CETRA 2014

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

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CETRA[2014]
3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

TITLE
Road and Rail Infrastructure III, Proceedings of the Conference CETRA 2014

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
"Tiskara Zelina", April 2014

COPIES
400

Zagreb, April 2014.

Proceedings of the
3rd International Conference on Road and Rail Infrastructures – CETRA 2014
28–30 April 2014, Split, Croatia

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EFFECT OF BITUMEN ORIGIN ON BEHAVIOR OF COLD RECYCLED MIXES USING FOAMED BITUMEN TECHNIQUE

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Abstract

Within the European research project COREPASOL supported by a group of countries associated in the Conference of European Directors of Roads, the effect of distilled bitumen gained from different locations on the characteristics (indirect tensile strength, water susceptibility and stiffness) of cold recycled asphalt mixtures has been assessed as a partial task. In the first step, the optimum foaming water was evaluated for each bituminous sample by optimizing the relationship between the expansion rate and the half-time. For the optimized foaming water content, one cold recycled mix design with different foamed bituminous binders has been used. The behavior of all experimental mixes has been tested by indirect tensile strength test done after 7 and 14 days for cured specimens, whereas the curing procedure respected Czech technical specification TP208. In parallel, stiffness testing has been done for each mix variant and a group of specimens has been water soaked between 7th and 14th day. These specimens were used for water susceptibility testing. After the first set of tests has been done, two foaming agents were used for selected bitumen represented by additives provided by Iterchimica and MeadWestVaco. For bitumen doped by such agents, the foam characteristics were evaluated again with a distinctive improvement in both foam characteristics particularly for one of the agents. Also this foamed bitumen has been later used for cold recycled mix laboratory production and testing. This paper presents the results obtained and findings with recommendations.

Keywords: cold recycling mixes, foamed bitumen, foaming agent, indirect tensile strength, stiffness modulus, water susceptibility

1 Introduction

Foamed bitumen lends itself to use as a binder for stabilizing various grain materials, including asphalt materials from the original, reclaimed asphalt pavement (RAP). Energy savings, sustainable road construction development and conservative use of material particularly in relation to the bituminous binder are the most important issues in the road building industry. The aspects represent a very strong incentive to use foamed bitumen technology all over the world, both from the economic and the environmental aspects [1]. Foamed bitumen technology can no longer be considered a real innovation. The technology of controlled foamed bitumen production was patented as early as in 1956 by Professor L. H. Csaniy of the Engineering Experiment Station of Iowa State University, originally as an improved binder for soil stabilisation in the construction of American military roads on the Pacific islands using solely volcanic ashes. After several years, the technology was abandoned; subsequently it was bought by Mobil Oil Australia that designed a fundamental improvement with which the technology has survived to this day. The mix spread significantly primarily in Australia already in the 1970's as a consequence of the oil crisis and skyrocketing prices of oil products which resulted in a search for alternative and economically viable technologies for road building and reconstruction. Until 1993, the method was covered by a patent and any interested parties could only buy the licence for the technological method from Mobil Oil. When the patent on the technological method expired the technology for bitumen foam production rapidly spread in a number of countries. From the perspective of technical development of foamed bitumen technology application, particularly in the field of cold recycling, this expansion was most supported by company Wirtgen. Besides, alternatives which can be classified today as warm asphalt mixes with applicability in traditional mixing plants (applications known from Norway, Great Britain or USA) have also found their use. With respect to the fact that the technology has gradually found its way into pavement reconstruction in a number of industrial countries, the myth according to which any technology using foamed bitumen can only be used to build pavements solely in developing countries has finally been destroyed.

At present, there is a broad range of design methods for foamed bitumen mixes. Each of them differs in the mineral component grain size, filler type and content, water content in the mix, as well as the purely experimental issues related to the test specimen sizes, type of mixing, test specimen compaction and curing. The design procedures for foamed bitumen mixes also strongly depend on the type and quality of the reclaimed aggregate since different countries have different pavement compositions from the point of view of the mix contents traditionally used [2] and the structure components themselves.

