THE APPLICATION OF FOAMED TAR TECHNOLOGY TO LABOUR INTENSIVE CONSTRUCTION OF LOW VOLUME ROADS

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1 INTRODUCTION

The increasing scarcity of good road construction materials, combined with long haulage distances have necessitated the use of methods to improve substandard or existing materials through recycling. Although in-situ recycling has grown in prominence as a road construction alternative it necessitates the need for expensive equipment and expertise. Foamed tar provides a viable construction method for low volume roads through the application of labour intensive construction principles. Thus, the aim of this paper is to investigate the constructability of low-volume roads using foamed tar stabilisation with the assistance of the local community in infrastructure development.

The paper will firstly introduce the subject of foamed tar stabilisation and address the perceived health aspects associate with this product. The construction of the foamed tar base course will be discussed extensively, with particular reference being placed on the construction process, and associated limitations, and the transportation, placement and compaction of the foamed tar stabilised material. The stockpiling ability of foamed tar and the structural capacity of the constructed test section will be evaluated. Finally conclusions will be drawn concerning the application of this technology and its success in providing an economically viable alternative for the construction of low volume roads through community involvement.

2 GENERAL ASPECTS OF FOAMED TAR TECHNOLOGY

2.1 Foamed Tar Production and Characterisation

Foamed tar is produced through the introduction of cold water to heated tar. The latent energy of the heated tar causes the water to vaporise forming steam which expands and is simultaneously encapsulated by a thin film of tar. A state is reached at which the expansion pressure within the foamed tar bubbles is in equilibrium with the surface tension of the encapsulating tar. This state is referred to as the metastable life of the foamed tar, and is dependant on the thermal conductivity of the tar and water (Jenkins *et al*, 1999). As the foamed bubbles cool to ambient temperature, the steam contained within the bubbles condenses resulting in the collapse of the individual bubbles and decay of the foamed tar.

21st Annual South African Transport Conference
'Towards Building Capacity and Accelerating Delivery'
ISBN: 0-620-28855-8
South Africa, 15 - 19 July 2002
Conference organised by: Conference Planners
CD-ROM produced by: Document Transformation Technologies

Foamed tar is characterised by three parameters namely, expansion ratio; half-life; and foam index. The expansion ratio (ER) is the ratio of the maximum volume of the foamed tar during it's metastable life in relation to the volume of tar prior to foaming. The ER of tar ranges between 3 – 6, about 50% of the average for foamed bitumen, but still producing mixes with strength superior to those achieved with foamed bitumen comparative tests (Morton, 2001). The half-life ($\tau_{0.5}$) is the time in seconds necessary for the foamed tar to decay to half of its maximum volume after foaming has been completed. The foam index (FI) is defined as the area under the foamed tar decay curve and represents the energy stored within the foamed mix. Jenkins (2000) made use of the foam index as an additional parameter for characterisation of the foamed mix, since the ER and $\tau_{0.5}$ are merely two points on the foamed decay curve and thus neglect to take account of the entire decay curve, especially the section after the half-life has been attained. The FI can be used to optimise the additive content (Jenkins *et al*, 1999) as well as the foamant water content and the foaming temperature (Morton, 2001). Increasing the foaming temperature decreases $\tau_{0.5}$, which can have a significant affect on the foamed product.

Investigations during this study have shown that the phenolic content of tar contributes significantly to its foaming characteristics. High phenolic content tars produce larger expansion ratio's under similar foaming conditions to standard gasification tars. However the loss of workability due to the decreased half-life is notable. Low phenolic content tars are poor foaming constituents, with little visual change in the appearance of the tar prior to and after completion of foaming. Although low phenolic content tars are not suitable for foaming applications and use in pavement stabilisation, the foaming of low phenolic content tars does produce a workable product that could be utilised as a chip coating in other forms of pavement construction. Best tar foaming results occur at a foaming temperature of 100 – 120°C and foamant water content ranging from 1 – 2.5%, producing a expansion ratio > 4 and a half-life > 30 seconds (Morton, 2001).

