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Road and Rail Infrastructure III

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IMPACT OF SELECTED CHEMICAL ADDITIVES ON PERFORMANCE BEHAVIOR OF WARM ASPHALT CONCRETE MIX

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Abstract

Warm mix asphalts are becoming a regular group of mixtures used in pavement structures in many European countries. Nevertheless there are still a lot of mind barriers which disallow a more distinctive use of this type of mixes especially with respect to improved healthy conditions for road workers and because of potential energy savings during mixing of such asphalt mixture. In parallel there are still ambiguities about possible weaknesses with respect to durability or cracking resistance. Last but not least the actual market offers quite large variety of different additives which needs suitable comparison and proof of real benefits of particular additives. Within the experimental study done as part of ongoing research at the Czech Technical University in Prague different chemical additives have been used representing synthetic waxes or surfactants, as well as comparing them with ready-to-use binders offered by some producers. Besides set of performance testing evaluated on binders a regular asphalt concrete mix of 0-11mm grading has been designed. For each type of additive used in 50/70 distilled bitumen assessment has been done to determine the appropriate reduced manufacturing temperature at which later test specimens have been produced. In general for most of the used additives the manufacturing temperature was reduced by 20-30°C. On the mixes traditional as well as performance based characteristics have been evaluated and compared. Gained results are presented in the paper.

Keywords: warm asphalt mix, low-viscosity binders, waxes, tensides, dynamic viscosity, durability, permanent deformations, crack propagation, flexural strength

1 Introduction

Reducing manufacturing temperatures of bituminous mixtures has become one of the main preoccupations in the road-industry worldwide. Warm mix asphalt technologies (WMA) allow the producers of asphalt pavement materials to lower the manufacturing temperatures at which the material is mixed and paved on the road. During the last decade warm mix technologies have rapidly developed especially in the USA. Recent overview of American specifications, ongoing research and the state of the practice is for example presented in [1]. Overview of 24 different WMA technologies used in USA is on a web site devoted to WMA (http://www.warmmixasphalt.com/WmaTechnologies.aspx).
WMA are used often also in some European countries for example in France and Germany. European Asphalt Pavement Association (EAPA) promotes the use of WMA. The position paper of EAPA on WMA with references dated 2010 is on its web page (www.eapa.org). There is also a practical guide on WMA on the web site of the German Asphalt Association (DAV; www.asphalt.de) dated 2009. German Road and Transportation Research Association FGSV

published in 2011 the basic guidelines related to WMA application "Merkblatt für Temperaturabsenkung von Asphalt".
There has been also an intensive research on WMA in the Czech Republic at the Czech Technical University in Prague (CTU) and Technical University of Brno (VUT) especially in the framework of the research seven years lasting virtual research centre CIDEAS focused on advanced structures and designs. This led to the publication of results on the national and international conferences [2, 3]. Some research on various WMAs has been also carried out by the Eurovia Services either within CIDEAS or as its own development realised in co-operation with the specialists of the Research Centre of Eurovia in France [4].
The traditional compacted asphalt mixes which constitute about 80-90 % of all pavement structures in the Czech Republic as well as a number of other European countries are produced, paved and compacted – depending on the bituminous binder applied – under temperatures ranging from 140 °C to 180 °C (for mastic asphalts which are not classified as compacted asphalt layers, the temperatures even exceed 240 °C). Such temperatures are required to achieve a sufficient balance between the necessary viscosity of the bituminous binder needed to ensure sufficient coating of the aggregate grains, good workability during paving and compaction, fast onset of mechanical strength and durability in asphalt pavement structure exposition to repetitive stress by transport and changing weather conditions. As a rule, traditional technological methods are energy-intensive and constitute sources of emissions of greenhouse gases as well as other hydrocarbon compounds and vapours emitted. Although, according to the latest IARC study, the vapours have no carcinogenic effects they are still widely discussed and monitored. Any reduction of the working temperature required reduces both the vapour concentration and the qualitative composition.
Possibilities for reducing the power consumption may not be searched for solely in material base optimisation and application of suitable additives or technical methods. In the case of asphalt mixes, the entire production process in the mixing plants must be improved; this involves as consistent insulation of the piping, storage tanks and the mixing equipment as possible as well as reducing the binder and resulting mix storage time; ultimately, this impacts a number of other factors. Similarly, considerable energy savings can be achieved through appropriate ways of aggregate storage (covered depositories with reduced moisture access). Due to that, a wholesome systemic perspective is necessary, i.e. perception of the production, transport, paving and compaction as a single system of partial processes where an effort is made to reduce its overall energy consumption. Undoubtedly, a related measure is a gradual transition to such power sources or power generation methods that will reduce in decrease of the greenhouse gas emissions generated – primarily of CO_2 – over time. Asphalt mix technology optimisation is a combination of both systems, i.e. the part depending on the product itself (asphalt mixes) and the part depending on the production facilities and machinery.
From the point of view of WMA design, a number of additives or certain technological procedures may be applied. The additives used to reduce the production or paving temperature for asphalt mixes can be classified in several basic categories:

