FOAMED TAR TECHNOLOGY:
AN INNOVATION IN PAVEMENT STABILIZATION

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ABSTRACT

The increasing scarcity of good road construction materials, combined with long haulage distances and increased environmental consciousness, have necessitated the use of methods to improve substandard or existing materials through recycling. In-situ recycling has grown in prominence as a road construction alternative. Stabilization agents such a bitumen emulsion, cement and foamed bitumen are being used extensively in in-situ recycling to produce satisfactory pavement structures. Tar is a readily available by-product of the fuel-from-coal process, with properties very similar to those of bitumen. However the lack of suitable construction methods, combined with the perceived carcinogenic effects of low temperature tar, have limited tars' application as a stabilizing agent. Tars' anti-stripping properties, combined with it's high resistance to fuel solvents make it an ideal binder for use in airport pavement construction. Foamed tar provides a viable, and safe alternative, for the production of airport pavement structures with high durability to the affects of water and fuel. The aim of this paper is to investigate the engineering properties of foamed tar and their resultant applicability to airport pavement construction. This paper firstly presents the foaming characteristics of foamed tar, based upon the principles of existing foamed bitumen technology. A method is presented for the optimization of foamed tar characteristics through the application of the Foam Index, half-life and expansion ratio of foamed tar. Factors affecting the foamability of tar are also addressed. The health aspects of the application of foamed tar technology to in-situ recycling are addressed, focussing specifically on tar produced through the gasification process. The various tar production methods are discussed and variations in their chemical composition highlighted with respect to the perceived carcinogenic components of tar. Furthermore, the confinement of fumes through the application of in-situ recyclers is also elaborated upon. The use of in-situ recycling as an alternative reconstruction method is addressed, within specific reference to foamed stabilization. Advantages and disadvantages of in-situ recycling to airport construction are investigated Thereafter, the engineering properties and stockpiling ability of foamed tar mixes are investigated. The ease of construction of foamed tar pavement layers will also be considered through the discussion of a test section that was constructed utilizing manual labor and foamed plant mixing of an aggregate base material. This test section was constructed using a standard foam generator and a concrete mixer. Standard compaction techniques were utilized for the compaction of the foamed granular base and non-destructive tests performed to evaluate the strength of the pavement. A comparison is made between foamed tar and other stabilization agents in terms of their strength and other engineering properties. Conclusions are drawn with respect to the application of foamed tar technology to airport pavement reconstruction as well as new construction, and the use of foamed tar as a viable stabilizing agent used in specific situations where alternative bituminous binders are unsuitable.

1. INTRODUCTION

Recent technological developments in the recycling of pavements have gained worldwide attention because of their potential cost saving as well as resource preservation. The recurring crude oil shortages, rising prices of crude and doubts concerning the availability of crude oil/bitumen, have made recycling cost effective and politically correct in numerous countries. In conventional maintenance methods for flexible pavements such as planing, recarpeting, reconstructing and surface treatment, the existing material is not fully utilized and thus can be judged to be a waste of valuable natural resources. Recycling makes use of this resource by minimizing the cost associated with new materials, conserving aggregate and limiting the plunder of natural hydrocarbon reserves (Asphalt Technology Course, 2000). Note that in this paper the term “bitumen” is synonymous with the American term “asphalt”.

Bitumen and tar possess similar stabilizing characteristics and produce high quality asphalt bases. Bitumen is however an imported product in certain countries and thus commands a premium price. Because of the similarities in properties between these binders and that foamed bitumen has been used successfully as a stabilizing agent, it was anticipated that foamed tar could also be utilized in a similar manner. Tar products are often used for the pre-coating of aggregates in surfacing operations. This practice is due to the excellent resistance to stripping of tar binders. Environmental and health concerns with the use of bitumen and tar need to be taken into account. Such concerns should however be based on facts and should be material specific. These aspects are touched on in this paper. Little experimental knowledge is available concerning the use of tar as a stabilizing agent and little research has been conducted internationally. This is thus a new field that needs to be investigated.

The aim of this paper is to investigate the engineering properties of foamed tar stabilized materials and its application to airport pavement construction. A brief review of the foaming process as applied to bitumen and the use of foaming technology in combination with in-situ recycling will be followed by a discussion of the optimization of the foaming characteristics of tar and health related concerns. Thereafter, the engineering properties of foamed tar mixes will be addressed and the construction of the stabilized test section discussed. Finally, a comparison will be presented between foamed tar stabilization and more conventional material stabilizers and conclusions drawn as to the applicability of foamed tar technology to airport pavement construction

2. LITERATURE REVIEW

To date only one investigation into the application of foamed tar technology has been undertaken worldwide. Due to the scarcity of information concerning foamed tar technology, this review will focus on general aspects of foamed binder (bitumen and tar) technology and an investigation into the application of foamed tar technology. This review will encompass the foaming of stabilizing agents and the application of in-situ recycling to foamed stabilization, highlighting the benefits of this process to pavement construction.