2.2 Foamed Tar Mixes

Foamed tar forms only one part of three constituents necessary for the production of a foamed tar mix. The other two constituents are the aggregate and the mixing water content. The aggregate properties that have the greatest effect on the foamed tar mix is the gradation of the aggregate and Plasticity Index (PI). To produce a satisfactory foamed tar mix it is necessary for the aggregate to contain 5-12 % fines (material passing through the 0.075 mm sieve). Unlike with Hot Mix Asphalt where the binder coats the aggregate, the fines of a foamed tar mix coat the individual foamed tar bubbles to produce the foamed tar mortar. This process is essential for the stabilisation of the larger aggregate particles within the mix. Most notably Akeroyd & Hicks (1988) as well as Ruckel *et al* (1982) and Francken & Vanelstraete (1993) produced guidelines for aggregates suitable for the foaming process as well as the binder content necessary to ensure effective stabilisation of the material.

High PI materials are unsuitable for foaming processes due to the increased surface area of the fine particles causing an increase in the binder content necessary to coat the fines and produce the foamed mortar. This binder increase would be uneconomical unless lime stabilisation was used in conjunction with the foaming process.

Water content plays a vital role in the mixing, compaction and storage of foamed tar mixes. Water is the carrier of foamed binder. It separates the fine particles and suspends them in a liquid medium assisting in the coating of all the mineral particles (Csanyi, 1960). Based upon investigations performed on foamed tar mixes, it is recommended that the water content of the aggregate prior to foaming should be calculated as follows:

$$MC_f = OMC - \left[\frac{BC}{2}\right]$$

Where: MC_f = moisture content at foaming,
BC = foamed binder content, and
OMC = optimum moisture content of aggregate (AASHTO T 180-97)

2.3 Engineering Properties

Foamed tar mixes possess similar engineering properties to foamed bitumen – a stabilisation agent that has been extensively and successfully used to improve the engineering properties of poor quality pavement construction materials. Table 1 contains a comparison of the engineering properties of foamed tar and other stabilising agents (Morton, 2001 and Jenkins, 2000). The anti-stripping property of tar in combination with the structure of the compacted foamed tar mix makes the foamed tar mixes highly impervious to the effects of water over long exposure periods. The resulting high indirect tensile strength (ITS) retention property (> 60 % retained) is unique to foamed tar mixes. Further factors affecting the engineering properties of foamed tar mixes include mixing techniques and curing and compaction methods. Combined with compaction, curing is necessary to remove the water within the foamed tar mix, and initiate the drying and hardening of the binder resulting in strength increase of the stabilised material.

Table 1. Engineering properties of crushed stone treated with various stabilising agents

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

2.4 Health Aspects of Foamed Tar

Over the past three decades tar has been earmarked as the carcinogen causing numerous forms of cancer in persons in direct contact with tar products. In road construction tar has been ignored as a binder due to these health aspects. Although tar is used in certain aspects as a pavement binder, where its unique anti-stripping property and ability to withstand exposure to petroleum fuels are indispensable, in certain European countries its use has been banned. The carcinogenic behaviour of tar is measured in terms of the quantity of Benzo(a)pyrene (BaP) a polyaromatic hydrocarbon (PAH) and known carcinogen, tested on experimental animals, and found in coke oven tar (Jamieson,1971). However, the tar used in the foaming process is not a coke oven tar but a tar produced through the Lurgi gasification process. Gasifier tar is produced as a by-product of the fuel-from-coal process and contains only 10 % of the BaP found in normal coke oven tar. Furthermore, this significantly reduced BaP content is only released into the atmosphere at temperatures in excess of 300°C (Louwrens, 2001).

The foaming process takes place in a confined area, thus limiting the exposure of workers to the foamed tar. During foaming, the tar is heated to between 100°C and 130°C; temperatures lower than what is necessary to release the PAH's. The foamed tar mix is laid cold, thus negating the possibility of exposure of workers and the public to the fumes commonly associated with hot mix processes. Thus foamed tar produced through the controlled foaming of gasifier tar does not produce a larger health risk than current hot mix practices and furthermore removes the inherent possibility of burning associate with hot mix practices.

