Cold bituminous emulsion mixtures - laboratory mix design, trial section job site and monitoring

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ABSTRACT

Presently the road construction engineering focuses on technologies, which allow reducing energy demand of the structures to be built. This is closely linked to cutting the release of CO2 emissions and at the same time to the effort reducing costs for new structures or for rehabilitation works. Cold emulsified asphalt mixtures are a kind of road building material which is defined by using specific type of binder and ambient mixing temperatures. Typical is that their cohesion in the early stage after paving is rather lower and increases gradually during the curing period. Specific properties of these mixes support their use mainly for low-volume roads. These mixes have longer tradition in France and partly in the UK. In the Czech Republic very limited laboratory and practical experience are available for these mixtures. Until recent time there were even no technical specifications giving rules for design and use of these cold mixtures. This paper presents laboratory methodology which was used for cold emulsified asphalt mix design and describes results from such design. Additionally long-term assessment of experimentally evaluated characteristics is included as well. Since the real behavior of such mix in pavement structure cannot be with sufficient credibility described by laboratory tests a trial section was realized in 2014. This should bring additional verification of the experimental findings. For the trial section a low volume road was selected where existing pavement dimensions were known and data about daily average traffic were available. Reconstruction was expected with subsequent monitoring of the new structure with respect to traffic and climatic effects. The trial section was divided into 6 subsections with 5 different options of pavement design to evaluate effects of designed cold bituminous emulsion mixes in wearing and binder course. The mixes were designed in some of the options with 30 % of reclaimed asphalt (RAP). Experience from the first trial section in the Czech Republic and data of site monitoring are presented in this paper.

Keywords: Asphalt, Cold Asphalt, Emulsions, Reclaimed asphalt pavement (RAP) Recycling, Testing

1. Introduction

Bituminous emulsion-based technology has been applied in the Czech Republic primarily in the form of coatings, tack coats, surface treatments and microsurfacings as well as cold recycling while the level of exploitation of emulsified asphalt concrete (EAC) has remained negligible if compared to the hot mix asphalt (HMA) technology [1]. In this context, the inequality between cold technologies and hot asphalt mix has to be pointed out [2]. However, the potential for expansion of emulsified asphalt concrete has been raised in the last few years with the demand for the construction or rehabilitation of roads with low traffic loads and an emphasis on environmentally friendly technologies along with very low energy demands during manufacturing. This acts as a springboard for research and laboratory activities aiming to characterise the properties of such materials and specify the technical parameters and requirements in the form of technical regulations. The next step was defining correct procedures and conditions of manufacturing, paving and compaction of such mixes and getting an idea of how the pavement would behave throughout its life; the information should encourage and increase trust in and level of EAC exploitation in the future not only in the Czech Republic.
This paper intends to summarise the findings of laboratory design within the framework of completion of a trial section by EAC mix technology. The motivation and purpose for the trial section was to verify the application of EAC mixes realized in the Czech Republic according to the final design within the technical specifications "Cold asphalt mixes" based on the US approach formulated in the so-called "Cold Mix Design Manual" as well as on the national technical standards used in France (NF). This allowed practical verification of both the viability of the technology and the functionality of the final pavement which forms a prerequisite of the subsequent development of any new technology.
The trial section was realized on a 3rd class rural road between Hraničné Petrovice and Moravský Beroun in July 2014 annual average daily traffic of 184 vehicles in total and informative traffic breakdown to 80 % passenger cars and 20 % heavy loaded vehicles and tractors in total). The project intended to verify the cold technology of emulsified asphalt mixes, mixed and paved in alternatives for both the wearing and binder courses, applying additionally 30 % reclaimed asphalt material (RAP) to some of the mixes. The project also involved in-situ cold recycling in the base layer with a thickness of 150 mm according to [3]. However, this technological stage was not monitored and inspected. For the realization, the trial section was divided into 6 subsections, approx. 300 m long each with 5 different options being verified and a control section. The composition of the pavement in individual sections is indicated in Table 1.
The existing pavement structure originates from the 1960's when the road was built on the basis of penetration macadam technology, followed by repairs by covering either by numerous thin emulsion surface dressings or asphalt overlays of varying composition. Therefore, the surface of such pavements cannot be recycled in a manner that would ensure recovery of the original function; they can only be recycled by in-depth cold recycling technology according to [3] with the intention of obtaining a good quality and homogeneous base layer. A new asphalt surfacing had to be paved on the base layer; the pilot application of cold emulsified asphalt mixes was identified as an cost-effective and environmentally-friendly option for low-traffic volume roads.

