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Advantages and limitations of using foamed bitumen

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Abstract: Foamed asphalt refers to a bituminous mixture of road-building aggregates and foamed bitumen, produced by a cold mix process. There are a lot of related issue that has not been sufficiently investigated so far. It is worthwhile to overview the main theoretical and practical results in the field in several countries including those of the authors of the paper. It is clear that the foamed asphalt is usually characterized by high quality and reasonable cost, can be used in cold road pavement rehabilitation, in addition to it the technique is environ-mentally friendly preserving natural resources. Using foamed bitumen reduces the emissions of carbon dioxide and gases resulting from combustion, especially when it is used as a cold rehabilitation binder and mixed with re-claimed asphalt pavement materials.

Keywords: foamed bitumen; warm mix asphalt; reclaimed asphalt pavement

1. Introduction

The use of foamed bitumen in road infrastructure projects starts in the mid-1950s [1]. First it was applied for soil and base stabilization using hot liquid bitumen foamed by steam [2]. In 1968, the foaming process was modified by Mobil Oil Australia [3]. In this process, known as mechanical foaming, the hot liquid bitumen was mixed by a controlled flow of cold water (rather than steam) in an expansion chamber, and was carried through a nozzle onto the aggregate mass [4]. The foamed

bitumen has been used in the stabilization of a variety of materials including RAP (Reclaimed Asphalt Pavement material) as a part of cold recycling, and can be applied as pavement and base material for low and heavily trafficked roads [5]. In order to improve the coating ability and workability of foamed bitumen, it was mixed with aggregates pre-heated to different temperatures [6]. Later, recent foaming technologies developed to be included the incorporation of zeolites, i.e. metal additives having some 18–20wt% of water in their internal structure [7].

2. Bitumen foaming techniques

Foamed bitumen can be produced by applying appropriate shares of air, bitumen and water. It has much lower viscosity (being in its liquid state) than the same bitumen before foaming process, and its volume is expanded up to (20) times its original volume; in such a way it becomes suitable for mixing with cold (even damp) aggregates [8]. So, bitumen foaming is a comprehensive concept that a small amount of cold water (1-4% by weight) is introduced into very hot (160-200 ℃) asphalt at a certain pressure. Then the hot bitumen – in direct contact with water – expands scattering the binder into air that spreads the bitumen 5-20 times its initial size, see in Fig. 1 [9].

Optimal amount of water needed for asphalt foaming spans between 2 and 4 wt% with regards to the asphalt mass, in case of insufficient amount of water the foaming is ineffective, whereas with the excessive water there is a significant risk of adhesion failure between asphalt and aggregate [10].

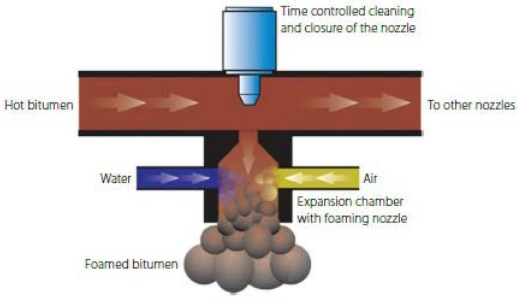

Figure 1. Schematic process of bitumen foaming

The following parameters of foamed bitumen are widespread [8]:

- Expansion Ratio (ER): ratio of the maximum volume of foam related to the original volume of bitumen (Fig. 2).

- Half Life (HL): the time measured in seconds for foam asphalt to descend from its maximum volume upon expansion to half the volume of expansion, see in Fig. 2 [11].
- Foam Index (FI): an area of the decay curve within specific limits providing an integrated measure of expansion and stability of foam [14]; it characterizes the "foamability" of a bitumen for a given foamant water application rate (Fig. 3) [6].
- Collapse rate of semi-stable bubbles (k-value): analysing images of the surface of foamed bitumen by taking periodically photos as it collapses over time and the bubble size distribution for a typical foamed bitumen using 1wt% water [12].