2.1. Foamed Bitumen

The use of foamed bitumen for the manufacture of base and surfacing materials has increased in popularity due to economic and practical considerations. Although the technology of foamed bitumen is relatively old, dating back to the late part of the 19th century, sophisticated machinery in the developed world, as well as the increased use of labor intensive construction methods in developing countries, has increased the viability of this form of bitumen construction.

The use of foamed bitumen dates back to 1889, when bitumen was first used in full-depth repairs in Nebraska to improve the bearing capacity of an aggregate base material. In 1928 August Jacobi produced and patented the first hot bitumen foaming system, and in 1957 Prof. Laids Csanyi of Iowa State University demonstrated the benefit of the addition of foamed bitumen to marginal quality aggregates (vd Walt *et al* 1999).

Foamed bitumen is characterized by means of the expansion ratio and the half-life values. These values can be calculated as follows:

- Expansion Ratio = Maximum volume of foamed bitumen/Volume of bitumen
- Half-life = Time measured in seconds for the foamed bitumen to subside to half the maximum volume at foaming (Jenkins *et al*, 1999b).

The foam index is a measure of the area under the foam decay curve, and measures the change in expansion with time, which reflects the energy stored within the foam. This index assists in the optimization of the mix with regards to foam content and application rate as well as additive content (Jenkins *et al*, 1999b). Figure 1 illustrates a generalized foam decay curve.

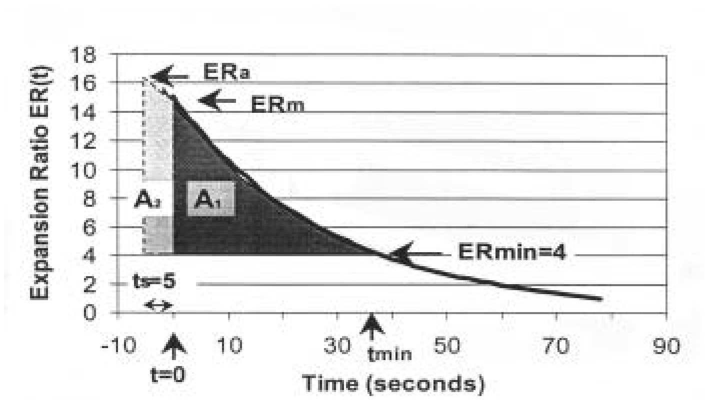

Figure 1. Illustration of foamed decay curve

2.2. Comparison between Stabilization with Bitumen Emulsion and Foamed Bitumen

This comparative study is based on investigations conducted by Jenkins (2000). Foamed bitumen exhibits higher tensile strengths than an equivalent emulsion mix. Emulsion compaction results were higher than those of the foamed bitumen and consequently better rut resistance was achieved from the emulsion treated materials. This occurrence was probably as a result of more favorable moisture content conditions during compaction. It should be noted that the foamed bitumen stabilization used as the basis for this comparison was a combination of foamed bitumen and a small percentage of cement. The addition of cement to the foamed stabilized mix could negatively affect the compactability of the material. Raveling occurred within the foamed bitumen stabilized sections, which were tested with accelerated pavement testing apparatus. The following factors were concluded to be the cause of this raveling

Surface finish: The surface finish obtained was found to be variable, even though the same material was used in both the emulsion and foamed bitumen stabilized sections The variability is influenced by the construction of the layer, specifically during rolling and placing of the material and was independent of the binder used.

Moisture content: Variations in moisture content caused by drying out of the layer and traffic results in variations in the density of the layer. The dryness of the foamed bitumen layer 3 days after compaction encourages raveling (Jenkins, 2000).

2.3. Foamed Tar

Foamed tar is the resultant product of the mixture of hot tar with cold water under the influence of pressured air. The interaction of the cold water and tar, heated to between 110°C and 130°C, causes the water to vaporize producing steam. Tar encapsulates this steam causing the water and tar mix to expand as the steam expands. Expansions attained vary between 4 – 6 times the original volume of the tar binder. Foamed tar mixes have similar engineering characteristics as to those obtained through foamed bitumen stabilization. Foamed bitumen stabilization is used extensively in combination with in-situ recycling in the process of rehabilitation of existing pavements and the construction of new pavements.

2.3.1. The Foaming Process

The addition of cold water to the hot tar initiates the following events. As the surface of the tar comes in contact with each individual water droplet the heat energy stored within the tar is transferred between the tar and the water, resulting in the boiling of the water droplet. The formation of steam, and resultant expansion, proceeds violently as the transferred energy exceeds the latent energy of the steam. Steam is forced into the continuous phase of the tar.

When this mixture of steam and tar is exposed to the atmosphere, the steam expands and a thin film of tar coats each individual steam bubble. An equilibrium state is reached whereby the surface tension of the tar counteracts the pressure exerted by the steam. The foamed tar bubble can remain in this state of equilibrium for a period of time, known as the metastable life. This metastable life is as a result of the low thermal conductivity of water and tar. Collapse of the metastable existence of each individually coated tar bubble occurs through cooling and condensing of the steam. This results in what is known as the decay of the foamed tar mixture.

