

# Developments in the uses of foamed bitumen in road pavements

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Following the lapse in patent rights on foam-producing nozzles, the use of foamed bitumen for the improvement of road construction materials has become more accessible and as a result, its use increased considerably in the 1990's. In addition, the applications of foamed bitumen process have diversified. No longer is the process only used for the production of cold bituminous mixes with good quality aggregates, but it is being applied to marginal materials including crushed building rubble, recycled materials such as reclaimed asphalt pavement (RAP), contaminated materials, surface dressings and even pre-warmed aggregates. Each application has its own requirements in terms of optimal foamed bitumen properties and mix requirements. This paper provides an overview of the applications of foamed bitumen, highlighting some of the fundamental differences between desired foam characteristics and typical mix properties.

*Keywords:* foamed bitumen, coldmix, marginal materials

## 1 Background to Foamed Bitumen

Foamed bitumen can be produced through the injection of small quantities of cold moleculised water, as a fine mist, into hot penetration grade bitumen in an expansion chamber. Whilst it is foaming (which may last about 20 seconds), the bitumen is in a temporary state of low viscosity and can be mixed with mineral aggregates at ambient temperatures and at in situ moisture contents. This is

analogous to a viscous egg being beaten into foam of low viscosity before being added to flour (mineral) and mixed for baking purposes.

The production of foamed bitumen is not reliant on mechanical energy but rather on heat transfer, as illustrated in Figure 1. The cold water droplets are heated above the latent heat of steam as they make contact with the hot bitumen (at about 170°C) and expand within bitumen bubbles to form foam. This foam is mixed with mineral aggregates to form a bitumen bound mixture.

With the growing global application of the foamed bitumen process in recent years, it has become increasingly necessary to more clearly understand the properties of the foam and the mix itself. The objective should be to gain an appreciation of the interaction of the foamed bitumen with the mineral aggregate at the various stages of the manufacture and construction process. In so doing, the optimisation of both the foam and the mix can become possible.

As the use of foamed bitumen has increased, so have the different areas of application. Back in 1957 Csanyi [1] perceived foamed bitumen as a means of improving the quality of marginal aggregates such as loess, to enable them to be used in road pavements. Subsequently, foamed bitumen has been found to produce cold mixtures when added to mineral aggregates of varying qualities, where the mix can be placed and compacted at ambient temperatures. These qualities have encouraged the use of foamed bitumen for rehabilitation of road pavements through the use of cold in place recycling.

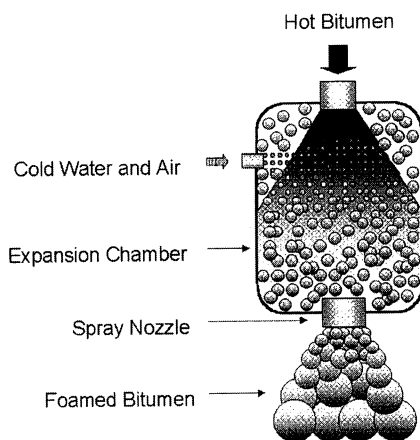


Figure 1. Foamed bitumen production

Some of the main applications of foamed bitumen include use as a binder for:

- a) specialist surface dressings,
- b) conventional cold mixes with good quality or marginal aggregates,
- c) cold mixes with Reclaimed Asphalt Pavement (RAP) material,
- d) half-warm (higher quality) foamed bitumen mixes, and
- e) encapsulation or immobilisation of contaminants such as asbestos or tar in mineral aggregates (where permitted).

Each of the various applications of foamed bitumen requires different characteristics from the foam for optimal performance of the mixture. These requirements not only influence the choice of the bitumen type, but also the preferred temperature of the bitumen for foaming, the selection of foam-enhancing agents or foamants (if any) and the application rate of the foamant water (the cold water added in Figure 1).

## 2 Optimisation of the Foam

### 2.1 Types of Foamed Bitumen

Two parameters are important when considering the suitability of foamed bitumen for use in binding mineral aggregate together. The parameters are:

- the Expansion Ratio, which is a measure of the viscosity of the foam and will determine how well the binder will disperse in the mix. It is calculated as the ratio of the maximum volume of foam relative to the original volume of bitumen, and
- the Half-life, which is a measure of the stability of the foam and indicates the rate of collapse of the foam during mixing. It is calculated as the time taken in seconds for the foam to collapse to half of its maximum volume.