Table 1: Pavement structure composition for the trial section

Sub-section No. 1		**Sub-section No. 2**	
PS-E;		PS-E;	
EAC 16; 50 mm	w = 4.3 m	EAC 16; 80 mm;	w = 4.2 m
PS-E;		Emulsion surface dressing;	w = 4.2 m
EAC 11; 40 mm	w = 4.2 m		
Sub-section No. 3		**Sub-section No. 4**	
PS-E;		PS-E;	
EAC 16; 80 mm;	w = 4.2 m	EAC 16 + 30 % RAP; 50 mm	w = 4.3 m
Emulsion surface dressing;	w = 4.2 m	PS-E;	
		EAC 11 + 30 % RAP; 40 mm	w = 4.2 m
Sub-section No. 5		**Sub-section No. 6 (reference)**	
PS-E;		PS-E;	
EAC 16 + 30 % RAP; 80 mm;	w = 4.2 m	ACL 16; 50 mm;	w = 4.3 m
Emulsion surface dressing;	w = 4.2 m	PS-E;	
		ACO 11; 40 mm;	w = 4.2 m
NOTE: PS-E – emulsion tack coat; EAC – emulsified cold asphalt concrete; ACL = asphalt concrete for binder courses; ACO = asphalt concrete for wearing courses			

2. Materials

The design of emulsified asphalt mixes (EAC) per se was carried out at the Faculty for Civil Engineering, CTU in Prague. The aggregates for the EAC mixes were obtained from local sources in the region of the trial section (quarries Bílčice – basalt and Valšov – graywacke). The aggregate is most appropriate for use primarily in road construction. The aggregate properties are indicated in Table 2. Screened reclaimed asphalt material (RAP) of grading 0/11 mm with residual binder content of 6.2 % by mass was also added to some of the mixes by 30 %. The grading composition of individual EAC mixes is indicated in Figure 3.

Table 2: Aggregate characterization

Aggregate grading	Maximum density (Mg.m^{-3})	Shape index (SI) (%)	Grading Fine (G_A/G_F) (-)	Coarse (G_C) (-)
HDK Bílčice 8/16	3 074	13	-	90/15
HDK Bílčice 8/11	3 067	21	-	90/15
HDK Bílčice 4/8	3 061	16	-	90/15
SDK Valšov 0/4	2 828	-	85	-

3. LABORATORY DESIGN OF EAC MIXES

In cooperation with MeadWestVaco European research centre and the Austrian manufacturer of emulsions, Vialit Asphalt, a suitable type of bituminous emulsion was designed and adjusted to this type of mixes. Slow-breaking cationic bituminous emulsion (C60B7) was applied. The emulsion parameters are indicated in Table 3. Straight-run bitumen 70/100 was used for the emulsion design with a continuous phase (water) with HCl and 1.2 % of emulsifier without fluxing agent recommended.