- Paraffin-type additives – operating on the basis of binder viscosity reduction when heated above the softening point of the binder itself while improving asphalt stiffness under temperatures below the softening point of the additive itself.
- Surfactants – the primary effect of these liquid additives is reducing the surface tension at the meeting of the bitumen and aggregate phases, thus improving the aggregate coating by the binder. The reduced surface tension which is achieved through temperature increases in common hot road asphalt results not only in improved adhesion but also improved compactability of the asphalt mix which allows decreasing the temperature employed during paving and compaction.
- Mineral additives applying the micro-foam process – the addition of such additives during the mixing of the asphalt mix (the most commonly used ones are zeolites) results in the formation of very fine foam that contains micropores and improves workability of the mix.

With respect to the nature of the additive, the application must take into consideration the time restrictions of its effect.
- Foamed bitumen mix process – in a special mixing device, water in the form of steam and air are injected in the hot binder through jets under high pressure. This creates foamed bitumen which, depending on the quantity of water, increases in volume several fold and facilitates the coating of the finer aggregate grains in particular; this in turn provides for a relatively high-quality mortar binding the larger aggregate grains to form.

2 Bituminous binders used for WMA designs

As part of research activities within the ongoing cooperation between CTU Prague and contractors/industry several variants of low-viscosity bituminous binders have been designed and experimentally prepared. In parallel three low-viscosity binders have been tested, which have been prepared by the refinery PARAMO and The Research Institute for Inorganic Chemistry. Binders labeled NV40, NV41 and 407 were delivered for this testing. These binders contained different content of additives based on tensides and synthetic waxes. For better comparison in case of some tests done with these three binders bitumen 50/70 with 1 % of IterLow additive and low-viscosity binder 50/70 with 3 % FT paraffin is used. For these the low-viscosity binders the origin of distilled bitumen was different from the bitumen used in delivered binders NV40, NV41 and 407. The mixing of all low-viscosity binders prepared by CTU was done at the temperature of 150-155 °C by using a laboratory mixing unit IKA and mixing speed of approx. 300 rpm. For assessed bituminous binders following tests have been done:
- softening point determination by means of the ring and ball method (EN 1427);
- determination of needle penetration under 25°C (EN 1426);
- dynamic viscosity determination (EN 13302)
- determination of the complex shear modulus G* and phase angle δ (geometry PP25, τ=2000 Pa, temperature interval: 20-60°C, frequency interval 0.1-10 Hz);
- frequency sweep for G* and δ with subsequent plotting of the master curve for the reference temperature of 20°C;
- multiple stress creep recovery test

Further are presented only some of the obtained test results.

Table 1 Basic empirical characteristics of bituminous binders

Bitumen	Penetration (0,1 mm)	Softening point (°C)	Penetration index (-)
50/70 (samp. 1)	64	49.2	-0.843
NV40	64	49.1	-0.842
NV41	61	50.8	-0.537
50/70 (samp. 2)	73	47.1	-1.058
50/70 IT	70	47.0	-1.229
50/70 FTP	48	75.4	3.49