Although experience of working with foamed mixes has helped to identify desired values for the expansion ratio and half-life, these two variables are dependent and their optimisation is not simple. The parameters are dependent variables, for example with both being a function of foamant water application rate, see Figure 2.

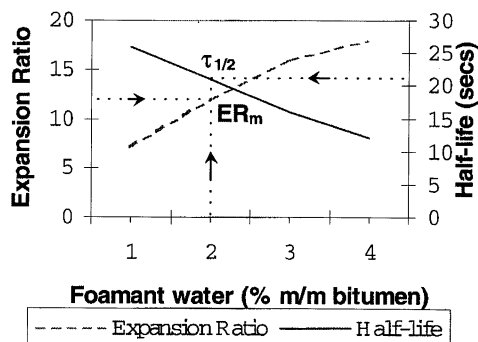


Figure 2. Example of Foam Characteristics Relative to Amount of Foamant Water Added

This figure is typical of a sensitivity analysis currently used to determine the amount of water that should be added to a particular type of bitumen in order to produce desired foam. The selection of an optimum foamant water application rate from Figure 2 is not possible and no account is taken of the fact that the optimal foam properties depend on its particular type of application e.g. cold mix or half-warm mix production.

The Foam Index, which is a measure of a combination of expansion ratio (ER) and half-life ( $\tau_{1/2}$ ), has been shown to be useful for identifying the optimal properties, Jenkins *et al* [2,3]. Instead of

using merely these two points that define the decay of the foam ( $ER$  and  $\tau_{1/2}$ ), the Foam Index is calculated from the entire curve of foam expansion versus time.

## 2.2 Foam Index

The area under a decay curve for foamed bitumen is defined as the Foam Index [2,3]. The area is calculated for the purpose of optimising the foamant water application rate and that of a foamant, if used. A value of 4 for the expansion ratio has been determined to be the minimum for appropriate mixing viscosity of the foam. In order to account for variation in the time needed to discharge i.e. spray the foam under laboratory conditions, which may vary from 2 to 20 seconds in different set-ups, the decay curve is extrapolated back over the duration of the spraying. In this way the actual expansion ratio ( $ER_a$ ) may be obtained from the measured expansion ratio ( $ER_m$ ), see Figure 3 and Figure 4.

$$\text{Foam Index} = A_1 + A_2$$

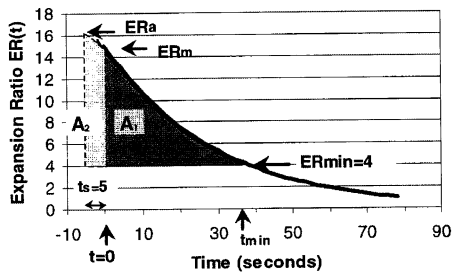


Figure 3. Foam Index calculation for Asymptotic Decay at one Foamant Water Application Rate

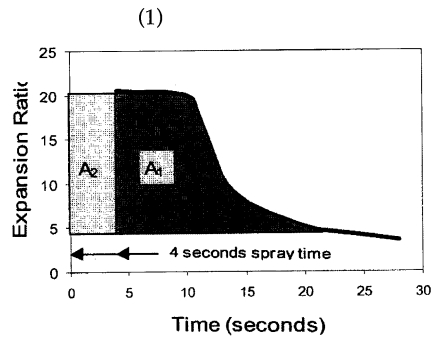


Figure 4. Foam Index for Non-Asymptotic Decay Foam at one Foamant Water Application Rate

A sensitivity analysis of the foam is necessary to determine the optimum conditions for foam production. The foamant water (or foamant) application rate is varied and the Foam Index determined. In this manner, a relationship as shown in Figure 5 is obtained.

The shift in Foam Index value for bitumen dosed with a foamant, is significant. This is a result of the proportionate increase in the FI to the increase in half-life. Consider, for example, the formula [2,3] for the calculation of the FI for foam with *asymptotic decay*:

$$FI = \frac{-\tau_{1/2}}{\ln 2} \left( 4 - ER_m - 4 \ln \left( \frac{4}{ER_m} \right) \right) + \left( \frac{1+c}{2c} \right) * ER_m * t_s \quad (2)$$

Where,

$ER_m$  = Maximum Measured Expansion Ratio (immediately after discharge, where net expansion of foam is considered, excluding the bitumen volume)

$ER_a$  = Actual Maximum Expansion Ratio (back-calculated)