3 CONSTRUCTION OF A TEST SECTION USING LABOUR- INTENSIVE CONSTRUCTION METHODS

In order to investigate the constructability of foamed tar mixes, a 40 m^2 test section was constructed using labour intensive construction principles. This test section forms part of a bus lay-by constructed on the University of Pretoria campus in February 2001. Figure 1 illustrates the structural design for the test section. The construction method and materials used in completion of this project are addressed and factors specific to foamed tar base course (FTBC) construction discussed. Furthermore a comparison is made between the structural characteristics of foamed tar pavements and conventional pavement structures (see Figure 1).

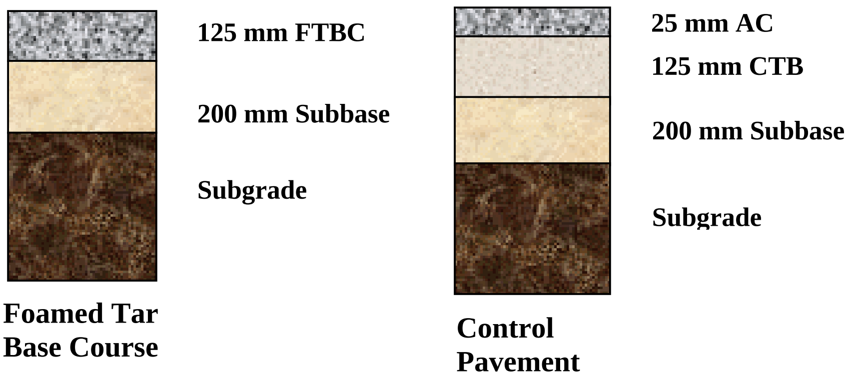

Figure 1. Structural design of FTBC and conventional pavement

3.1 Construction Materials

Binder and aggregate form the primary constituents of the FTBC. A 50 –60°C EVT gasifier tar supplied by Sasol was utilised to produce the foamed binder. The foamability of the tar was optimised using the foam index, half-life and expansion ratio with respect to foaming temperature and foamant water content (Morton, 2001). The following foaming parameters were used during the foamed tar mix production process:

- Foaming Temperature - 115°C
- Foamant Water Content - 2% per mass of binder

The aggregate used in the foaming process was a G2 crusher run obtained from Bon Accord with a continuous grading and a maximum aggregate size of 37.5 mm. PI was not a standard descriptor and the aggregate met the specifications shown in Figure 2. The aggregate was delivered for foaming in two batches with variations in fines content and material passing the 19 mm and retained on the 13.2 mm sieves (see Figure 2).

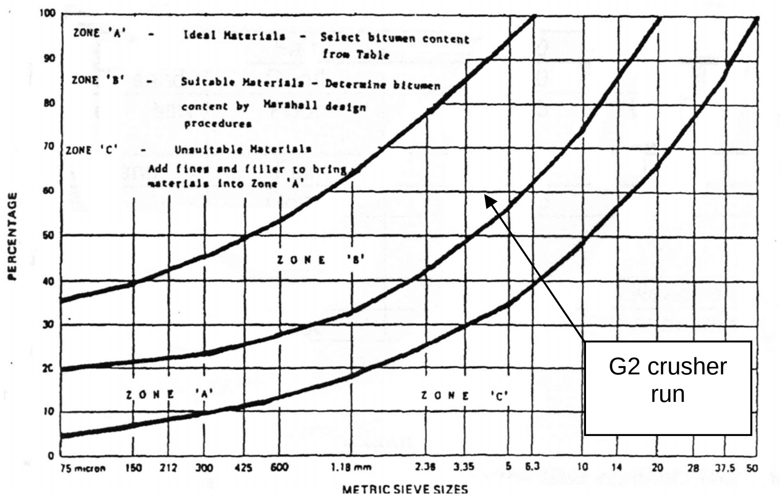

Figure 2. Material grading envelope including G2 crusher run gradation (Akeroyd & Hicks 1988)