2.3.2. Factors affecting the properties of the Foamed Tar Mix

Numerous factors play a role in the engineering properties of the foamed tar mix. Most of these factors deal with the manner in which the binder is distributed within the aggregate mix. The following factors affect the dispersion of the binder (Jenkins, 2000):

Foamed tar characteristics – expansion ratio, half-life and foam index

Composition of sand and mortar fractions - foamed bituminous material has a greater affinity for fine material and gap-gradings are not advisable since balling can occur which results in the non-coating of the larger particles

Mixing technique – because of the short life of the foamed tar, the mixing method influences the characteristics of the mix directly.

Aggregate moisture content – water is the distribution medium of the binder and is thus of crucial importance.

Aggregate temperature – increased aggregate temperature improves binder dispersion.

2.3.3. Curing of Foamed Tar Mixes

The following factors influence the on-site curing of the foamed bituminous mix (*Jenkins et al*, 1999a):

Air temperature, relative humidity and rainfall data of the area

Depth and temperature of the layer

Air permeability of the compacted mix

Drainage conditions at the boundary of the layer and the depth of the water table.

The strength developed after an early or intermediate cure represents the most critical time period, and if foamed mix pavements exhibit premature stress, it usually occurs within the first couple of days after construction and not after weeks and months as in other construction methods (Ruckel *et al* 1982). A higher air temperature combined with a low relative humidity causes greater drying out of the mix and stiffening of the mortar (Jenkins & vd Veen, 1999a).

3. ADVANTAGES OF FOAMED TAR STABILISATION

Foamed tar, as with foamed bitumen, has numerous advantages over other cold mixes and Hot Mix Asphalt (HMA) with respect to its use as a stabilization agent. These advantages are applicable to all forms of pavement construction including airport pavement construction. These ***advantages*** can be summarized as follows (Jenkins, 2000):

Conservation of energy: The foamed tar is applied in a heated state to cold, damp aggregate, thus negating the necessity to preheat the aggregate which consumes the majority of heat needed in conventional processes.

Suitability of aggregate: Although few investigations have been conducted in this regard, it can be stated with fair certainty, based on the aggregates already tested and the knowledge of foamed tar behavior, that foamed tar will be more suited to a variety of aggregates than bitumen emulsions which are compatible only to specific ionically charged aggregates.

Lower binder contents: The foamed tar process partially coats the larger aggregate within the mix. This fact ensures that the binder is used efficiently in binding together the small particles and forming a well structured foamed mortar that binds in the larger aggregate.

A reduction in compaction moisture content difficulties: The foamed tar causes a significantly smaller increase in the moisture content of the recycled material that has been stabilized with foamed tar, in comparison to the same material that has been stabilized with emulsion. Thus where materials are at optimum moisture content prior to recycling, foamed tar is a more suitable stabilization agent.

Early strength characteristics: Although the early strength of foamed mixes is less than HMA, foamed mixes are significantly stronger at early age than bitumen emulsion, and can be trafficked immediately after placement, providing the stresses are not excessive.

Stockpiling ability: Foamed tar mixes can be stockpiled for future use without any significant strength reduction if the mix is kept at optimum moisture content. Stockpiles that have been exposed to severe environmental conditions exhibit lower strengths than materials that have been stockpiled in airtight bags. Leaching and binder run-off is dramatically reduced when compared to emulsions.

Labor intensive advantages: Due to the fact that the foamed tar mix is a cold mix and that the finer particles bind to the foamed tar bubbles, the material retains an unmodified aggregate characteristic and can be placed using labor intensive methods.

4. COLD IN-SITU RECYCLING AND FOAMED TAR TECHNOLOGY

Foamed tar technology is inherently suited for use in cold in-situ recycling of existing pavements. Cold in-situ recycling has numerous benefits over more traditional rehabilitation methods. The most prominent of these include the following: (Wirtgen Cold Recycling Manual, 1998)

Environmental: Use is made of the existing pavement, thus decreasing the number of spoil sites necessary and minimizing the volume of additional material that needs to be imported from quarries.

Recycled layer quality: Modern recycling machines ensure a consistent and high quality mix.

Structural integrity: Cold in-situ recycling produces thick, bound layers that do not contain weaknesses at interfaces due to their homogenous nature.

Subgrade disturbance: Cold in-situ recycling causes significantly fewer disturbances to poor quality subgrades than conventional rehabilitation methods. It is a single pass process, with tracks or high flotation tires passing only once over the exposed subgrade.

Shorter construction time: Modern recycling machines are capable of high production rates and thus shorter construction times. This reduces traffic disruption time and is thus a benefit to the pavement user.

Traffic safety: This process results in significantly increased levels of safety to workers and road users.

Cost effectiveness: All the factors mentioned above, make cold in-situ recycling a cost-effective method of pavement rehabilitation.