Table 3: Bituminous emulsion characterization

Property	Particle polarity (-)	pH value -	Bitumen content (%)	Dynamic viscosity @ 25°C, shear rate 1 s^{-1} (mPa.s)	Residuum (sieve 0.5 mm) after 7 days storage (%)
C60B7	positive	2.2	62	45	1.0

The mixes were processed in the laboratory with the intention of reproducing mixing in the mobile mixing plant as much as possible. The laboratory mixes were produced using a twin-shaft mixer Wirtgen WLM 30. Due to the reasons stated below, the individual mixes were mixed by the "One Step" method at 18-25ºC. The mixing aimed to coat the aggregate grains with the binder while avoiding composite over-mixing, thus destroying the bitumen film. Czech technical pre-specifications for cold emulsified mixes stipulate test specimens to be prepared in cylindrical moulds with 150.0±1.0 mm diameter and 200-300 mm height. Nevertheless, cylindrical test specimens of 101.60 ± 0.1 mm diameter and 63.5±2.5 mm were selected as more appropriate for the purposes of design and experimental research. The test specimens were compacted by static pressure of 5.0 MPa by pressing the pistons from both sides with permitted release of excess water. The test specimens were left in the moulds at (20±2)°C for (24±6) hours. The curing conditions included air curing at (20±2)°C with 40-70 % humidity for 7 days and also combined curing in water with 7 days air and 7 days water saturated. The requirements for mechanical properties of the emulsified asphalt concrete define the way of determining the optimum moisture content (modified Proctor test), bulk density of the compacted mix, voids content, minimum soluble binder content, indirect tensile strength at 15°C after 7 days dry conditioned and moisture susceptibility parameters. The particular volumetric, physical, mechanical and deformation parameters of the individual emulsified mixes (following the optimisation thereof) are indicated in Table 4. Tensile strengths and fracture toughness were determined for the mixes designed in semi-cylindrical specimens after 28 days curing as well.

Table 4: Characteristics of designed cold emulsified asphalt mixes

Mix characteristic	Symbol	Unit	Requirements (CZ specs)	EAC 11	EAC 11 + 30 % RAP	EAC 16	EAC 16 + 30 % RAP
Soluble bitumen content	B_{min}	% wt.	Wearing course 5.6*/5.2** Binder course */4.2**	6.1	6.2	5.4	6.6
Moisture content (modified Proctor test)	w_{opt}	%		5.7	5.2	5.4	5.4
Maximum density	ρ_{mv}	kg/m^3		2460	2478	2529	2533
Bulk density	$\rho_{b,dim}$	kg/m^3		2211	2250	2230	2231
Voids content (specimen)	V_m	% vol.	5.0 – 12.0	10.1	9.2	11.8	11.9
Indirect tensile strength ratio	ITSR	%	70	73	77	71	71
Indirect tensile strength (dry)	ITS_d	MPa	0.30	0.53	0.43	0.43	0.42
Indirect tensile strength (wet)	ITS_w	MPa		0.39	0.36	0.3	0.3
Stiffness @15°C (7 days air curing)	IT-CY	MPa	Declared values	1 880	1440	1396	1285
Stiffness @15°C (7 days air curing and 7 days saturated)	IT-CY	MPa		800	920	895	887

Stiffness ratio @15°C	ITMR	%		43	64	57	69
Optimum moisture	w	%		5.65	5.3	5.35	5.4
Density (Proctor modified)	$\rho_{b,dry}$	kg/m^3		2 195	2077	2077	2080
Flexural strength @-5°C		MPa		0.51	1.39	0.5	0.77
Fractural toughness @0°C	Kic,i	N/mm$^{3/2}$		26.47	25.54	18.31	25.28
Fractural toughness @-10°C	Kic,i	N/mm$^{3/2}$		21.54	22.59	22.22	27.62
* Max. particle size 11 mm **Max. particle size 16 mm							