In general, any bituminous binder which comes into contact with water when hot starts foaming and increases its volume several fold. However, this is not desired in most cases. The principle of foamed bitumen production is pumping air (under the pressure of approx. 10 bar) and water (1-5 %-wt. under the temperature of 15-25°C) under the pressure of 4-5 bar into the hot bitumen binder (50/70 – 160/220 applying temperature of 170-190°C). In contact with the hot bituminous binder, water immediately changes to steam. This is gradually captured and closed in minute bitumen foam bubbles; once it has transformed into steam the foam expands and increases in volume several fold. In this state, it is dosed into the aggregate. The entire foaming process takes place in an expansion chamber where the hot bituminous binder is fed and the steam and air added through jets. Subsequently, the resulting mix is pressure-pumped into the aggregate. When the foaming is maximal the bituminous binder bubbles gradually collapse; their surface attempts to adhere closely primarily to the fine aggregate particles which generates bitumen binder droplets that subsequently join one another and create a thin bitumen film; this coats the larger aggregate particles. Here, it is necessary to mention the effect of thermal susceptibility of the bituminous binder, or sudden changes of bitumen viscosity in contact with cold water during the foaming process which affects the foaming capacity and quality of the foam produced that must be taken into consideration. Thermal susceptibility can be defined as a change of bitumen viscosity depending on temperature changes [3]. In comparison to a bituminous binder or emulsion, foamed bitumen has much greater surface and different surface tension which allows sufficient coating of particularly the fine aggregate particles with a smaller quantity of bitumen. In this regard, the content of fine particles in the mix design is important as the mix operates on the principle of coating the particles with the foam and the created mastic thus created subsequently binds the larger aggregate grains together. A part of the foam is naturally caught on the surface of larger aggregate grains.

In general, the foamed bitumen quality is expressed as the proportion of the maximum bitumen foam volume achieved and the volume of the original bitumen binder when foamed, that is, the expansion ratio (ER). With superior quality foamed bitumen, the expansion ratio should be at least 8-15. Another quality parameter for foamed bitumen is defined as the half life time ($t_{1/2}$) which is the time (in seconds) during which the maximum volume of the bitumen foam is reduced by 50 %. The longer the half life time, the better quality of bitumen foam; half life time of over 15 seconds is considered superior quality (as a standard, $t_{1/2}$ should be between 8 and 15 seconds). The half life time expresses bitumen foam stability and is indirectly pro-

portionate to the expansion ratio. Both parameters mentioned depend, to a certain degree, on the type and origin of the bituminous binder, hot bitumen temperature as well as the quantity of pressurised air added and the pressure under which water is injected in the hot bitumen. The intensity and effectiveness of the foaming effect might be influenced by regulation of basic physical conditions like temperature, humidity and pressure [1, 4]. From the point of view of sufficiently homogeneous mixes, the size and arrangement of the mixing device (e.g. the injection zone size, mixing apparatus type, optimum aggregate composition, or optimal proportion of fine particles) is also important, on top of the expansion ratio.
In this regard, this paper aims to evaluate the effect of bituminous binders obtained from various locations and by various producers with different parameters (effects of the origin of crude oil) and of foaming additives on the properties of foamed bitumen and cold recycling mixes. The production, test methods and cold recycling mix assessments were carried out according to the Czech technical specifications TP 208 [5]; indirect tensile strength was monitored for 7 and 14 days' curing under predefined conditions in test specimens of 150 mm diameter compressed by static pressure. Other parameters examined were water susceptibility and stiffness modulus determined by the IT-CY method under EN 12697-26.

2 Materials and test methods applied

Within the framework of assessing the effect of bituminous binders and foaming additives on cold recycling mixes, bituminous binders from different locations and by different producers were selected. A set of test methods according to [5] was defined for the test mix assessment as such. From the perspective of the composition of the recycled mix aggregate skeleton, sorted reclaimed asphalt material of fraction 0/22 from the Středokluky mixing plant was used; extraction with determination of the content of soluble binder and a grading analysis indicated in Fig. 1. were performed. The binder content was detected as 5.6 %-wt. The optimal moisture content of the cold recycling mix for the composition as specified below was determined according to [7].