5. OPTIMIZATION OF THE FOAMING CHARACTERISTICS OF FOAMED TAR

The foaming characteristics of tar are optimized with respect to the foamant water content and the foaming temperature. Optimization is achieved through the calculation of the Foam Index from the foam decay curve. Figure 2 illustrates the optimization process of tar. An additional factor affecting the foaming characteristics of tar is the chemical composition of the tar, particularly the phenolic content. High phenolic content tars exhibit improved expansion rates, with the subsequent decrease in half-life, in comparison to standard gasification tar. Low phenolic content tars are non-foaming, although there is evidence to suggest that these low phenolic content tars could potentially be used as a chip coating product (Morton, 2001).

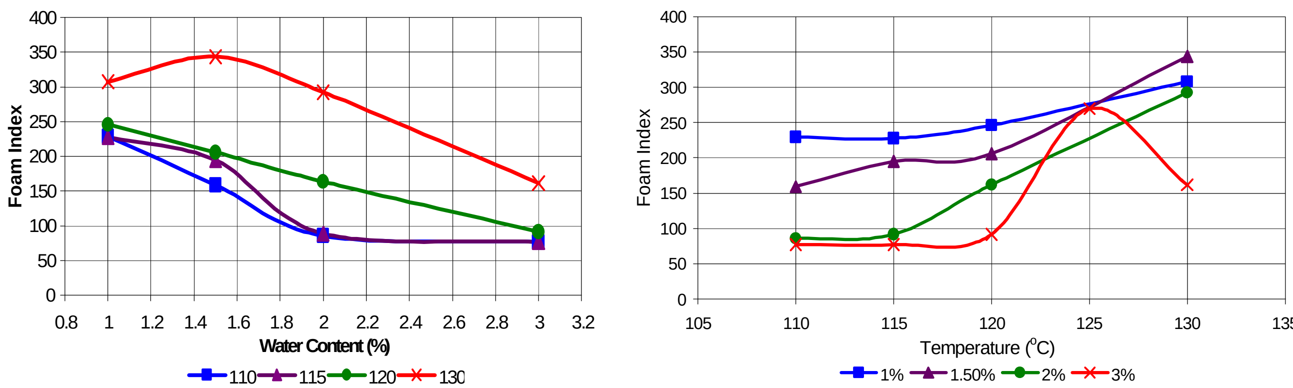

Figure 2. Optimization of foaming temperature and water content

6. HEALTH ASPECTS RELATED TO FOAMED TAR

Coke oven tar, produced through the heating of coal to approximately 1100 °C, is highly aromatic, containing large proportions of polyaromatic hydrocarbons (PAH). Gasifier tar is produced through the introduction of water and oxygen to coal at a temperature of 750 °C to produce gas, which is used for the production of fuels, and approximately 5% tar. Gasifier tar is less aromatic containing approximately 10% of the PAH content found in coke oven tars. Gasifier tar's primary constituents include phenols, hydrogenated aromatics and aliphatic hydrocarbons. Sasol is a major producer of gasifier tar as a by-product of their fuel and gas production, and market gasifier tar under the name Sasol Carbo-Tar (Louwrens, 2001).

The carcinogenic effects of tar are well documented, but only at elevated temperature, greater than 300°C. Although tar contains approximately 10 000 times more poly-cyclic aromatic hydrocarbons, temperatures in excess of 300°C are necessary to release these hydrocarbons (Louwrens, 2001). There is a perception that all tars are carcinogenic and there is little understanding that the constituents of tar produced by the different processes are significantly different. Table 1 presents a comparison of the constituents of a coke oven tar and gasifier tar, and indicates those components, namely certain of the polyaromatic hydrocarbons, which are reputed to be carcinogenic when large quantities are painted on and are absorbed by the skin.

Benzo(a)pyrene(5) is one of the most thoroughly investigated PAH's. It is used as an indicator or marker substance for the classification of carcinogenic materials. Table 1 indicates that Benzo(a)pyrene(5), the most prevalent PAH and a suspected carcinogen, is only released from the gasifier tar to the atmosphere at temperatures in excess of 360 °C (Louwrens, 2001). By using foamed technology, which only requires the heating of the tar to approximately 120°C, the hazardous vapors are restricted. The final foamed mix is cold, thus releasing no harmful vapors to the environment. These facts, combined with the structure of the foamed tar mix, make it a safe, viable construction material (Morton, 2001).

Table 1
Comparison of Benzo(a)Pyrene(5) concentrations in coke oven tar and gasification tar (Louwrens, 2001)

Tar distillation fraction (°C)	**BaP (ppm)**	
	Gasification tar	**Coke oven tar**
Feed	900	8 076
<200	0	0
201-245	0	70
246-280	0	10
281-300	0	33
301-320	0	6
321-340	0	154
341-360	0	80
360-375	1	51
>375	2 731	11 407

7. THE ENGINEERING PROPERTIES OF FOAMED TAR MIXES

7.1. Introduction

This section discusses the engineering properties of foamed tar mixes that make this stabilization method inherently suitable to all forms of pavement stabilization. Three materials were tested during this investigation, which could be classified as an good quality aggregate base (GW; CBR>80), a good quality subbase (GW; CBR>20) and a highly plastic subgrade (SC). Standard testing procedures as applicable to foamed bitumen mixes were adhered to during the investigation of the foamed tar mixes. Samples were compacted[1] cured @ 40°C for 3 days to simulate long term curing of foamed mixes, as prescribed by Ruckel *et al* (1982). In addition to the standard test procedures for foamed bitumen mixes, the Marshall stability and flow of foamed tar and the performance of foamed tar mixes under gyratory compaction were investigated. The stockpiling ability of foamed tar mixes will be discussed and the strength retention of foamed tar mixes subsequent to soaking will be highlighted..