As is obvious from the results of empirical testing, low-viscosity type binders achieve values comparable to the reference binder. As an interesting benchmark, binder 50/70 by different producers is added; this was applied to prepare the options with IterLow and FTP. A minimal to zero effect of the surfactant IterLow is seen in contrast to the well-known, significant effect of FT paraffin as known from both literature and practice. Particularly with respect to the results indicated below, the evaluation of the penetration index (PI) is interesting. Here, it can be seen that the binders prepared within the framework of low-viscosity bitumen development in the PARAMO refinery demonstrate a minimum PI change. These are binders with

lower thermal sensitivity; from the point of view of resistance to deformation they are rather average bituminous binders. In the case of the second set of low-viscosity binders related to the 50/70 sample 2, it is obvious that the application of IterLow results in further reduction of the thermal sensitivity of the bituminous binder to the detriment of the ability to show sufficient resistance to deformation. Contrastingly, the binder with FT paraffin behaves in the opposite manner; its resistance to deformation (stiffness) improves substantially; however, this is likely to mean a higher thermal sensitivity at the same time, particularly in the low temperature area. No measurements were taken for binder marked 407 with respect to the fact that the primary purpose involved an application of the binder in the asphalt mix. Due to the limited quantity, there was not enough material to test the binder in itself.
In the case of dynamic viscosity measurements taken, conversion to the shear rate 20 rpm, which is considered a standard parameter in USA. The results are presented in Table 2. It is more than obvious that both options prepared by PARAMO have an effect on viscosity reduction of the bituminous binder. This is also confirmed by the chart below. From our point of view, the low values of the binder by a different producer are affected by the circumstance that the parameters of the binder seem rather like those of bitumen 70/100 which should demonstrate superior viscosity parameters in general.

Table 2 Results of dynamic viscosity testing

Bitumen	Dynamic viscosity @ 6.8 s^{-1} (20 ot./min.)	
	T=135°C	T=150°C
	(Pa.s)	(Pa.s)
50/70 (sample 2)	0,5	0,3
50/70 (sample 1)	0,7	0,8
NV40	0,4	0,2
NV41	0,4	0,2

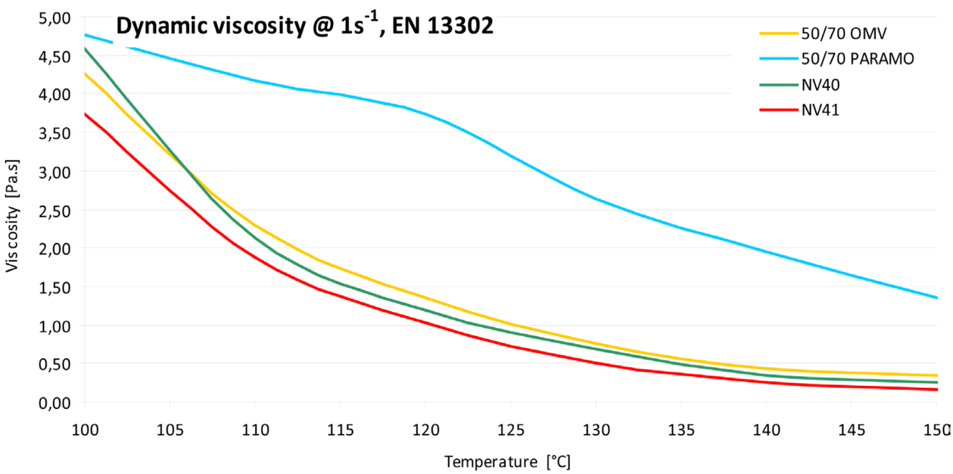

Figure 1 Dynamic viscosity (viscosity curves) at shear rate of 1 s^{-1} and temperature interval 100-150°C

From the perspective of the flow curves with shear rate of 1 s^{-1} it is obvious that the variants of experimentally prepared low-viscosity binders NV40 and NV41 under assessment reduce the viscosity value throughout the entire thermal interval. A slight decrease in the case of 100 °C is caused by its proximity to the temperature where the bituminous binder gradually changes from the liquid or quasi-liquid phase to the solid phase. Simultaneously, under this temperature there will be a loss of functionality of the additives applied to reduce temperature. In contrast, within the 105-140 °C interval dynamic viscosity of low-viscosity binders is five times lower (when compared to binder 50/70 sample 1). The other distilled bitumen compared has almost identical viscosity curve as binder NV40.