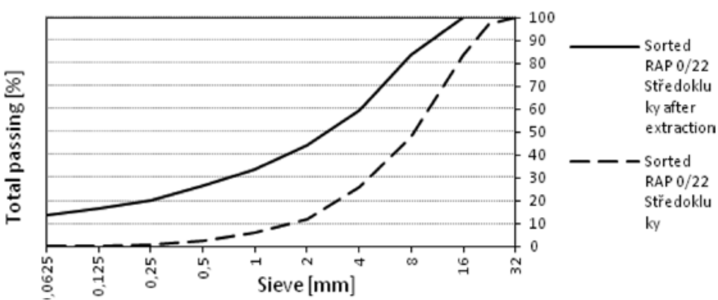

Figure 1 Granularity of reclaimed material 0/22 Středokluky

Bituminous binders of 70/100 and 160/220 penetration grade which are traditionally used in the Czech Republic were utilised in mix design and production. Three representatives of distilled bitumen 70/100 and two representatives of distilled bitumen 160/220 were assessed. In the case of the former group, the bituminous binders were based on Russian crude oil (Russian Blend); in the case of some other bitumen variants, there was a blend of several sorts of oil with a significant representation of North Sea raw material (Mittelplatte crude oil). The EM mark with some binders means "fit for emulsifying"; the crucial factor is the salt content and neutralising number of these binders. This is usually different for each sort of crude oil. Bitumen 160/220 was compared to the binder allegedly based on Venezuelan crude oil which, from the perspective of bitumen exploitation rate and quality of the resulting distilled bitumen, is among the best. Only the characteristics of softening point and penetration under 25°C were examined for all of the assessed bituminous binders always two samples for penetration and four rings for softening point. Additive A (Iterchimica; Iterfoam) is used as a foaming thixotropic agent. The additive is of a dark, oily colour and from the chemical perspective it is a combination of different amine compounds. In the case of additive B (MeadWestVaco; Evotherm), the additive is an oily liquid of amber colour, based on derivatives of fatty acid amines. The additive is intended for applications in the field of low temperature asphalt mixes. Its application as a potential foaming agent constituted an assumption, not verified as yet, with respect to improving the surface activity (which is improved by this additive). The producer declares production and laying temperature reduction for the asphalt mix by 30-45°C. The additive has volume weight of 970 kg/m^3 and flash point CoC over 204°C, [8, 9]. The value of penetration and softening point was determined for each binder, see Table 1.

Table 1 Selected properties of the bitumen binders applied

Binder	Characteristic	
	Penetration under 25°C [0,1 mm]	**Softening point [°C]**
Azalt 70/100 (Total)	83	46,8
Aqualt 160/220 EM (Total)	156	41,6
Aqualt 70/100 EM (Total)	79	47,4
70/100 EM	86	46,2
160/220 EM (Nynas)	165	40,8

The next step was optimising the foamed bitumen primarily from the perspective of the parameters it must meet. For the sake of good coating of the reclaimed material in the mix, the quantity of water applied to the foam should be optimised to keep the expansion ratio ≥ 8 and the half life time ≥ 6 s in compliance with the recommendations according to [4] for aggregate of temperature ≤ 25ºC. The expansion ratios and half life times of experimentally assessed foamed bitumen variants depending on used and examined bituminous binders are indicated in Fig. 2. What is rather interesting is the increased half life time of the foamed bitumen with foaming additive A while the half life time is ten-fold higher, thus allowing a longer mixing time. Contrastingly, and contrary to the expectations, additive B deteriorates slightly the quality of the foam, nevertheless not being primarily indicated as a foaming agent. The poor quality of the foam with the additive resulted in abandoning its application in cold recycling mixes in the future. The values of optimal quantities of water added to the bitumen according to the aforementioned parameters are indicated in Table 2.

Table 2 Quantity of water added to the bitumen during foam production

Bituminous Binder	Optimum added water [% of bitumen]
Azalt 70/100 (Total)	3,8
Aqualt 160/220 EM (Total)	1,8
Aqualt 70/100 EM (Total)	2,4
70/100 (Vialit)	1,1
160/220 (Nyanäs)	3,0
Azalt 70/100 (Total) + 0,4% additive A	3,8
Azalt 70/100 (Total) + 0,6% additive A	3,8
Azalt 70/100 (Total) + 0,4% additive B	not defined
Azalt 70/100 (Total) + 0,6% additive B	not defined