$C$  =  $ER_m/ER_a$

$\tau_{1/2}$  = half-life (seconds)

$t_s$  = time of spraying to discharge all foam (sec)

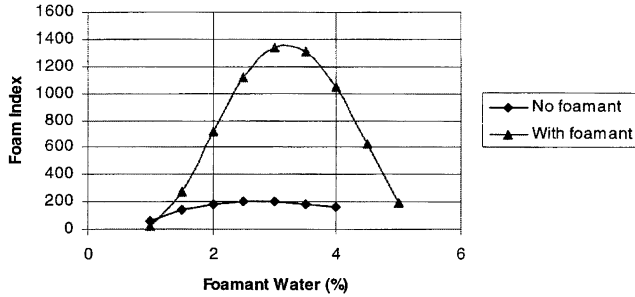


Figure 5. Optimisation of Foamed Bitumen Characteristics for a Typical Bitumen (Calref 150/200) using the Foam Index

Using Equation 2, an increase in  $\tau_{1/2}$  will proportionately increase the FI. In order to take account of the different types of foam that different mixes require e.g. expansion is important for encapsulation but stability is relatively more important for cold mixes, the Foam Index should not be considered in isolation but rather in conjunction with  $ER_a$  and  $\tau_{1/2}$ . The limiting values of these parameters for different types of foamed mixes are provided in Table 1.

Table 1. Limiting Values of Foam Characteristics for Different Mixes, based on Asymptotic Decay Foam

Foamed Bitumen Mix Type	Minimum Values		
	$ER_a$	$\tau_{1/2}$	Foam Index (sec)
Surface Dressing	10	30	131
Cold Mix	15	15	164
RAP & Half-warm	17	13	180
Encapsulation	25	10	257

The limiting values for  $ER_a$  and  $\tau_{1/2}$  have the effect of providing slightly higher optimum foamant water application rates for foam intended for encapsulation mixes (thus encouraging higher expansion) and lower optimum values for surface dressing type mixes (thus ensuring longer half-lives).

### 3 Applications of Foamed Bitumen Mixes

As the usage of foamed bitumen increases in roads industry, so the variety of applications increase too. Although the initial purpose of foamed bitumen was to improve the quality of marginal aggregates to a standard acceptable for use in road pavements, current applications go beyond this level and promise to extend further.

The dispersion of the bitumen in a foamed mix is not the same as that of hot mix asphalt (HMA). With HMA, the bitumen completely coats the aggregate of all different sizes and is distributed as a continuum within the mix. Foamed mixes are characterised by only partial coating of large mineral aggregate particles and a distribution of bitumen droplets in the mix. A number of variables influence the binder distribution. The main factors are:

- **Foamed bitumen characteristics:** The viscosity (measured by the Expansion Ratio) and stability (measured by the Half-life) of the foamed bitumen influence the manner in which the binder is distributed in the mix [3].
- **Mixing technique:** A variety of mixing techniques exist for the manufacture of foamed mixes, including twin-shaft pugmills, in situ recyclers and free-fall mixers, each of which has a different mixing energy and duration. Considering the short life of the foamed bitumen, measurable in seconds, the type of mixer directly influences the characteristics of the mix.
- **Aggregate gradation:** Due to the foam bitumen's affinity for the finer mineral aggregate particles, the binder has a greater concentration in the fine fraction of the mix. Gap-graded foam mixes can experience balling where the bitumen does not bond with the larger particles at all.
- **Aggregate moisture content before mixing:** The moisture in the mix is the medium for the distribution of the foamed binder. Without moisture, lumps of fine aggregate and binder are formed, and the mortar of the mix i.e. sand, filler and binder, behaves in the same manner as HMA mortar. The inclusion of moisture in the filler-foamed binder component i.e. mastic, makes it stiffer than that of HMA at the same filler-binder ratio [5]. Although the moisture content at which the aggregate has its maximum volume (fluff point) is recommended for cold foam mixes i.e. 65% to 85% of Modified AASHTO Optimum Moisture Content (OMC), this is not applicable to absorptive and half-warm aggregates.
- **Aggregate temperature:** The temperature of the aggregate before mixing has an overwhelming influence on the equilibrium mix temperature. The transfer of heat from the foam at just over 100°C to the aggregate at less than 30°C will influence the rate of collapse of the foam i.e. the rate of viscosity increase of the binder during mixing. The overall temperature of the mix will increase by less than 10°C with the addition of foamed bitumen.