3 Assessment of asphalt mixes

In the second part of the experimental assessment asphalt concrete mixture of ACO11+ type has been selected with a design fitted for aggregates from Libodrice quarry (amfibolite). The procedure defined by Czech technical specifications TP238 for determining the proper specimen manufacturing temperature was firstly applies for the mixes with different low-viscosity binders. At the determined temperature the bulk density of compacted Marshall specimens for a WMA is equal or close to the bulk density known for a reference mix. For this reason the reference asphalt mix is produced with traditional temperature dependent on the binder used (150 °C in the case of this assessment). Then the test specimens for WMA mixes are produced for temperatures 110 °C, 120 °C, 130 °C, 140 °C and 150 °C with determination of bulk densities. By applying iterative method the comparable bulk density to reference mix is searched and the temperature at which such temperature is gained, determined. Nevertheless, based on the results received it was again demonstrated that this approach is at least arguable and during next revisions of the technical specifications TP238 this approach should be critically reviewed. It might be applicable to mixes where paraffins or waxes are used, but definitely not for mixes where different surfactants are applied. Presently it is not fully obvious, what approach could suitably replace the existing one (testing and assessment of dynamic viscosity, application of gyratory compactor for specimen preparation and determination of compaction effort, another procedure to be defined).
The bitumen content determined for reference mix optimization was 5.2 % by mass. The reference mix was produced at a temperature of 150°C. For remaining variants always the described temperature optimization has been done with the production of test specimens for the temperatures described above. Resulting temperature recommended for each variant of WMA mixes has been set in the range between 120 °C and 130 °C. For the mixes of second set, where additives like RH, IterLow, FTP, Zycotherm and industrially ready-to-use bitumen ECO2 have been applied, it is necessary to underline, that for the production of low-viscosity bituminous binder a basic bitumen was applied, which officially was declared as 50/70 pen grade, nevertheless by its parameters rather fulfilled criteria of a 70/100 bitumen. This fact has to be kept in mind especially during the later evaluation and discussion of gained results. For asphalt mixes with selected referential temperature subsequently selected tests have been done:

- determination of bulk density of compacted test specimen;
- determination of maximum density and void content of an asphalt mix;
- determination of water susceptibility by indirect tensile strength test (ITS ratio);
- determination of water susceptibility by applying one frost cycle and assessment of indirect tensile strength (ITSR_f);
- resistance to permanent deformations by wheel tracking test;
- stiffness modulus assessment (IT-CY test method);
- determination of flexural strength at -5° C;
- determination of asphalt mix resistance to crack propagation at 0 °C.

Results of done specimens compaction temperature optimization and the progress of basic empirical results as well as functional characteristics are presented further in this paper.

Table 3 Basic characteristics of assessed warm asphalt mixes

Mix variant	Compaction temperature (°C)	Bulk density (g/cm³)	Maximum density (g/cm³)	Voids (%)
ACO 11+ REF 50/70 (sam. 1)	150	2,673	2,745	2,61
ACO 11+ NV40	120	2,661	2,740	2,88
ACO 11+ NV41	130	2,639	2,747	3,93
ACO 11+ 407	120	2,676	2,740	4,16
ACO 11+ 3% FTP	130	2,584	2,722	5,07
ACO 11+ 3% RH	120	2,620	2,722	3,76
ACO 11+ 1% IT	130	2,570	2,722	5,57
ACO 11+ 0,1% Zycotherm	150	2,621	2,722	3,71
ACO 11+ ECO² (130°C)	130	2,520	2,657	5,16
ACO 11+ ECO² (120°C)	120	2,537	2,657	4,53

Out of the basic characteristics listed (volumetric weight and void content) it is the void content that is crucial. Here, it was discovered that with the exception of the mix with 3 % FTP, all of the remaining mixes meet the requirement for ACO 11+ mix type stipulated by CSN EN 13108-1 (2.5-4.5 %-vol.). It is obvious that the mix with binder NV41 where a lesser temperature reduction was recommended demonstrates a greater void content increase in comparison to the reference mix. The fact rather supports prioritisation of the option with binder NV40. At the same time, it should be taken into consideration whether, in case of binder 407, the limit temperature should be 130 °C. In such a case, better compaction and lower void content in the test specimen might probably be achieved.
In the case of the second set of experimental mixes, it can be noticed that from the perspective of void content, additive RH records very good results under compaction temperature 120 °C. As long as, chemically, the binder is of a type similar to FTP, a greater potential is obvious in this regard; superior compaction is achieved even under lower temperatures. In the case of Zycotherm, the test specimens were not produced under lower working temperature since the verification of possible reduction of the working temperature as specified in the preliminary TP238 did not correspond with this option. Based on the findings, we can probably consider a maximum working temperature reduction to 135-140 °C which, however, will result in a slightly increased void content. An interesting trend appears in the case of the industrially manufactured low-viscosity binder marked ECO². It is shown that specimens prepared under the temperature of 120 °C achieved lower values when compared to a working temperature increased by 10 °C.
During the ITSR test which is currently the determining factor from the point of view of asphalt mix durability assessment, test specimens are prepared by compacting (2x25 blows by impact compactor). The specimens are divided into two groups – one left at room temperature and the other soaked in water and, subsequently, tempered in a water bath for 3 days at 40°C. Then, an indirect tensile strength is taken and a strength ratio is determined; according to CSN EN 13108-1 its value should be below 70 % for an ACO11+ type mix. In the case of the ITSR_f test, the aforementioned procedure is modified in compliance with the American methodology (AASHTO 283T) and the specimens are water-soaked for shorter periods but, afterwards, placed in a freezer at approx. -18°C for 16 hours. Then, the specimens are immediately placed in a water bath at 60°C for 24 hours. The method should result in the specimens being stressed more by various effects and, therefore, lower indirect tensile strength (and a poorer strength ratio value) is expected. In relation to the modified ITSR indicator, CTU proposed a 10 % lower permitted threshold in relation to the standard ITSR indicator threshold to provide for the effect of frost in particular.