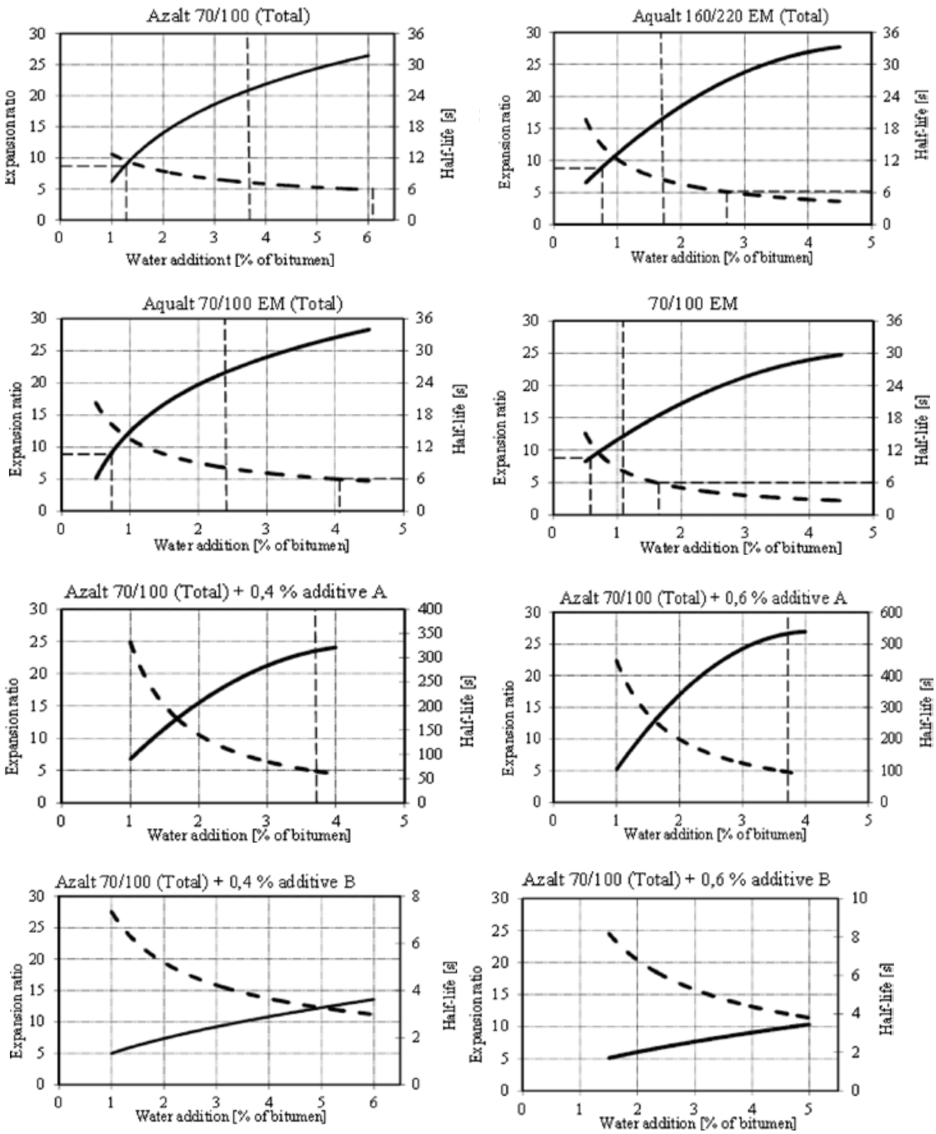

Figure 2 Foamed bitumen parameters (Expansion ratio and half life time)

Foamed bitumen was injected in the mix under the temperature of 170°C by means of the Wirtgen WLB10S laboratory equipment. The mix as such was mixed using a twin-shaft compulsory mixing unit Wirtgen WLM 30. The recycled mix obtained was subsequently put in cylindrical moulds and compacted by static pressure of 5.0 MPa. Technical conditions for cold recycling mixes [5] stipulate test specimen preparation by cylindrical moulds with 150±1 mm diameter and 200-300 mm height. The basic volumetric parameters were determined for the test specimens prepared, as well as the indirect tensile strength under [5] and stiffness modulus by means of a non-destructive test by repetitive indirect tensile stress under 15°C according to [6] and water susceptibility. Specimens were tested after 7, 14 days' dry curing under 20 ± 2°C and after 14 days of exposure to air and water.

