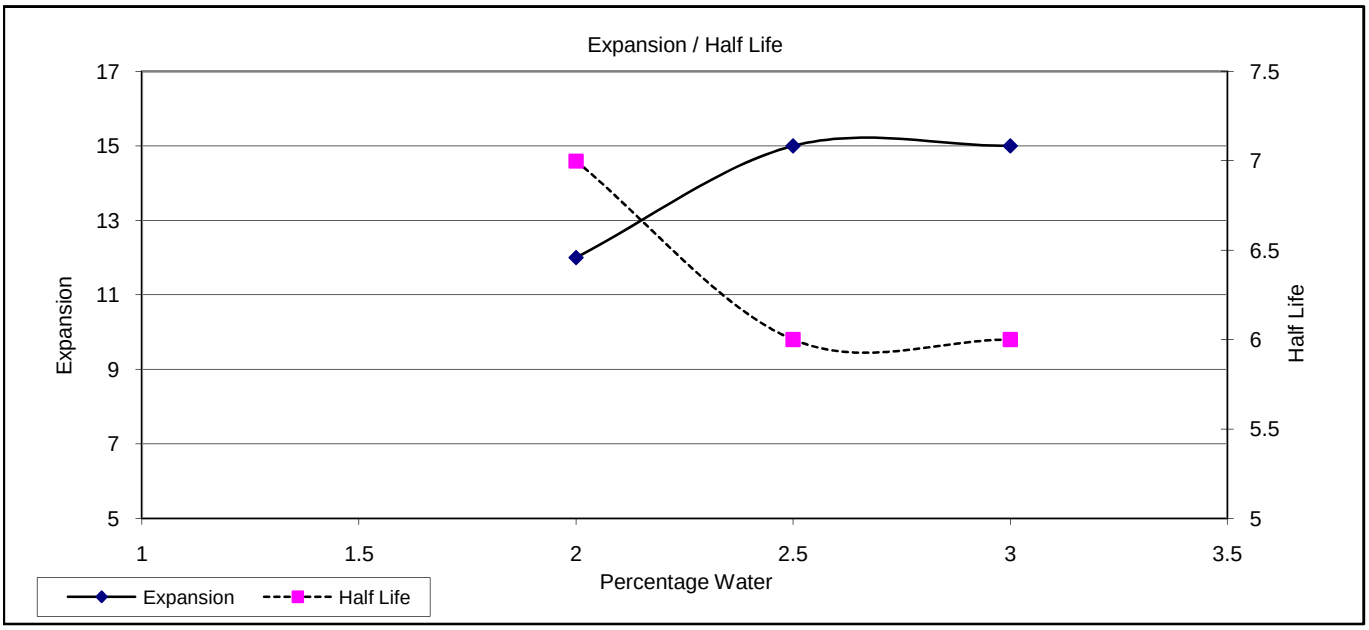
Setting

Quantity required (g):	500
Timer setting (sec)	5.00

Water

Quantity required (%):	2	2.5	3	
Flow meter setting (l/h):	7.2	9.0	10.8	

% Water	Expansion	Half Life
2	12	7
2.5	15	6
3	15	6



OPTIMUM FOAM MOISTURE CONTENT **2.5%**

Quality Assurance Testing

1 Scope

This section covers the requirements in regards to monitoring the quality of the work and materials and routine tests to be carried out.

2 Quality Requirements

The properties to be controlled are;

Material / Structure	Test	Test Method	Quantity	No of tests (minimum)
Bitumen	Foaming characteristics	Visual – see below	Per tanker	1
Foamed bitumen stabilised Material	Strength characteristics	ITS – see below	Lot	2
Foamed Bitumen stabilised Base layer	Compaction	AASHTO T191	Lot	4
	Moisture Content Determinstion	At compaction test positions	Lot	4
	Density – Moisture Content Relationship	Modified AASHTO T180	Lot	1

Note: The above minimum numbers of tests are suggested and should be increased if necessary to conform to clients specifications.

- Foaming characteristics

  The recycler shall have a test nozzle attached to one side of the spray bar from which a quantity of foamed bitumen is injected into a straight sided container while recycling. The half-life is the measure of the time taken for the foamed bitumen to reach half the height of the maximum expansion noted in the container. The container is then set aside for at least 1 hour or until the foamed bitumen has subsided completely and the unexpanded volume of the quantity of bitumen injected into the container is noted. The expansion ratio is the ratio of the maximum expansion to the unexpanded volume where the unexpanded volume is taken as one unit.

  The minimum expansion ratio recommended to achieve optimum dispersion of the foamed bitumen is 8 times.

- ITS Test

  Samples for the ITS test shall be taken off the discharge chute of the KMA and sealed in such a manner that no moisture is lost from this material. If necessary, additional moisture is added to the sample to bring the sample to optimum compaction moisture. The procedures described below are then followed.

  The minimum ITS values recommended is;

  Dry ITS 80% of ITS value used in pavement design

- Compaction

  The foamed bitumen stabilised material shall be placed, shaped and compacted to a mean dry density as specified for the material blend and cumulative design traffic and in terms of

Modified AASHTO T180 per lot, generally a day's work. No individual density shall be below 2% of the specified compaction.

Determination of the field moisture content at time of testing is essential for correction of the nuclear density gauge measurements. The nuclear density gauge reads the hydrocarbons in the bitumen as moisture and therefore the moisture reading recorded by the nuclear density gauge is incorrectly high.

The moisture content prior to foamed bitumen treatment shall be a maximum 80% and at the time of compaction shall be between 80% and 100% of the corresponding Optimum Moisture Content.