[1] Samples compacted using standard Marshall compaction effort (75 blows each side)

7.2. Aggregate Base Foamed Tar mixes

7.2.1. Stability & Flow

From the stability results of the aggregate base it is evident that an increase in binder content[2] (BC) does cause an increase in the stability of the material, but that this strength increase is not linear. When comparing the stability of the material for 3% and 5% BC mixes it is noticeable that the increase in binder content of 2% has little effect on the stability. This could indicate that the material has been saturated with binder and thus reached an optimal level of about 3% binder content (BC). The flow increased proportionately with an increase in BC varying between 4.2 mm for the 1% BC mix and 6.8 mm for the 5% BC mix.

7.2.2. Indirect Tensile Strength (ITS)

The aggregate base material gave good results with respect to dry indirect tensile strength. It is evident from Figure 4 that the ITS results exhibit a similar pattern to that observed when comparing the stability of foamed tar mixes of varying binder content. As the binder content increases, so the ITS values increase. It should be noted that the ITS results were extremely good and in excess of those obtained in most other forms of material stabilization excluding cement stabilized materials.

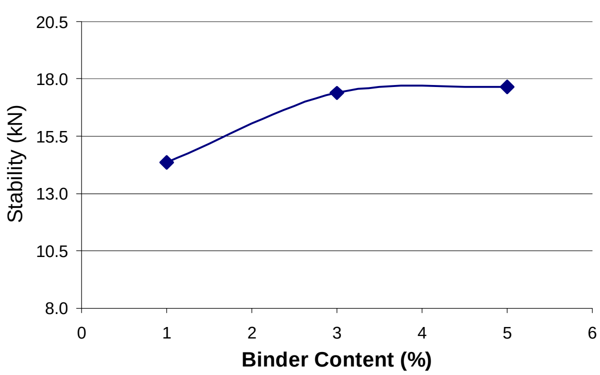

Figure 3. Aggregate base foamed tar stability results

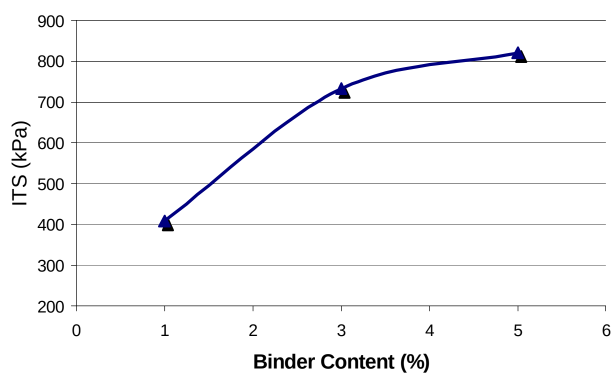

Figure 4. Aggregate base ITS results

7.4. Test Results for Aggregate Subbase

7.4.1. Indirect Tensile Strength

The aggregate subbase gave satisfactory ITS dry and ITS soaked results. The ITS dry results are illustrated in Figure 5 while Figure 6 shows the ITS soaked results. The addition of 1% cement to the mix resulted in the foamed tar mix being vividly dryer than the mixes containing

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2 Binder Content (BC) is defined as the percentage of binder by mass of dry aggregate

only foamed tar. The addition of cement did cause an increase in the ITS of the soaked samples, when compared to the foamed tar mixes not containing cement.

However, the addition of cement decreased the ITS dry values when compared to their counterparts lacking the cement additive. The addition of cement to the moist aggregate prior to foaming instigates the hydration process. Thus when the foamed tar is introduced to the mix, the free moisture within the mix has been decreased, limiting the amount of water available for distribution of the foamed binder within the mix. This effect could be observed visually by comparing the mixes immediately after foaming. Furthermore, the mixes were compacted 24 hours after mixing to investigate the effect of stockpiling the mix. During this 24 hour period, the hydration process had removed most of the moisture needed for adequate compaction and formed limited microstructure bonds, which hampered the achievement of compaction.