3.2 Construction Equipment

During the foaming operation of the aggregate use was made of the following equipment at the Specialised Research Technologies (SRT) laboratories in Pretoria:

- Pan-type concrete mixer (max load of 80 kg)
- Heating ovens
- Wheelbarrows and spades
- Foam generator (in conjunction with air compressor)

The concrete mixer utilised was a pan type mixer with mixing blades revolving in opposing direction to the pan. Although this mixer ensured adequate mixing ability, the build up of excess foamed tar on the mixing blades hampered the production process. Due to limited space availability the ‘virgin’ and foamed material was stockpiled 50 metres from the foaming plant necessitating the use of wheelbarrows to haul the aggregate.

In addition to the transport of the aggregate between the stockpile and the foaming plant, the 50-60°C EVT tar needed to be heated prior to placement in the heating pot of the foaming generator. The heating pot had a capacity of 9.5 litres, which was insufficient to ensure the desired production rate. The tar was thus ‘poured’ into 25 litre drums, which were heated in the ovens to 110°C and thereafter used to replenish the tar in the heating pot. The heating pot merely served as a vessel to maintain the correct foaming temperature of the tar.

3.2.1 Foam Generator

The generator was designed for the experimental foaming of bitumen and has been used extensively in foamed bitumen investigations. It consists of a maze of piping, two pumps, an electric motor, a heating pot and foaming nozzle. A retrofitted pneumatic system operates the opening and closing of the foam nozzle, which is electronically controlled to ensure accurate account of the duration of foaming.

The foam generator circulates the tar between the heating pot and the foaming nozzle through temperature controlled copper piping. Heating of the entire tar circulation system is necessary to ensure a continuous uniform flow rate and prevent blockages within the foaming nozzle. The foam generating apparatus does not consist of a foaming chamber as in the original design by Csanyi (1957), but merely of a foaming nozzle where the heated tar is introduced to the cold water flow under air pressure. This process uses the atmosphere as its foaming chamber, thus negating the need for a foaming chamber on the foam generator. A slow foaming rate of 14 ml/sec was selected for production to compensate for the slow mixing rate in combination with the large quantity of aggregate being foamed in each batch. In this manner binder was adequately distributed throughout each batch.

3.3 Production

3.3.1 Personnel

For the production of the necessary 5m^3 foamed tar stockpile, four construction workers were seconded from the Roads Department of the City Council of Pretoria. One member of this crew was a laboratory assistant, capable of assisting in the monitoring of the foam generator. Thus a five man crew were responsible for the production and stockpiling of the mix.

3.3.2 Quantities

A binder content of 5 % per mass of aggregate was used during the construction of the foamed tar mix. This binder content was selected based upon investigations of the engineering properties of foamed tar mixes (Morton, 2001), in conjunction with the recommended binder contents given in TRH 14 (1985) for tar stabilised base materials. With the tar possessing a relative density of approximately 1, this meant that 525 litres of tar needed to be foamed and mixed with the 10.5 tons of G2 crusher run. This amounted to 210 foaming operations. Table 2 contains a summary of the production quantities of the 5 m^3 foamed tar stockpile. The moisture content of the aggregate was measured at 4% average over the 6 days of production.

Table 2. Production quantities for FTBC

Cumulative		**Per Mix**	
Aggregate	10.5 tons	Aggregate	50 kg
Tar	525 litres	Tar Content	2.5 litres
Water	10.21 litres	Water Content	50 ml

3.3.3 The Production Process

The aggregate was transported by wheelbarrow from the stockpile to the location of the mixing plant over a distance of approximately 50 metres. The aggregate was then tipped into a container that held approximately 50 kg of loose material. Once the aggregate was placed in the concrete mixer, it was mixed for 10 $\pm$ 2 seconds before the foaming process was initiated. The aggregate was foamed for 180 seconds while being continuously mixed, and was thereafter mixed for an additional 10 $\pm$ 2 seconds before being removed from the mixing pan and transported back to the stockpile area and dumped at a site adjacent to the virgin aggregate. The floor of this site was covered with plastic to prevent contamination of the foamed tar mix and ‘soiling’ of the concrete floor by the tar. Figure 3 illustrates the foaming plant consisting of foam generator and mixer.