3 Discussion of the results

The summary results of the parameters examined in the recycled mixes are indicated in Fig. 3. For indirect tensile strength and each period of curing at least four specimens were tested. Cold recycling mixes with bituminous binders of higher penetration gradation demonstrate slightly lower indirect tensile strength values from the point of view of final tensile strengths and, at the same time, dry curing of the test specimens. However, the trend is not too obvious and might be affected, with respect to the void contents achieved, by a lack of homogeneity in the reclaimed material. In contrast, the mixes containing higher penetration value bituminous binders are less susceptible to water. This indication might support the theory of superior binder coating of the aggregate. The stiffness modulus values copy the trend mentioned within the framework of indirect tensile strength. It should be stated that all mixes meet the requirements for foamed bitumen-bound recycled mixes given by [5]. The foaming agent examined did not manifest itself, i.e. it failed to affect the parameters examined and, therefore, we can only consider its application from the point of view of the possible extended mixing time which could positively influence the quality of mix coating.

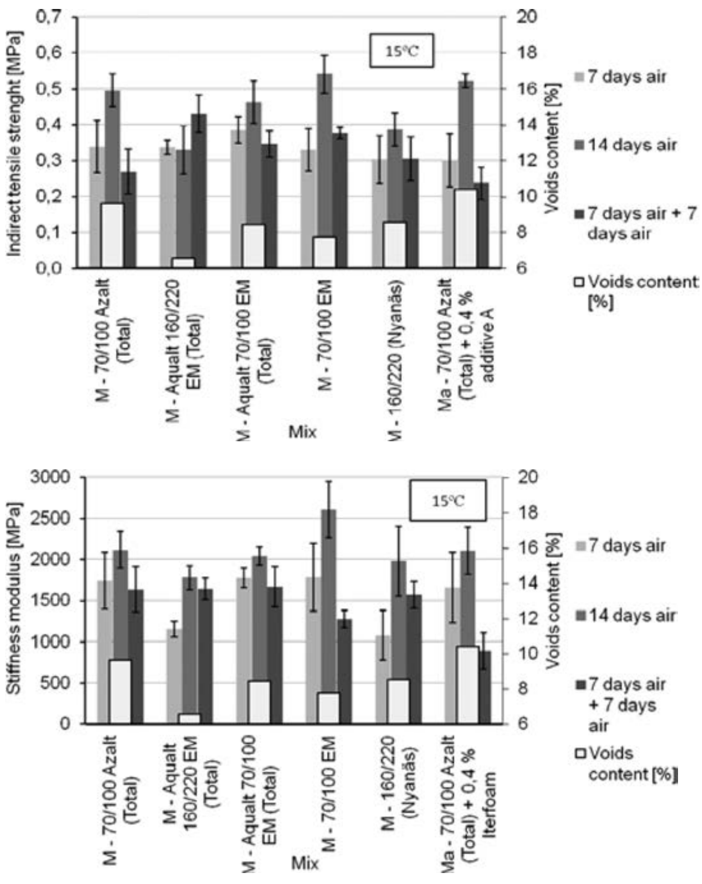

Figure 3 Parameters examined (ITS and stiffness modulus) of cold recycling mixes

4 Conclusion

The objectives of researching the relationship between bitumen properties and the characteristics of the resulting foam depending on the strength and deformation parameters of recycles mixes achieved with respect to the aforementioned test results are well understandable within the framework of the attempt to unify the design and production regulations within the European COREPASOL project. The difference in inputs in individual countries can be rather big according to the assessments obtained. The study emphasises the assessment of the effect of the bitumen origin on the cold recycling mix properties while the existing current results concerning the issue can be summarised as inconclusive at least.
From the results gained by the research it is obvious that bituminous binders of different penetration and origin usually have similar problem of satisfactory expansion ratio but very low half-life time. This finding corresponds very well with the practical site experience and affects the quality of material coating during cold recycling application. At the same time it could be shown that addition already of 0.4 % of a suitable foaming agent results in a distinctive increase in half-life showing very stable foamed bitumen. If these results are compared to cold recycled mix strength results, however, the water sensitivity of the mix with foam containing foaming agent was increased and even the strength after 7 days curing reached rather a lower value. The theoretical but hardly accountable reason could be a longer time period necessary for settlement of the bitumen coating.

Acknowledgments

This paper has been supported by the research project COREPASOL carried out as part of the CEDR Transnational Road research Programme Call 2012. The funding for the research was provided by the national road administrations of Belgium (Flanders), Denmark, Finland, Germany, Ireland, Netherlands, Norway, Sweden and UK. This paper has been further supported by the CTU student research project SGS13/125/OHK1/2T/11.

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