Figures 5 and 6 illustrate the ITS strength retention of the aggregate subbase foamed tar mixes. It is evident that the foamed tar stabilized subbase aggregate retained in excess of 60% of its strength prior to soaking. It is noticeable that there is an increase in strength retention with an increase in binder content. The foamed tar mixes with 1% cement content as additive, do exhibit increased strength retention over the standard foamed tar mixes without the addition of cement. The strength retention of foamed tar mixes are comparable, and at higher binder contents, greater than the results obtained with more conventional stabilization methods. This factor illustrates the combination of two of the most beneficial properties of foamed tar stabilization, namely the antistripping property of tar and the low permeability of foamed tar stabilized materials. Foamed tar mixes ability to withstand the negative effects of moisture make it ideal for use in climatic conditions where variation in soil moisture conditions are considered important

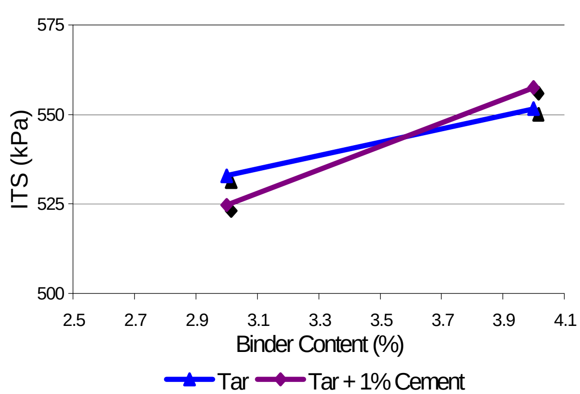

Figure 5. Dry ITS results for subbase

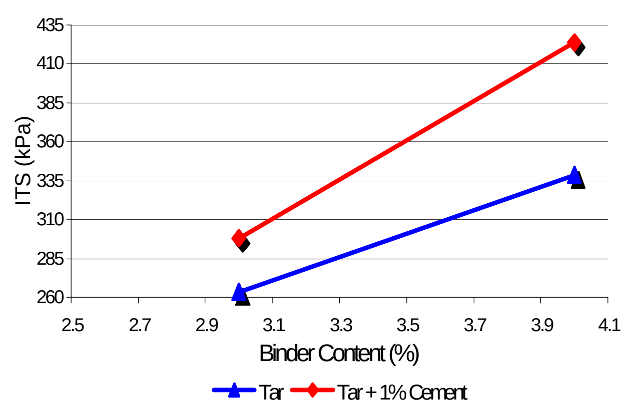

Figure 6. Soaked ITS results for subbase

7.5. Test result of the high plasticity subgrade material

The subgrade stability and ITS results were extremely low as a result of the high clay content of the material. The addition of foamed binder to high PI materials causes the foamed tar to 'ball' and become completely encapsulated by the clay fines[3]. Thus the clay fines separate the foamed tar from the aggregate-fines matrix. Therefore, the addition of the binder to these specific materials does not encourage the binding of the fines matrix and the larger aggregate. Thus materials containing plastic fines should be modified through standard lime modification processes prior to foamed stabilization. This process has been successfully applied to combat the negative effect of plastic fines on the foaming process.

7.5. Gyratory Compaction Investigation of Aggregate Base Material

The major advantage that Gyratory compaction analysis offers over standard Marshall compaction is that the compaction can be monitored as the number of load repetitions are increased. This provides the researcher with the ability to 'simulate' the compaction that occurs as a result of traffic after construction compaction has been completed[4]. It also indicates whether the material will reach its recommended compaction level and if the percentage voids stabilizes after a certain number of applied repetitions.

In order to relate the Gyratory compaction results to actual loading situations based on the design traffic, the following table was extracted from the Asphalt Technology Course Notes (2000). Table 2 relates traffic loading to number of gyrations for an average design temperature of 41-42°C.

Table 2
Traffic loading versus gyration repetitions (Asphalt Technology Course Notes, 2000)

Traffic Loading	Design Traffic (E80's x10^6)	N_{ini}*	N_{des}	N_{max}
Low	0.3-3	8	100	158
Intermediate	3-10	8	113	181
High	10-100	9	146	240
Extreme	>100	10	165	275

****N_{ini} = <89% MTRD***
N_{des} = 96% MTRD
N_{max} <98% MTRD

If the material continues to densify under repeated loading, it indicates that the binder content is in excess of optimum and ultimately causes the layer to deform continuously under heavy loading and high repetitions. The Gyratory results for the aggregate base material with binder contents of 1,3 and 5% respectively are illustrated in Figure 7. This graph illustrates the decrease

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[3] Fines are defined as material smaller than 0.075 mm in diameter
[4] At the time of investigation the Marshall Compaction Device available for sample compaction had not been retrofitted with compaction monitoring equipment

in air voids content as a function of load repetition related to maximum theoretical relative density of the foamed tar mixes.