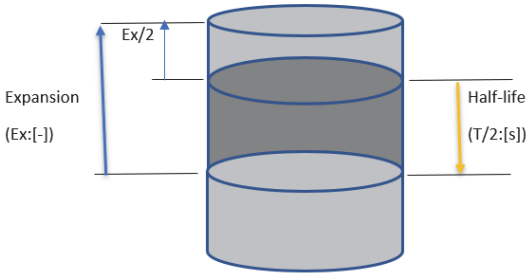

Figure 2. Main parameters for foamed bitumen

3. Production methods of foamed bitumen

Foamed bitumen can be produced by the injection of water and air into hot bitumen at 150-180 °C [13]. The reaction between water and hot bitumen leads to heat exchange between water and bitumen. Consequently, water is converted into steam that is pushed into the bitumen chain under pressure forming many vapour-containing bitumen bubbles containing [14].

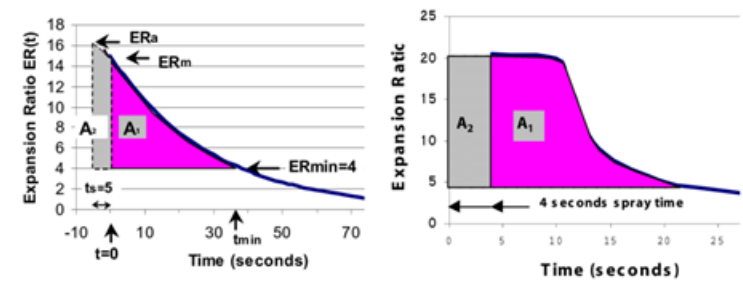

Figure 3. Foam Index calculation for Asymptotic and Non-Asymptotic Decay [14]

There are various techniques with different levels of water contents by bitumen weight 1-3%, bitumen temperatures 140-200 ºC and air pressures of 100-1000 kPa. In the foaming process, the water vapour is coated within a binder in the form of many small to large sized water bubbles [5]. For example, in case of Wirtgen WLB 10 S foaming plant, foaming is done by adding 3 wt% water to hot bitumen at 160°C at a compressed air of 500 kPa [11].

Another widely used technique is the addition of zeolite to bitumen at a rate of 5% by the total asphalt binder [15]. Zeolites allow for asphalt foaming due to the incremental release of water stored in their internal structure. Discharge of zeolite water from the crystalline structure is a long-term process. Therefore, it is feasible to improve warm mix asphalt (WMA) workability during production, construction and compaction [10].

4. Mechanical structure of foamed bitumen formation

In a research paper [16] the mechanical process of foamed bitumen creation was introduced indirectly, when it was aimed to assess the dispersion of aqueous nanoparticles. The occurrence of clumps after the dispersion of these particles was confirmed indicating that the formation of foamed asphalt is not only that water turns into vapour, since bitumen consists of a group of oils, and the contact between water and hot oil leads to oil dispersion. Then the oil particles contact surrounding water vapour, since the asphalt is hydrophobic, thus air bubbles are created. After foaming bitumen gradually bonds aggregate grains (Fig. 4). The foam dissipates very quickly and hence vigorous mixing is required to distribute adequately the bitumen throughout the material. During the mixing process, foamed bitumen layers encapsulate fine particles that form a slurry that effectively binds the mixture together [5]. Foamed bitumen usually contains 0.5% additive 97% bitumen and 2.5% water.

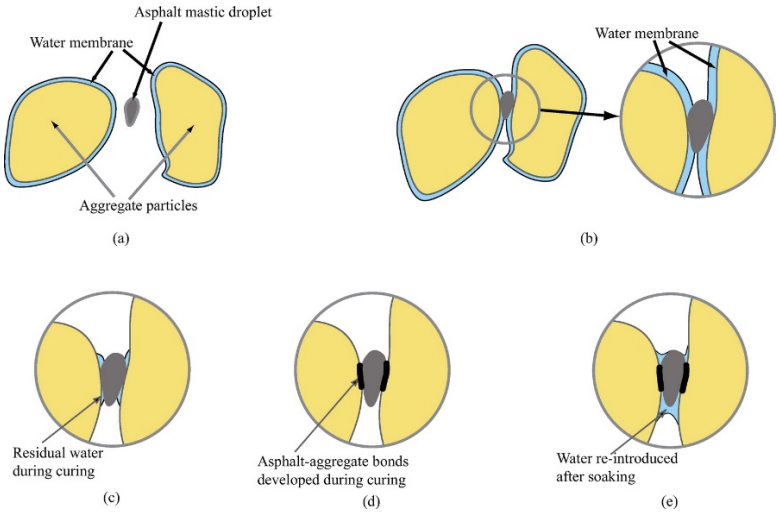

Figure 4. Coating phases of foamed bitumen [16]