3.3.4 Production Constraints

During the six days of production between 30 January and 7 February 2001, the environmental conditions varied significantly. The first three days were extremely hot, with maximum air temperatures between 29 – 33 °C. On the evening of Thursday 1 February heavy rains were experienced which continued over the weekend of 3 and 4 February.

Figure 3. Foaming plant consisting of foam generator and mixer

The high atmospheric temperature during the first stage of production ensured that the aggregate temperature was in excess of 40° C. This has the effect of increasing the half-life because of a smaller temperature differential between the aggregate and the foamed binder, resulting in improved foaming characteristics, mix distribution, and ultimately mix strength. However, the hot, dry conditions caused the development of an outer crust on the mix stockpile. Although this proved to have little visible effect on the foamed tar mix, merely sealing in the moisture investigations of the strength characteristics of this dried material showed that the strength of the mix is affected by duration of stockpiling, as shown in Figure 4. It is advisable to protect the stockpile from excessive heat and direct sunlight by covering the stockpile with a tarpaulin if stockpiling duration extends more than 7 days (Morton, 2001).

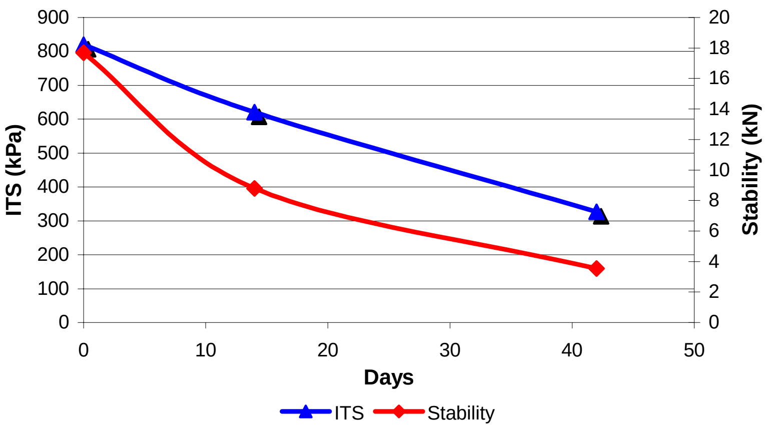

Figure 4. Effect of stockpiling on strength of foamed tar mixes (5% binder content)

The cold wet weather proved to be a distinct disadvantage to production rate as well as to the quality of the product produced. The lower ambient temperatures meant that frequent blockages occurred in the foaming nozzle that needed to be rectified by heating the nozzle with a gas burner. This was a time consuming operation. The moist atmospheric conditions in combination with the rain increased the moisture content of the aggregate above the optimum of 7% thus retarding the production process. The moist conditions caused the fine material to cling together as well as to the surface of the mixer, facilitating an increased aggregate mixing time before foaming could commence. This additional mixing was to ensure that the fine material was dispersed sufficiently within the mix for satisfactory foaming of the material. Rain was unable to penetrate the foamed mix or wash out the fines, which were held within the mix by the foamed tar binder. Consequently the wet weather had no effect on the foamed tar stockpile

3.4 Transport and Placing of the Foamed Tar Mix

The loading and transportation of the foamed tar stockpile was completed with the 'trailer-loader-backacter' (TLB) and a tip truck. The stockpile was moved from SRT to the construction site in Roper Street in two loads. The tipper truck was used to tip the foamed tar mix in four small stockpiles directly onto the subbase on which the FTBC was to be constructed. Thereafter the construction crew used shovels to distribute the foamed tar material into position and levelled the base course with a straight edge. The layer was spread out at a thickness of approximately 140 mm. Figure 5 illustrates the placing of the FTBC prior to compaction.

It should be noted that the use of the TLB and tip truck was only necessitated by the distance from the mixing plant to the site. The plant could not be placed on site at time of construction since the street under construction was still open to traffic during the production of the foamed tar stockpile. In standard construction circumstances the plant would be placed adjacent to the site negating the need for heavy construction equipment.