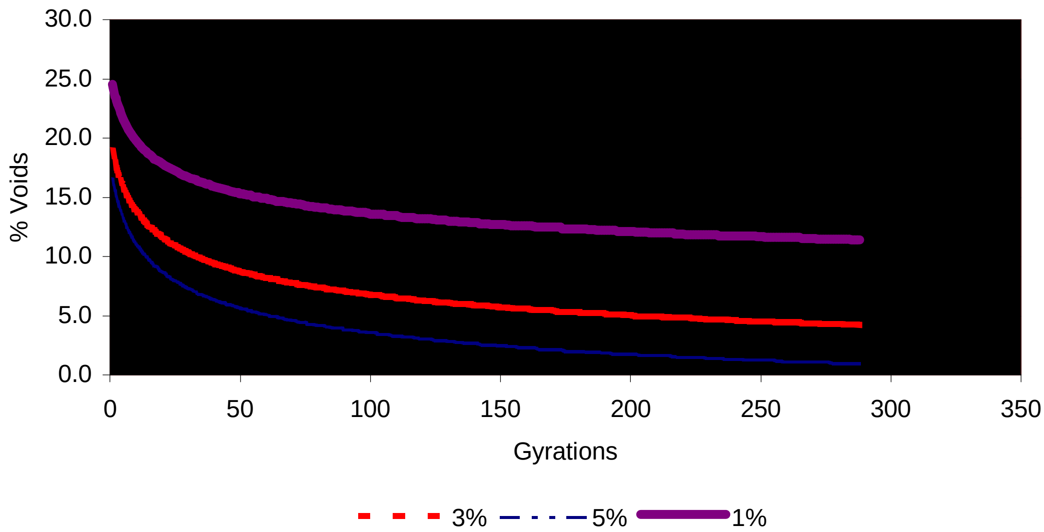

Figure 7. Gyratory compaction results of aggregate base material

As can be seen from Figure 7, the percentage voids of the 5% G2 mix in the region 100 - 150 gyrations varies from 3.5 - 2.5 %. This situation is ideal, since sufficient voids remain in the structure to ensure that the structure will not deform under excessive increases in loading, but not too large to result in the structure losing its inherent strength and impermeability to the ingress of water. At excessive loading conditions, relating to 250 - 300 gyrations, the 5% mix's voids content is approximately 1.5 - 1.0 % which is becoming critical and could result in deformation of the structure under heavy loading. If this loading situation is applicable, it would be advisable to make use of the 3% BC mix, which would effectively possess approximately 4% voids at excessive loading conditions.

The 1% BC mix possesses a high percentage of voids (13.5 - 12%) under normal loading criteria (100 - 200 gyrations). Due to the large number of voids, the mix is permeable to the effects of water on a pavement layer and also possesses lower strength characteristics. The 5% and 3% BC mix's are easily compacted with 84 % and 80 % respectively of the total expected densification occurring within normal loading parameters associated with construction compaction.

7.6. Stockpiling Ability of Foamed Tar Mixes

Foamed tar mixes do not experience any loss of their engineering properties when the mixes are adequately stored in bags protected from the effects of moisture loss. This fact was established during the testing described in the previous section. The foamed material was stored in bags and tested over a period of 4 weeks. Certain verification tests were completed that showed that the material could be stockpiled in airtight container without any loss to compactability and strength properties.

Protection of the stockpile with a tarpaulin was not investigated. Yet, based on the results given in the chapter, it is foreseen that if the foamed tar mix is kept moist and cool the binder will not have opportunity to harden and influence the properties of the outer surface of the foamed tar mix. However, sealing the moisture into the foamed tar mix by placing the mix in an airtight bag, will give the best results in terms of stockpiling the foamed tar mix for an indefinite period.

8. CONSTRUCTION OF FOAMED TAR BASE COURSE (FTBC)

To illustrate that foamed tar stabilization can be implemented in the field and to investigate the performance of the foamed tar material, a test section was constructed. Figure 8 represents the pavement structure constructed and the control section. The test section was 40 m^2 in size and 10.5 tons of foamed stabilized aggregate base was prepared using labor intensive construction methods. 50 kg aggregate batches were foamed in a pan concrete mixer and then stockpiled until placement of the foamed tar base course (FTBC). The entire production of the foamed tar stockpiled was completed in 8 days using 3 workers. Placement of the foamed material was performed using standard construction methods applied to aggregate bases. The material was compacted at ambient temperature using a standard 2 ton vibratory steel drum roller operating at 45 Hz. Figure 9 illustrates the compaction of the FTBC, while Figure 10 shows the final compacted FTBC.

In order to measure the performance of the test section, a slurry seal was used as a surfacing of the test section. This surfacing alternative was chosen to ensure that the strength of the base course could be analyzed independent of the surfacing strength. Slurry seals posses insignificant strength and thickness and, thus the falling weight deflectometer (FWD) testing performed on the test section was not influenced by a strong surfacing. This negated the possibility of overestimating the strength of the base course.