Table 4 Assessment of mix water susceptibility

Mix variant	ITS_{dry} (MPa)	ITSR	ITSR_f	Modulus ratio
ACO 11+ REF 50/70 (sam. 1)	1,91	0,90	0,83	0,78
ACO 11+ NV40	1,68	1,08	1,03	1,12
ACO 11+ NV41	1,65	1,06	1,04	1,05
ACO 11+ 407	1,45	1,00	-	1,02
ACO 11+ 3% FTP	1,37	1,13	0,67	1,58
ACO 11+ 3% RH	1,05	1,23	0,90	1,22
ACO 11+ 1% IT	1,59	1,10	1,07	1,08
ACO 11+ 0,1% Zycotherm	1,70	1,08	0,77	0,93
ACO 11+ ECO2	–	–	–	–

Last but not least, besides ITSR and flexural strength of specimens not soaked in water or frozen, the calculated value of the elasticity modulus can be determined (this is easy to calculate from the indirect tensile strength and the horizontal deformation values). No requirements are stipulated for this parameter; it is only quoted as an informative value. It may be used as a guide for the assessment of material stiffness when the test specimen reaches destruction (collapse). In the case of using the flexibility modulus characteristics to determine the ratio of the proportion between the dry and soaked specimens, this is an alternative to the ITSR characteristic.
From the perspective of the test of asphalt mix resistance to permanent deformation, standard CSN EN 13108-1 stipulates a requirement for PRD_{AIR} and WTS_{AIR} solely in relation to mixes ACO 11S (5.0% and 0.07 mm, respectively). For "+" mixes, the value is merely declared; no limit value is determined. Class "S" is used for roads with very high intensity of heavy loaded vehicles. As is obvious from the measurements taken, the mixes assessed meet the requirement of the "S" class criterion; only the mix with 1 % IterLow significantly exceeds the WTS_{AIR} indicator. When the mixes are compared to one another, we can see that there are no material influences from the point of view of the first indicator. This also applies to the second indicator. The improved value of PRD_{AIR} in the mix with NV41 and, contrastingly, deterioration of the WTS_{AIR} indicator which suggests that with continuing stress, the depth of track increases more rapidly, are interesting. What is important is that no negative impact on deformation characteristics was recorded with a lower production temperature. Even in the case of the mix with 3 % FTP where a higher void content (and, therefore, a higher risk of additional compaction) was noticed, the mix shows very good characteristics in relation to permanent deformation. Limit results were achieved by the mix with IterLow; in the case of the WTS_{AIR} indicator, this version failed to meet the standardised requirements. An increased value of the parameter is indicated also in the case of Zycotherm.