4. TRIAL SECTION - IN-PLANT PREPARATION

The emulsified asphalt concrete was prepared in the supplier's production plant. The originally recommended sequence mixing (preparation of a mineral mixture with or without RAP > 4 mm mixed with one half of the water content and the emulsion; subsequently, adding fine-grained aggregates and mixing again with the remaining bituminous emulsion) was abandoned. A mobile mixing unit – Wirtgen KMA 200 – was used. The bituminous emulsion was dosed from tank trucks by means of pumps (see Figure 1) with a temperature of 20-35°C. In contrast to the original intention, the aggregates for individual mixes were prepared in the standard asphalt mixing plant due to the fact that the used KMA unit allowed separately using only reclaimed material in parallel to the dry aggregate mix being added in the feed hopper. This means it was impossible to separate e.g. the coarse aggregates from fine particles and mix the emulsion and aggregate with the mixing water in sequence. Unfortunately, this method involved undesired impact of the pre-heating, since the selected pre-processing of aggregates did not allow dosing and pre-mixing the aggregates without heating in the drying drum (filter contamination by fine particles) and it was necessary to heat the aggregates. Such pre-mixed hot aggregates were subsequently put in the double shaft mixer of KMA unit. The fact that pre-heated aggregate was transported to the mobile KMA unit and, subsequently, dosed straight to the mixer with a direct influence on the moisture parameters and, particularly, on a change in the emulsion breaking parameters is a logical consequence. This method with hot (approx. 100-120°C) aggregates can be marked as inappropriate causing increased water evaporation and, especially, considerable acceleration of emulsion breaking which deteriorated the already imperfect coating of primarily large virgin aggregate particles and, resulted probably in a less appropriate moisture susceptibility, as well as loss of macro-texture by wresting out of aggregate particles from the surface (ravelling). Moreover, a mix prepared by this method would not meet the requirements for mix parameters according to the initial experimental design.
The verification production to ascertain the necessary mix water quantity commenced with no complications. The mix was easy to compact and demonstrated visual characteristics of continuously coated material. During the completion of the first part of the first stretch, it became obvious during emulsion breaking and consolidation that the compacted mix *per se* was not cohesive enough. It was identified that the mixing unit doses only a part of the required bitumen emulsion quantity. Due to that, any further paving was suspended in order to determine the cause. The problem was caused by the lack of technical readiness of the production device (inappropriate maintenance and a considerable quantity of sediment from previous sessions remaining in the pump and dosage system). This resulted in clogging dosing jets and, probably, also diminished the pump functionality.