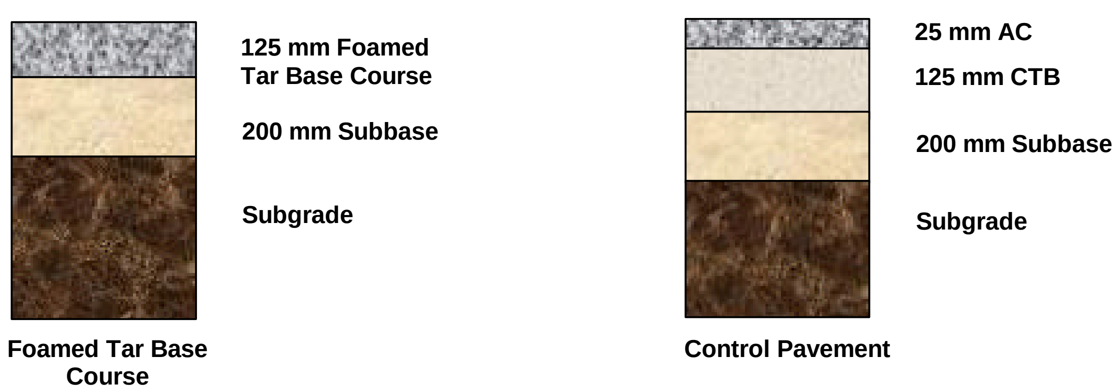

Figure 8. Foamed tar base course pavement structure and control section

Figure 9. Vibratory compaction of FTBC

Figure 10. Compacted FTBC

In order to compare the strength of the foamed tar base course with conventional design methods, FWD testing was performed on a control section consisting of a 125 mm cement treated base and a 25 mm asphalt layer substituted for the foamed tar base course. The performance testing is still in progress, but based on initial analyses the deflections obtained from the foamed tar base course were 40 % lower than those obtained from the control sections.

9. COMPARISON OF STABILISATION CHARACTERISTICS

Table 3 contains a summary of the engineering properties of two materials commonly encountered on recycled projects. This summary is partly extracted from a similar summary contained in the Wirtgen Cold Recycling Manual (1998). It should be noted that the modulus values given in Table 3 for foamed tar stabilization are based on the initial results of the non-destructive testing of the FTBC.

Table 3
Engineering characteristics of stabilized materials (WCRM, 1998 and Morton, 2001)

Crushed Stone (maximum size 53 mm, PI <6, CBR> 80)				
Test Parameter	**Cement Stabilized**	**Bitumen Stabilized**		**Tar Stabilized**
	2-3% cement	**1-1.5% cement + 3.5-6% emulsion**	**1% cement + 1.5-3% foam**	**3% foam**
Density % Mod AASHTO	96-98	98-100	98-102	98-102
UCS (MPa)	1.5-3	n/a	n/a	-
ITS (KPa)	n/a	400-800	400-900	500-900
Retained Strength	n/a	>60	>60	>60
Resilient Mod (MPa)	~5000 (Pre-cracked)	3000-6000	3000-6000	> 1000

Natural Gravel (PI < 10, CBR ~30)				
Test Parameter	Cement Stabilized	Bitumen Stabilized		Tar Stabilized
	2-3% cement	1-1.5% cement + 3.5-6% emulsion	1% cement + 1.5-3% foam	3% foam
Density % Mod AASHTO	95-97	97-100	98-100	98-100
UCS (MPa)	1.5-3	n/a	n/a	-
ITS (KPa)	n/a	250-500	250-500	400-600
Retained Strength	n/a	>50	>50	>60
Resilient Mod (MPa)	~5000 (Pre-cracked)	3000-6000	3000-6000	>1000

10. CONCLUSIONS

For good quality materials, with little or no PI, the strength of the foamed tar stabilized material increases with increased binder content at a constant compaction effort. This non linear strength increase is due to increased coating of particles in combination with a lower voids content.

The fines content and PI play an important role in the suitability of a material for foaming; whether modification is necessary prior to foaming; and what binder content should be utilized for the production of a successful stabilized material.

Foamed tar mixes provide continuous coating at high binder contents of greater than 3%. This is in contrast to foamed bitumen, which results in balling, and the formation of "stringers" within high binder content foamed bitumen mixes.

The anti-stripping characteristic of tar and its inherent impermeability to the ingress of water results in increased strength retention values (ITS soaked/ITS dry) in comparison with the results obtained from other stabilizing agents.

Foamed tar mixes can match and even better the strength properties of other stabilization agents commonly used in the road construction industry.

The ability of foamed tar technology to be applied to in-situ recycling makes it a viable stabilization alternative when pavement need to be rehabilitated within time constraints.

Foamed tar is resistant to most common solvents encountered on airport pavements and thus provides a durable pavement layer.

Based on Gyratory compaction results of low PI foamed tar mixes the increased binder content of mixes results in a lower percentage of voids in the mix under simulated construction and traffic loading. It is important to ensure that sufficient voids are present during the lifetime of the pavement layer to inhibit permanent deformation of the pavement under loading.

The chemical composition of gasification tar is vastly different from the composition of coke oven tar. The reduced PAH concentration of gasification tar, in combination with the cold mix construction method and isolated, low temperature foaming process, significantly reduce the health risks associated with tar based pavement construction.

The numerous advantages of foamed tar in terms of strength with regard to other forms of stabilization, in combination with the economic, environmental, safety and efficiency of foamed recycling of materials provide airport engineers with a new, viable alternative to pavement construction and rehabilitation.

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