3.5 Compaction of Foamed Tar Base Course

Compaction of the FTBC was performed by a 1 tonne Bomag and a 2 tonne steel vibratory roller operating at 45 Hz. The material was compacted with the smaller compaction machines because of the limitations resulting from the 20 x 2-metre construction area. Approximately 20 passes were completed with the 2 tonne roller, after the Bomag had been used for the initial compaction. Figure 6 shows the Bomag being used in compaction of the test section. During compaction it was noticeable that two factors would play a vital role in the finished product, namely segregation, which was the primary factor, and gradation.

Figure 5. FTBC prior to compaction

Figure 6. Compaction of FTBC

The loading by the TLB and transportation and tipping of the foamed mix by the 6 ton tip truck caused segregation of the mix. Because of the limitations placed on the size of the construction site, it was not possible to make use of a grader to blade the material and remix the fines with the sand and stone constituting the foamed tar mix. Another factor contributing to the segregation was the use of rakes to spread the mix, causing the larger and coarser material to collect on the southern extremity of the site, (see Figure 6). It should be noted that the mix, in its entirety, did conform to the grading requirements specified by Jenkins (2000) and Akeroyd & Hicks (1998).

As mentioned previously, the grading of batch 2 lacked fines. During compaction of the foamed tar mix produced using batch 2 aggregate it was evident that insufficient fines were available to form a suitable mastic between the larger aggregate particles. The combined effects of segregation, and in certain localities gradation, produced a coarse final product with visible air voids illustrated in Figure 7.


Figure 6. Segregation of FTBC mix


Figure 7. FTBC section lacking fines

Bulking of the layer was surprisingly low, with the approximately 140 mm thick loose layer only consolidating 15 mm during compaction. No additional moisture was added to the material during initial compaction, although water was used for the recompaction of the areas suspected of a lack of fines. The addition of water resulted in no marked difference to the compaction effort necessary to ensure the formation of a strong, durable layer.

3.6 Recompaction

Due to the problems experienced concerning segregation, combined with the damage caused to the FTBC by heavy machinery operating on an adjacent site, it was necessary to rip and recompact an isolated section of the FTBC before sealing. To improve the grading of the areas lacking in fines, 100 kg of minus 19 mm foamed tar mix was produced and added to the ripped material before recompaction. Water was also added to the ripped material to adjust the water content of the 'rejuvenated' material to that of the material prior to initial compaction.

It was noticeable that although this recompaction occurred two days after initial compaction, the foamed tar mix still compacted easily upon rolling with the Bomag. This observation further substantiates the claims made by other researchers of foamed stabilising agents that although compaction plays an important role in the strength gain, curing and hardening of the binder does not occur within 48 hours of placement and compaction. This allows the engineer to recompact or rehabilitate unsatisfactory sections quickly, easily and cost effectively. This is one of the major advantages of foamed tar stabilisation over conventional stabilisation with emulsion or cement. Figures 8 and 9 illustrate the recompacted FTBC and the final test section after surfacing with a 5 mm Slurry seal, respectively.

Figure 8. Recompacted FTBC

Figure 9. Completed test section

4 STRUCTURAL ANALYSIS

Laboratory investigations of foamed tar mixes have shown that foamed tar stabilised materials match, and in certain circumstances, surpass the strength and durability characteristics of foamed bitumen or emulsion stabilised materials (Morton, 2001). In order to ascertain the structural capacity and field performance of foamed tar mixes, non-destructive performance testing was carried out on the constructed test section. The Falling Weight Deflectometer (FWD) was utilised for this testing.