Table 5 Results of wheel tracking test (small device, air bath at 50 °C)

Mix variant	Relative rut depth after 5 000 cycles v mm – PRD_{AIR} (%)	Increment of rut depth WTS_{AIR} (mm)
ACO 11+ REF 50/70 (sam. 1)	2.2	0.026
ACO 11+ NV40	2.3	0.030
ACO 11+ NV41	1.9	0.034
ACO 11+ 407	n.a.	n.a.
ACO 11+ 3% FTP	2.0	0.019
ACO 11+ 1% IT	4.5	0.074
ACO11+ 0,1% ZT	2.6	0.048

The last group of testing presented here is characteristics that describe the asphalt mix behaviour under low temperatures while it is technically possible to assess the behaviour under temperatures ranging from 0 °C to -10 °C. The method of determining flexural strength is based on a three-point beam test when two stress levels are selected (50 mm/min and 1.25 mm/min), as specified in TP151. At present, the test is only required for HMAC type mixes with a minimum strength criterion of 6 MPa for the lower stress speed and temperature of -5 °C. Flexural strength determination under the higher speed can be perceived as an indicator of potential problems with cracking under low temperatures. The other test method applied to compare the individual mix versions is the asphalt mix resistance to crack propagation in compliance with CSN EN 12697-44 which is conducted on semi-cylindrical test specimens by means of a three-point test with weakened profile (a groove of 10 mm depth) at the point of stress by a constant force. When compared to the flexural strength test, the latter method appears to be a more appropriate method to assess actual crack propagation of the mix.

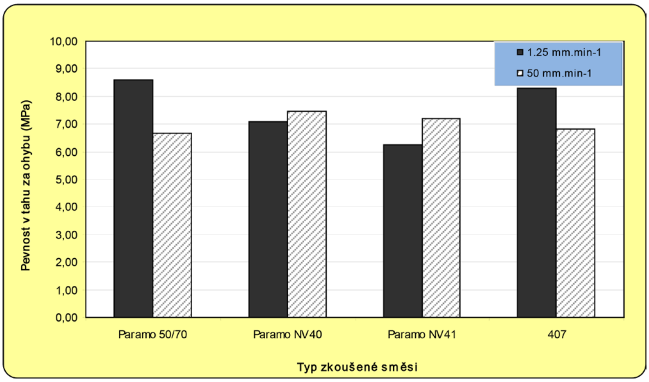

Figure 2 Results of flexural strength test, set I

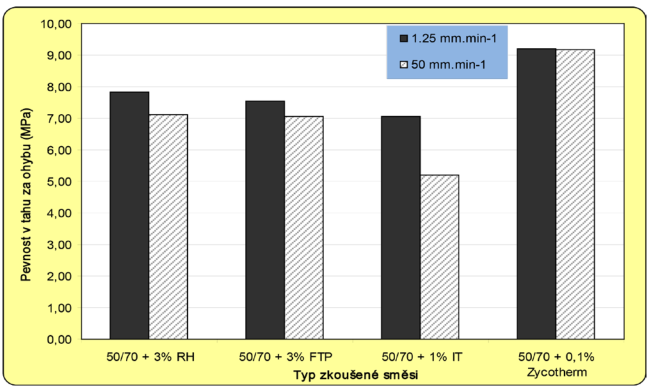

Figure 3 Results of flexural strength test, set II

If, in accordance with TP151, we restrict ourselves to the values obtained for the lower stress speed, it is obvious that none of the low-temperature mixes from the first set of mixes assessed reaches the maximum detected for the reference mix although the values exceed the 6 MPa limit. It is also shown that from the perspective of the parameter of mix behaviour under low temperatures the best behaviour was detected for the asphalt mix with binder 407. When binders NV40 and NV41 are compared, the former is more appropriate. The aforementioned statement is very well confirmed by the crack propagation resistance test summarised in Table

6. The crucial indicator therein is the fracture toughness $K_{ic,i}$ where, again, the highest values were recorded by the reference mix and, from the point of view of low temperature asphalt mixes, the option with binder 407 appears to be the most suitable mix.

Table 6 Results of resistance of asphalt mix against crack propagation

Mix variant	Strain $ε_{max,i}$ (%)	Fractural toughness $K_{ic,i}$ (N/mm$^{3/2}$)	Stress $σ_{max,i}$ (MPa)
ACO 11+ REF 50/70 (sam. 1)	1,30	40,80	5,50
ACO 11+ Paramo NV40	1,43	36,70	4,95
ACO 11+ Paramo NV41	1,23	34,84	4,68
ACO 11+ 407	1,23	37,69	4,54
ACO 11+ 3% RH	1,38	35,49	4,78
ACO 11+ 3% FTP	1,33	36,06	4,85
ACO 11+ 1% IT	1,23	39,30	5,31
ACO 11+ 0,1% Zycotherm	1,23	33,69	4,54
ACO11+ ECO^2 (130°C)	1,00	31,86	4,28
ACO11+ ECO^2 (120°C)	2,71	27,41	3,69