- Curing of Foamed Bitumen Base Layer

Allow the completed base to cure for a minimum of 4 days or when the moisture content of the upper 100mm of the foamed bitumen layer is below 50% of the corresponding Optimum Moisture Content, but not more than 14 days, before applying the surfacing. A light application (approx. 0.05 litre/sq metre) of a diluted (30%) emulsion is recommended after 4 days curing.

The completed layer can be opened to traffic immediately after final compaction.

- Daily Records

Daily production records shall be kept for each day's production and shall include the quantity of bitumen, Portland cement or lime and quantity of material mixed.

An as-built data record shall be compiled which will list the daily production as above and results of all relevant quality assurance testing for that particular day's production.

3. Field Compaction Control

The in situ density of the compacted layer is determined using a nuclear density gauge in the following manner:

- the drill rod is driven to at least 50mm below the bottom of the treated layer;
- determine the wet density of full depth of layer (WD_f);
- obtain a moisture sample for the full depth of the layer at the test position.

The moisture content is determined by standard laboratory procedures. The sample can be dried completely in oven at 105deg C.

The dry densities are calculated using this moisture content in equation 1:

$$DryDensity = \frac{WD}{100 + MC} * 100 \qquad \text{[equation 1]}$$

Dry Densi

where: WD = wet density [kg/m³]
MC = moisture content at testing [%]

The average dry density for the full layer depth of a lot (generally one days work) shall be a minimum of 100% of modified AASHTO T180. No individual result shall be less than 98%.

4. Preparation and Testing of Samples in Laboratory

4.1 Testing Requirements

Samples shall be taken during mixing and taken to the laboratory within two hours of sampling and the ITS briquettes shall be compacted within four hours of being sampled.

In the laboratory, the following tests shall be carried out.

4.1.1 Determination of the Maximum Dry Density and Optimum Moisture Content

The Maximum Dry Density and Optimum Moisture Content (OMC) is determined from a representative sample as per the moisture-density relationship test, AASHTO T180 (generally one per day is required, unless a significant change in the material blend is noted whereby one per material blend is required)

4.1.2 Indirect Tensile Strength Briquettes

The material for manufacture of the ITS briquettes shall be prepared as follows;

- Determine the moisture content of the remaining field sample;
- Weigh out 5kg (for 3 briquettes) of the field sample;
- Sieve through the 19mm sieve and determine the mass of the material retained on the 19mm sieve;
- Using a portion of the remaining field sample extract the material retained on the 12.5mm sieve but passing the 19mm sieve;
- Weigh out an amount equal to the mass of the material retained on the 19mm sieve from the original 5kg sample and add to this sample such that the mass once again totals 5kg;
- The sample then adjusted to OMC;
- Manufacture 100mm diameter briquettes for strength testing (ITS dry).

4.2 Manufacture of 100mm Diameter Briquette Specimens

- Prepare the Marshall mould and hammer by cleaning the mould, collar, base-plate and face of the compaction hammer. Note: the compaction equipment must not be heated but kept at ambient temperature.
- Weigh sufficient material to achieve a compacted height of 63.5mm $\pm$ 1.5mm (usually 1150g is adequate). Poke the mixture with a spatula 15 times around the perimeter and 10 times on the surface, leaving the surface slightly rounded.
- Compact the mixture by applying 75 blows with the compaction hammer. Care must be taken to ensure the continuous free fall of the hammer.
- Remove the mould and collar from the pedestal, invert the briquette (turn over). Replace it and press down firmly to ensure that it is secure on the base plate. Compact the other face of the briquette with a further 75 blows.

- After compaction, remove the mould from the base-plate and extrude the briquette by means of an extrusion jack.

Note: With certain materials lacking cohesion, it may be necessary to leave the specimen in the mould for 24 hours, allowing sufficient strength to develop before extracting.

4.3 Briquette Curing procedure

Place the briquettes on a smooth flat tray and cure in a forced-draft oven for 72 hours at 40°C. Remove from oven after 72 hours and allow cooling to ambient temperature.

4.4 Determination of bulk density

After cooling to ambient temperature, for each briquette:

- Determine the mass.
- Measure the height at four evenly-spaced places around the circumference and calculate the average height.
- Measure the diameter.
- Calculate the bulk density using equation 2:

$$BD = \frac{4 * M_{Briq.}}{\pi * d^2 * h} * 100000 \qquad \text{[equation 2]}$$

where:	BD	=	bulk density	[kg/m³]
	M_{briq}	=	mass of briquette	[g]
	h	=	average height of briquette	[mm]
	d	=	diameter of briquette	[mm]

Exclude from further testing any briquette whose bulk density differs from the mean bulk density of the batch by more than 50 kg/m³.

Note: The bulk density can be verified by using the “weigh-in air / weigh-in water” method.

4.5. Determination of Indirect Tensile Strength (ITS)

The ITS test described below is used to test the briquettes under equilibrium moisture conditions. The ITS is determined by measuring the ultimate load to failure of a briquette that is subjected to a constant deformation rate of 50.8 mm/minute on its diametrical axis. The procedure is as follows:

- Place the briquette onto the ITS jig;
- position the sample such that the loading strips are parallel and centred on the vertical diametrical plane;
- place the transfer plate on the top bearing strip and position the jig assembly centrally under the loading ram of the compression testing device;
- apply the load to the briquette, without shock, at a rate of advance of 50.8 mm per minute until the maximum load is reached;

- record the maximum load P (in kN), accurate to 0.1kN.
- calculate the ITS for each briquette to the nearest 1 kPa using equation 3:

$$ITS = \frac{2 * P}{\pi * h * d} * 10000$$ [equation 3]

where

ITS	=	Indirect Tensile Strength	[kPa]
P	=	maximum applied load	[kN]
h	=	average height of the specimen	[cm]
d	=	diameter of the specimen	[cm]