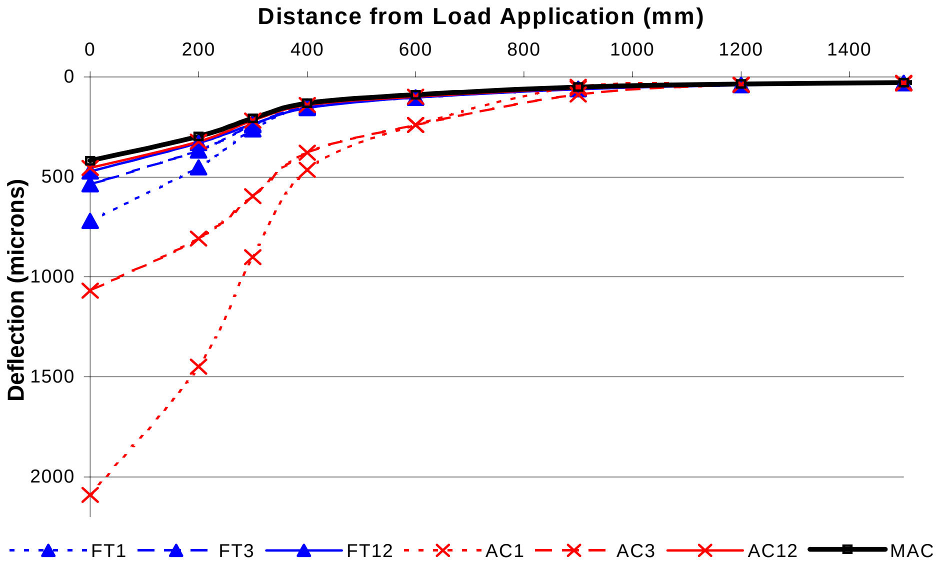

Figure 10. Deflection basin measurements from FWD testing

Figure 10 illustrates the average deflection basins obtained at 1, 3 and 12 months after construction for the FTBC (FT), the existing macadam pavement (MAC) and the cemented base and asphalt overlay (AC) constructed adjacent to the foamed tar test section. It is noticeable that the AC pavement initially (1 – 3 months) exhibits substantially higher deflections than the FTBC pavement 200 – 600 mm region, which is an indicator of the structural capacity of the base layer in a pavement. This illustrates the rapid strength gain of the FTBC over the conventional AC pavement. At 12 months the FTBC and AC pavement display similar deflections to the macadam pavement. This further substantiates the strength of the FTBC as the structural capacity of macadam is well-known. It simulates the strength of a pavement that has been constructed at least fifteen years prior and shows no significant damage in terms of rutting and deformation. Thus the results of the FWD analysis of the foamed tar test section can be viewed as highly promising.

5 CONCLUSIONS

Foamed tar mixes are inherently suited to labour intensive construction principles. Standard construction and foam generation equipment can be utilised to successfully construct a foamed tar stabilised pavement material. Limitations placed upon the experimental project in terms of batch size and tar heating can be overcome through the use of a larger and more efficient mixer and retrofitting the foam generator with a larger heating pot. Approximately 2 tons of foamed tar stabilised material was produced per day under these limitations by a construction crew of five. Since foamed tar mixes are applied at ambient temperature labour intensive construction can be employed for the loading, unloading, and spreading of the material prior to compaction. The stockpiling ability of foamed tar provides flexibility of construction with regards to placement and compaction time, as well as scheduling of workers. Materials can be foam stabilised and stockpiled for later placement and compaction by the same personnel.

The water content within the foamed aggregate affects the binder distribution within the mix. The grading of the aggregate used for foamed tar mix production is crucial for adequate foamed mix production. A continuous grading produces the best foamed mix. The percentage fines (<0.075 mm) are important and should be between 8 and 12% per mass of the aggregate sample. The relationship between fines (<0.075 mm), sand (0.075 - 4.25 mm) and stone (>4.75 mm) affects the formation of the foamed tar mortar.

Mixing rate and mixing time need to be considered with respect to foaming rate. The foaming rate should be matched to the half-life of the foamed tar. The workability of foamed tar mixes is similar to that of unmodified granular materials and compaction methods applicable to granular bases are applicable to the compaction of foamed tar mixes. Foamed tar mixes exhibit rapid strength gain in comparison to certain conventional pavement construction methods as validated by non-destructive performance testing using the FWD.