5. Benefits of foamed bitumen and foamed asphalt with addition of RAP

5.1. Technological benefits from using reclaimed asphalt pavement material (RAP) and/or foamed bitumen

RAP (Fig. 5) is less variable than aggregate, and the "old" bitumen in it, is considered often as an active component during the mixing [17]. The materials slowly unite under the influence of the dynamic loads applied from the traffic loads, and the effective scraped materials act as a bond with 30% of the volume of crushed stone [18]. Foamed asphalt can be stockpiled with no binder runoff or leaching. Since foamed asphalt remains workable for much extended periods the usual time constraints for achieving compaction, shaping and finishing the layer are avoided. Foamed asphalt layers can be built also in rather poor weather, without jeopardizing the good quality of the asphalt layer.

Figure 5. RAP material storage [18]

5.2. Temperature

Foamed bituminous mixtures can be produced also in low temperature. Recycled foamed asphalt mixtures have small shrinkage stress at lower temperatures and thus less premature damage from pavement cracks [19]. Wirtgen group demonstrated the possibility of mixing at low temperatures; the results obtained are demonstrated in Table 1 [11].

Table 1. Temperature limits for binder types [11]

Binder type	***Foamed bitumen***	***Emulsion***	***Road bitumen***
Mixing temperature (°C)	>10	>5	140-160
Aggregate temperature (°C)	15	10	140-200

5.3. Environmental benefits

Using reclaimed asphalt material (RAP) coming from “old” pavement makes it possible to reduce the volume of new “virgin” material that is available in limited quantity [11]. The overall energy consumed by recycling is less than that of any other rehabilitation method [20]. Foam treatment can be used with a wider range of aggregate types than other of cold mix processes [22]. When using foamed bitumen, energy conservation can be attained since this technique makes it necessary to heat

the binder and not the aggregate fractions, which can be used in cold and damp without drying. The poisonous evaporation of volatiles does not occur this time unlike hot asphalt mixtures.

Harmonious, high quality mixing of RAP with water and added agents can be achieved using modern recyclers; controlled pumping systems can ensure the accurate addition of fluids, see Fig. 6 [22]. When using foamed bitumen as asphalt binder, higher shear strength and less moisture susceptibility of aggregate can be attained. Another of its advantages is increased resistance to fatigue and flexibility while its strength approaches that of cemented mixtures.

5.4. Structural issue

Modern recycling machines have the ability of producing rather homogeneous, durable and thick asphalt layers [23].

5.5. Minimized disturbance

The disturbance of the underlying pavement layers is rather small because recycling is typically a single-pass operation and the wheels of the machine run without contacting lower layers when running on top of the reclaimed material [4].

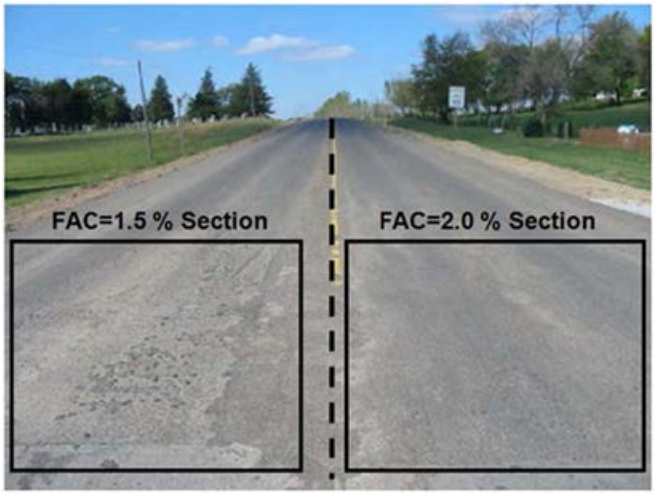

Figure 6. Homogenizing foamed bituminous mixture increasing the rate of water [22]

5.6. Reduction of construction time

In the case of cold recycling in place, the mixing and the paving are carried out in the same process reducing construction time and costs. Besides, traffic disruption for shorter periods results in additional benefits for road users [21].