#### 3.1 Cold Mixes with Foamed Bitumen

The manufacture of a cold mix through the application of foamed bitumen to moist mineral aggregate at ambient temperature is the most widely practised form of the foamed bitumen process. As the foam is agitated into the mineral aggregate, the bubbles collapse quickly leaving small bitumen droplets and partially coated aggregate. The moisture in the mix provides a medium in which the

droplets of bitumen can be dispersed in the mix. The moisture also provides the mix with a unique quality i.e. the ability to be worked and compacted at ambient temperatures after mixing.

The types of materials that have been utilised for the manufacture of foamed mixes include sands, weathered gravel, crushed aggregate and RAP. The foamed mixes produced can be used for base and sub-base layers for pavements. The layer thickness, position of the layer in a pavement structure and the level of traffic are all factors that influence the selection of the appropriate material for treatment with foamed bitumen. Some of the features of these cold foamed mixes include:

- Low energy consumption because only the bitumen is heated and not the aggregate. Nor is the aggregate dried.
- Good resistance to permanent deformation relative to the equivalent hot mix.
- Less susceptibility to loading frequency (and temperature) than HMA, refer [6].
- Lower tensile strengths than equivalent HMA.
- Ability to be stockpiled for several months.

The selected binder content of foamed mixes is invariably lower than the equivalent hot mix. This is primarily due to the partial coating of the large aggregate by the foamed bitumen, leaving more bitumen free for making up the mix mortar. Bitumen with a penetration of softer than 80 is usually selected for use as the foam.

Several practical requirements form part of cold foamed mix application:

- Aggregate temperatures should not drop below 10°C, as this has an inverse effect on the tensile strength of the mix, see Figure 6.
- Moisture content of the aggregate before mixing should be just below optimum (approximately 60% to 80% of OMC for the natural aggregate from Modified AASHTO compaction). The moisture content is measured as the percentage m/m of water on the dry aggregate.
- Some form of anti-stripping agent is recommended in the foamed mix, either in the form of amines or about 1% of active filler. This reduces the moisture susceptibility of foamed mixes, which can be high.
- Compaction levels of 97% to 100% of Modified AASHTO density can be readily achieved, but void contents equivalent to HMA are often not achievable, due to the moisture present in the mix at the time of compaction.
- Cold mixes with foamed bitumen are most vulnerable in terms of deformation and ravelling, early in their life before significant curing has taken place. Curing is the process whereby water is dispelled from a mix with time after compaction and is dependent on climate, layer depth, air voids, permeability and other factors. It is usually associated with strength gain of a cold mix. The rate of curing and strength gain of foamed mixes is considerably quicker than bitumen emulsion mixtures.

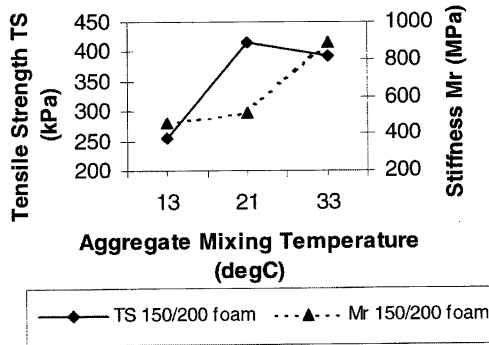


Figure 6. Influence of Aggregate Temperature on 80th Percentile Tensile Strength and Stiffness (Mr) of Foamed Gravel Mix measured in SCB Tests (4 tests per point)

### 3.2 Half-warm foamed bitumen mixes

The significant benefits that can be achieved through moderate heating of the aggregates before treatment with foamed bitumen have until recently been ignored. However, a feasibility study into these “Half-warm foamed bitumen mixes” undertaken in 1999 [7] has yielded positive results and highlighted the potential benefits.

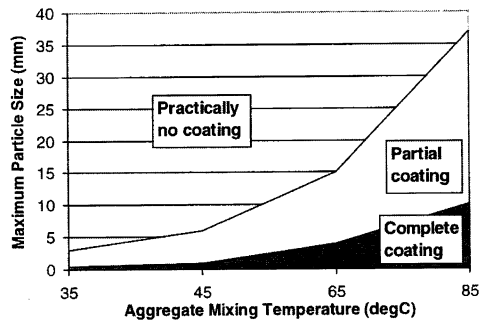


Figure 7. Particle Coating as a Function of Aggregate Temperature during Mixing with Foamed Bitumen, for a particular crushed aggregate

The primary reason for heating the mineral aggregate in half-warm mixes is its influence on bitumen distribution. The coating of the mineral aggregate particles of an asphaltic mix has an influence on the performance of the mix. Improving the distribution of binder within a bituminous mix can increase the durability, resistance to water damage and consistency of that mix. For this reason, specifications of minimum film thickness of binder on the aggregate in hot mixes are used in various countries. The implications of improvement in this parameter through the use of half-warm mixes are self-evident.