Segregation of foamed tar mixes affects the strength of the compacted layer and should be avoided. The strength of foamed tar mixes relies on a continuously graded mix with good binder distribution. If the mix segregates during transportation or placement, areas will occur where there is a lack of foamed mortar between the large aggregates, ultimately resulting in a weaker pavement structure.

Foamed tar mixes can be recompacted within 48 hours of initial compaction. The compaction effort applied by the roller does not remove all the water from the foamed tar mix. Thus there is sufficient water available to ensure that the mix can be recompacted up to 24 hours after initial compaction provided that additives such as cement, commonly associated with foamed bitumen stabilisation, were not used in the stabilisation process.

Foamed tar requires less energy to produce than Hot Mix Asphalt since no heating of the aggregate is required during the process. This substantial energy saving in combination with the economic benefits of using a widely available by-product, make foamed tar an efficient and viable stabilisation alternative. This labour intensive construction process is especially relevant in circumstances where low volume roads need to be constructed cheaply and community involvement and economic upliftment are primary concerns.

6 ACKNOWLEDGEMENTS

This work was supported by a grant from the Technology and Human Resources for Industry Programme (THRIP); a partnership programme funded by the South African Department of Trade and Industry and managed by the National Research Foundation. The industry partners were Sasol Carbo-Tar, and the City Council of Pretoria, whose assistance is gratefully acknowledged.

REFERENCES

1. AASTHO. (1998). *Standard Test Methods for Transportation Materials and Methods of Sampling and Testing.* American Association of State Highway and Transportation Officials.
2. Akeroyd, F.M.L. and Hicks, B.J. (1988). *Foamed Bitumen Road Recycling*. Highways, January. London, UK. Pp 42-45.
3. Csanyi, L.H. (1957). *Foamed Asphalt in Bituminous Paving Mixes*. Highway Research Board Bulletin Volume 10 No. 160. Pp 108-122.
4. Csanyi, L.H. (1960). *Bituminous Mixes Prepared with Foamed Asphalt*. Iowa Engineering Experiment Station Bulletin No. 189, Iowa State University, USA.
5. Francken, L. and Vanelstraete, A. (1993*). New Developments in Analytical Asphalt Mix Design*. Proceedings of the Eurobitumen Conference, Stockholm.
6. Jamieson, I.L. (1971). *Carcinogenic potency of tar in road construction*.
7. Jenkins, K.J. (2000). *Mix Design Considerations for Cold and Half-Warm Bituminous Mixes with Emphasis on Foamed Bitumen*. Doctoral Thesis, University of Stellenbosch, South Africa
8. Jenkins, K.J., van de Ven, M.F.C. and de Groot, J.L.A. (1999). *Characterisation of Foamed Bitumen.* Proceedings of 7th Conference on Asphalt Pavements of Southern Africa, South Africa.
9. Louwrens, H. (2001). *Personal Correspondence Concerning the Chemical Composition of Sasol Carbo-Tar.* University of Pretoria, South Africa.
10. Morton, B.S. (2001). *The Foamability of Tar and Engineering Properties of Foamed Tar Mixes.* MEng Dissertation. University of Pretoria, South Africa.
11. Ruckel, P.J., Acott, S.M. and Bowering, R.H. (1982). *Foamed-Asphalt Paving Mixtures: Preparation of Design Mixes and Treatment of Test Specimens.* Transportation Research Record 911Pp 88-95, TRB, Washington D.C.
12. TRH 14. (1984). *Guidelines for Road Construction Materials*. Committee of State Road Authorities, Pretoria, South Africa.

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Bruce Morton studied at University of Pretoria acquiring his bachelors degree in Civil Engineering in 2000 and a masters degree in Transportation Engineering in 2001. He has recently completed a masters of science degree at the University of California, Berkeley specializing in Traffic and Transportation Studies. He was the principal investigator into the use of foamed stabilization methods at the University of Pretoria and assisted in the California Accelerated Pavement Testing Program at the Pavement Research Center in California. His experience and research interests focus on foamed treated materials stabilization, labour intensive pavement construction of low volume roads, and HVS accelerated pavement testing.