5.7. Safety

It is an advantageous fact from traffic safety point of view that recycling machine works within a single traffic lane (Fig. 7), and the road can be used immediately after the completion of rehabilitation [11]. Saving in time comes from the fact that foamed asphalt can be compacted immediately and can carry traffic almost immediately after compaction is completed.

5.8. Cost

Time and movement reduction and saving material resources results in decreased cost. Not only its construction costs are not as much as the typical cold asphalts have but also the transportation costs coming from its limited bitumen and water needs [25].

Figure 7. Use of a single lane

6. Limitations of the usage of the technologies

The design procedure of foamed bituminous mixtures (FMA) including foaming, mixing, compression, curing and tests are rather uniform [25]. Since its production requires fairly high (some 180 °C) temperature, there is a risk of burning of binder [24].

Asphalt mixtures with foamed bitumen are not suitable for all pavement types, e.g. for wearing course repair and light asphalt pavement, it cannot be used [17].

The use of foamed bituminous asphalt mixtures is not really wide-spread in the world. The reasons of this situation include the limited number of related international literature, not too high strength, increased sensitivity to moisture and rutting. Recently there have been a lot of research and investigation to solve the difficulties mentioned by the use of crushed asphalt aggregate [26]. It was shown that several of these negative phenomena could be considerably reduced by utilizing RAP aggregates.

7. Some foamed asphalt mixture design methods

The most popular methods of designing foamed asphalt mixtures which are:

1. South African design method (Foam Index, aggregate gradation, resilient modulus, shear parameter, permanent deformation under repeated loading) [27].
2. Queensland design method (pavement design software CIRCLY, maximum design modulus for foamed bitumen layer, bitumen content, strength of post cracked phase, Poisson's Ratio, indirect tensile strength) [28].

English design method (use of the gyratory compaction method, optimized mixing water content and compaction effort, consideration also Reclaimed Asphalt Pavement material, optimised the foamed bitumen content, indirect tensile stiffness modulus, indirect tensile strength) [29] [30].

8. Foaming bitumen research in Syria

In Syria, a bitumen foaming apparatus (Fig. 8) was made for research purposes. The device consists of an asphalt chamber, a water tank, and an air compressor, in addition to an electrical network to measure temperatures and control external and internal heating. After adjusting the measuring instruments, the valves are opened and the materials enter the expansion chamber where the foaming process takes place.

Figure 8. Foaming bitumen device

The laboratory test series performed covered the investigation of foamed bituminous mixtures with four binder types (foamed bitumen with 1.5…2.0…2.5…3.0 wt% water content using base bitumen 65 penetration) and five aggregate variants with 0…25…50…75…100 wt% RAP. The optimum water content of asphalt mixture was determined using Expansion Rate and Half Life parameters, see point 2 (Figure 9).

Figure 10 shows the Marshall-stability results of 20 foamed bitumen asphalt mixture variants. Foamed bitumen was produced using a moisture content of 2.3m% (see Figure 10) at 190 °C binder temperature. The foamed bitumen bound asphalt mixture variants were created by 1.5, 2.0, 2.5 and 3.0 wt% binder contents. Each of these 4 mixture variants was produced using the following RAP contents:

- Type (A) – 100% new aggregate.
- Type (B) – 75% new aggregate + 25% RAP.
- Type (C) – 50% new aggregate + 50% RAP.
- Type (D) – 25% new aggregate + 75% RAP.
- Type (E) – 100% RAP.

Significant differences can be seen between the Marshall-stability values in Figure 10 coming – among others – from the different residual binder share in RAP materials.