Regarding the second set of experimentally evaluated mixes, it is obvious that the best values of flexural strength were achieved by the asphalt mix with bitumen where Zycotherm was applied as an additive. In this case, if compared to the reference mix, a better flexural strength value was achieved. Good results were recorded also for the application of additive RH. An interesting finding was noticed from the perspective of strength values of the asphalt mix with Zycotherm where basically the same values were reached for both speeds while the values even more significantly exceed the results of the reference asphalt mix. In contrast to that, the results obtained in the asphalt mix resistance to crack propagation test do not relate to the flexural strength test values. Particularly if the result obtained for the asphalt mix with Zycotherm is assessed, it is obvious that the values obtained from the semi-cylindrical specimens are the worst in the comparison of both mix sets while the result is confirmed by the significantly higher deformation generated. A similarly contradictory result arises from a comparison of the values for the asphalt mix with IterLow; where in the case of flexural strength determination the mix recorded the lowest values amongst the second set of mixes while a value comparable to the reference mix with a lower deformation level was achieved from the perspective of fracture toughness. These findings thus open a whole area for discussion concerning the possibility of mutual substitutability of the two aforementioned test methods. Looking at the results of both tests, we can cautiously formulate a hypothesis on a possible link between the results of both methods.

4 Conclusion

As is obvious from the results presented, the most suitable solution for low-viscosity bituminous binders cannot be determined with absolute clarity. The greatest working temperature reduction is achieved by options with NV40 and 407 in the first set while, in the second case, a slightly higher void content is reached. Nevertheless, the mix with this binder still scores highest in relation to stiffness and low-temperature properties characteristics. No test of resistance against permanent deformation was taken for this mix with respect to the limited quantity of the bituminous binder. The option with binder NV40 achieved balanced results. In both cases, further improvements can be expected if the asphalt mix, or test specimen production takes place under the temperature of 130 °C. Due to the above mentioned, we recommend paying attention and possibly undertaking further optimisation measures in relation to these two binders. At the same time, we emphasise that the experimental results be

confirmed by a test section, or possibly, before a test section is completed, by experimental methods with another asphalt mix type.
In the case of the second set of mixes assessed, no clearly best option can be determined. From the point of view of low-temperature characteristics, the options with additives RH and FTP have even properties from the perspective of flexural strength and crack propagation. With resistance against crack propagation, the mix with IterLow scores best while the same binder causes the poorest result from the flexural strength point of view although all of the options meet the minimum requirement for VMT mixes according to TP151 in absolute values. The mixes with FTP demonstrate good stiffness modulus values at 15 °C; in the case of binder ECO^2 the result is similarly satisfactory. In contrast to that, the stiffness values were too low for the mixes with Zycotherm or RH. If a separate evaluation of the result for the parameter of resistance against permanent deformation is made the higher values in the case of the mix with IterLow are noticed. This fact is principally very well complemented by the PI values detected. Nevertheless, it should be considered whether test specimen preparation under 120 °C or even 110 °C would yield similarly satisfactory results (the IterLow manufacturer even mentions a possible working temperature reduction to the 90 °C level). In such a case, the binder would present a well-balanced compromise between the individual characteristics. With respect to additive RH, the question is how the benefits or shortcomings of its application might be compensated by the price. This is an additive of Chinese origin and, therefore, a more aggressive pricing attitude can be expected. From the perspective of technical data, the mix was assessed under 120 °C while thermal optimisation according to TP238 would probably rather suggest 130 °C. Tests of the asphalt mix with FTP proved the traditional findings that can be tracked in other studies conducted as well. The issue of behaviour of the bituminous binder with FTP under low temperatures can probably be tackled in the future solely by combined modification with polymers.
It should also be emphasised that no problem with durability as indicated by ITSR was detected for any of the versions examined. In general, this area is critically researched in the long term in many cases as a number of studies available and verification testing undertaken suggest that low-temperature asphalt mixes might be highly susceptible to ITSR parameter deterioration. This fact is indicated, solely in the second set of mixes under examination, by the asphalt mix with the FTP-modified binder when a single freezing cycle method is applied. Such saturation and stressing of test specimens results in a significant decrease of the ITS values.

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