Particle coating is especially significant to foamed-mixes where the bitumen droplets or “spot-welds” of bitumen provide the tensile strength in the mix and if they are more evenly distributed, it could create a more continuous network or web of binder, which would increase the fatigue resistance of the mix. A visual inspection of mixes made using the half-warm process was shown to indeed provide improved particle coating, see Figure 7.

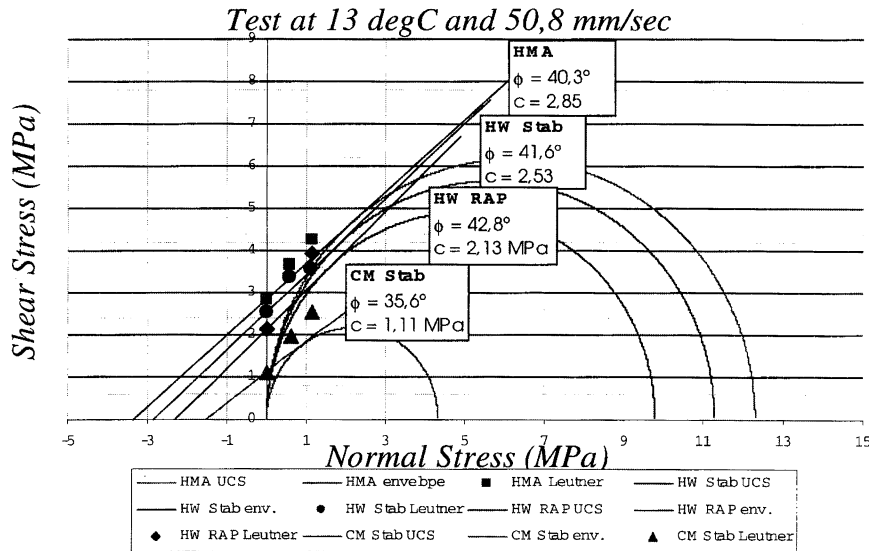


Figure 8. Shear Properties of Hot Mix (HMA) Stab, Half-warm Foamed (HW) Stab, Half-warm Recycled (HW RAP) Stab and Cold Mix (CM) Stab.

The influence of the improved binder dispersion found in half-warm foamed mixes, on mechanical properties of the mix, is observed with continuously graded material called Stab, see Figure 8. All the materials in this figure have the same aggregate, gradation, binder content and degree of compaction (with some variability). A combination of compressive tests and shear tests on the same mix components combined in four different processes and compacted to the same density is shown in the Mohr-Coloumb space. The benefits of heating the aggregate before the application of the foamed bitumen is apparent the notable increase in the failure envelope. The improved binder dispersion is reflected through greater cohesion in the mix.

#### 4 Conclusions & Remarks

Some general comments may be made with regard to foamed bitumen mixes:

- The characteristics of the foam from specific bitumen should be optimised according to the type of application. The Foam Index is a useful function for this optimisation procedure, assisting in the selection of a suitable water application rate.

- The intrinsic properties of cold foamed bitumen mixes provide them with desirable characteristics compared with HMA. For example, lower binder contents may be utilised which will reduce temperature susceptibility of the mix. The moisture susceptibility of foamed mix is, however, poorer than HMA.
- Pre-warming of aggregates before treatment with foamed bitumen improves the tensile strength and compaction levels of a foamed mix. The influence of the Half-warm Foamed Bitumen Process on the mix properties has been determined in terms of Mohr circles, where improved failure envelopes to cold mix have been calculated.

## 5 Nomenclature

$ER_a$	=	Expansion Ratio (actual)
$ER_m$	=	Expansion Ratio (measured)
$\tau_{1/2}$	=	Half-life measured in seconds
FI	=	Foam Index
RAP	=	Reclaimed Asphalt pavement
HMA	=	Hot Mix Asphalt
OMC	=	Optimum Moisture Content

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