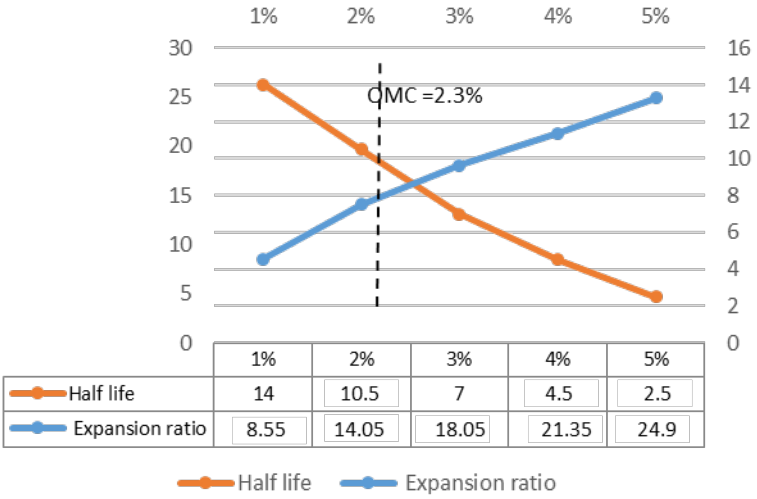

Figure 9. Calculation of the optimum water content (OMC) of foamed bitumen at 170 °C

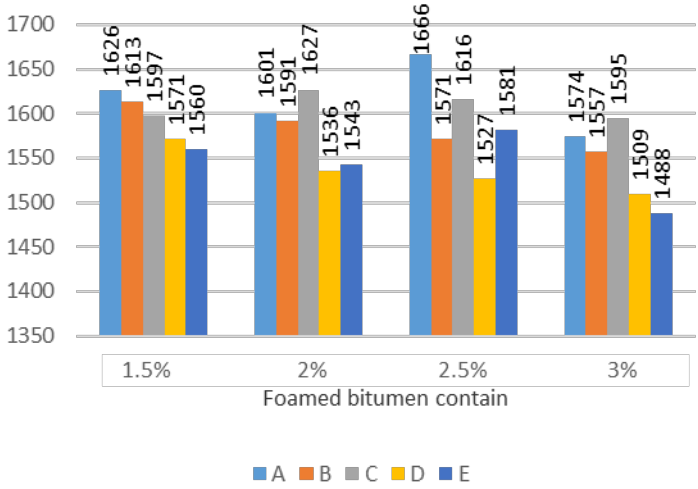

Figure 10. Marshall-stability results (kg)

The results presented in Fig. 9 and 10 will be utilized as inputs for the future PhD thesis of one of the paper authors.

9. Concluding remarks

Foamed bitumen is produced by adding small amounts of water to hot bitumen. When injected into the hot bitumen the water evaporates abruptly, causing foaming of the bitumen in the saturated steam; the bitumen expands by 20 to 30 times its original volume. Foaming of the bitumen results in a number of improvements: more durable coating con be reached also in case of cold and wet aggregate fractions; less viscous binder can be produced in the foaming process; this type of binder has a rather low temperature typically not exceeding 60 °C. Cold-treated material produced with foamed bitumen can be stored for very long time. The use of foamed bitumen can be even more environmental friendly when also reclaimed asphalt pavement material is utilized.

The increasing use of asphalt mixtures with foamed bitumen binder can be considered as a successful solution of road industry for energy efficient, environment-friendly and cost-effective construction techniques. This kind of asphalt is a cold bituminous mixture of various aggregate types and foamed bitumen. The technology of foamed bitumen process is more than 70 years old and used in a lot of countries all over the world, there are still many related topics that has not been sufficiently tested so far. That is why it is worthwhile to overview the main theoretical and practical results in the field in several countries including those of the authors of the paper. It is clear that the foamed asphalt is usually characterized by high quality and reasonable cost, can be used in cold road pavement rehabilitation, in addition to it the technique is environmentally friendly preserving natural resources. Using foamed bitumen reduces the emissions of carbon dioxide and gases resulting from combustion, especially when it is used as a cold rehabilitation binder and mixed with reclaimed asphalt pavement materials.

Since the road construction and maintenance techniques are relatively new, no global reference mix methods are existing. That is why there are still a lot of related unsolved research areas.

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