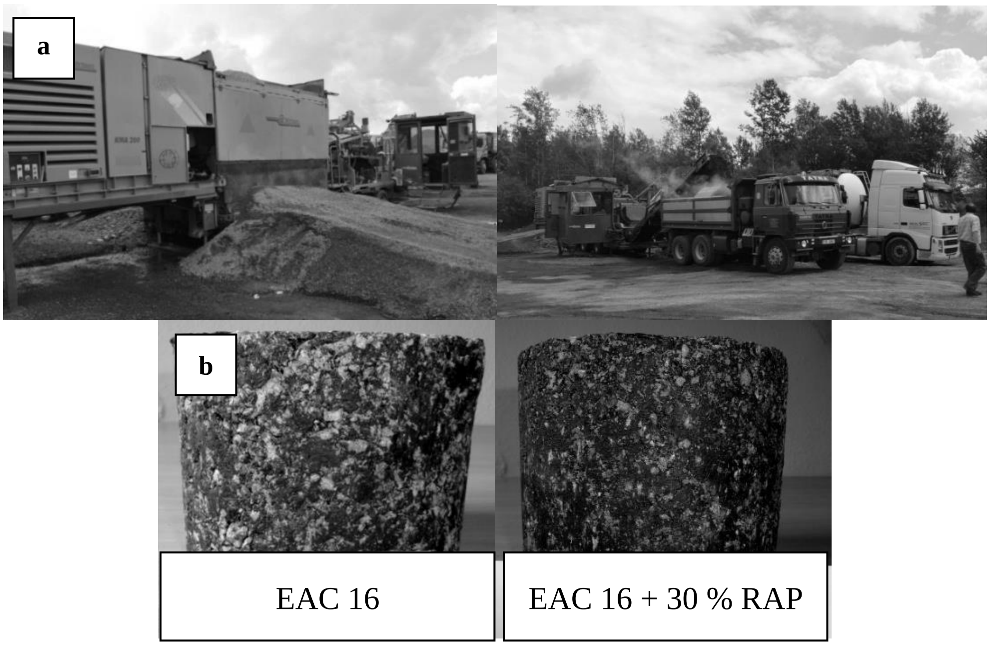


Figure 1: a) Wirtgen KMA-200 / undesirable pre-heating of aggregate – water evaporation from the mix b) quality of coating in the emulsified asphalt mix

It is also not obvious, and the information was not disclosed, whether the recipes changed during the mixing of the dry aggregate mix (for EAC16 and EAC11) – the grading curves of the four mixes differed according to the applicable mix designs. Verification was not possible during the first days of production; no analyses completed by the contractor's laboratory were submitted afterwards, either. The impression gained during the second site visit was that pre-mixed aggregate was stored on the same piles without distinguishing whether it was EAC11 or EAC16, although both EAC16 and EAC11 were prepared in the course of the day. Additionally the content of emulsion and water differed for each mix which affected the resulting parameters. It would have been ideal to have samples and extractions taken of all 4 mixes; however, the contractor failed to do that. Addressing the issues associated with the mixing, CTU Prague only had the opportunity to take a few specimens and mix samples from the binder course which were analysed (see Table 5).

Table 5: Results of control testing done during trial section realization

Mix	Residual binder content [%]	Maximum density [g/cm^3]	Bulk density [g/cm^3]	Voids content [%]	ITS - [MPa] air curing		ITS decrease [%]	Stiffness modulus - [MPa] air curing		ITMR [%]
					7 days	14 days		7 days	14 days	
Section No. 5 (EAC 16 + 30 % RAP)	6.0	2.520	2.257	10.2	0.41	0.54	61.1	1550	2190	48.6
Section No. 3 (EAC 16)	5.8	2.653	2.242	14.4	0.33	0.37	56.1	990	1480	48.7

Table 5 summarises the analyses of mixes extracted within the framework of the test section completion. The results demonstrate:

- Indirect tensile strength values are comparable, although the result of the EAC16 mix prepared for the test section is slightly lower;
- Contrastingly to the laboratory mix design, mixes extracted directly from the mixing unit demonstrate a deterioration in terms of ITSR parameter (moisture susceptibility);
- In case of stiffness modulus, the conclusion is similar to that concerning indirect tensile strength. Mix EAC16 demonstrates a lower value of this characteristics; the considerably smaller drop in ITMR (moisture susceptibility expressed by stiffness modulus characteristic) is quite interesting.

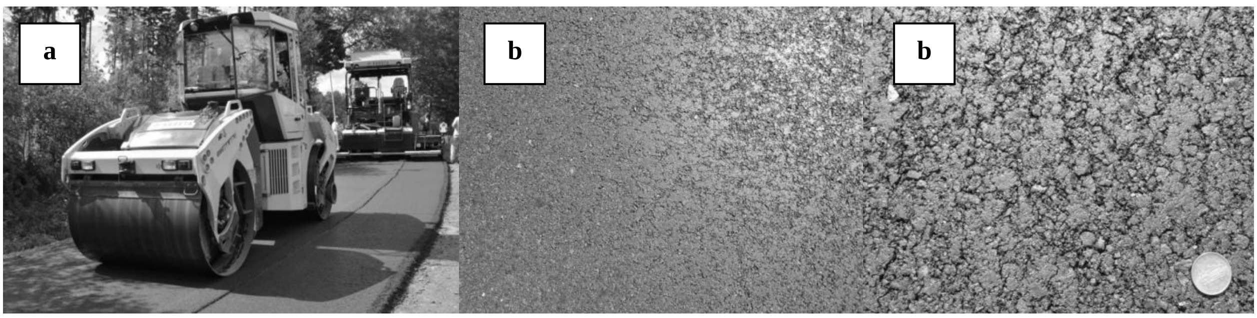
5. PAVING AND COMPACTION

The mix was transported directly to the site and paved by VÖGELE SUPER 1803-2 paver within the entire pavement width (Figure 2a). The compaction set consisted of two steel-drum rollers, the former being BW 154 AD (11 t) and the latter BW 120 AD (2.5 t). Regarding the compaction (see Figure 2a) following approach should have been applied:

- At least 4-6 passes by a steel roller without vibration (to prevent tearing of the mix). A higher number of passes is recommended in general to ensure that the aggregate particles can wedge as good as possible.
- After approx. one hour, a few passes by a rubber-wheel roller to iron the surface; a visual check of compaction quality is needed at this moment at the latest (surface showing no tears in the mix or minor transverse cracks).
- To finish, 1-2 passes by a light-weight steel roller may be performed.

No fundamental problem was identified during the paving as such. Only on some spots excess water was obvious during the site monitoring.

Regarding the compaction the recommended procedure was not applied – the light-weight roller with steel wheels was even not present during on site at the beginning. The first (crucial) compaction stage followed the recommendations on site, with the maximum number of passes by a medium-weight or heavy rollers with steel wheels (no vibration). However, identical rollers were used to iron out the surface after about 60 minutes; this means the surface was not smoothed out as needed and the minor transverse cracks or the occurrence of local "tearing" of the paved layer were not eliminated (see Figure 2c).



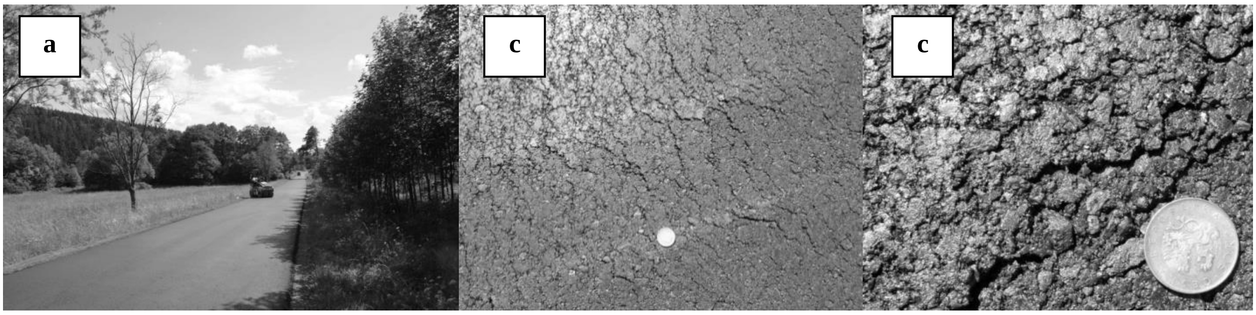


Fig. 2: a) EAC mix laying and compaction – section no. 5
b) examples of the condition of compacted EAC layer with no tears during compaction
c) transverse cracks in the surface of compacted EAC layer which then must be "ironed" by a suitable roller

6. CHECKS OF TRIAL SECTION AND OVERALL EVALUATION

The finished trial section was firstly inspected in approx. two months after paving. The inspection consisted of a visual check of the individual sections and a set of tests performed with borehole samples.
Four samples for each of sections 1, 3, 4 and 5 were taken from the road. The quality of bonding between the EAC layers was not good; the parameter could not be determined for the borehole samples. It is also obvious that the required layer thicknesses were not observed in the individual sections. In some places, very small thickness was detected in the binder course. In relation to the essence of EAC mix as such, this is not a fundamental problem as one of the advantages of this type of mixtures is its applicability when various elevations are evened out in the pavement profile. From the point of view of general pavement structure, this finding can be considered as a failure which might have an impact on the general performance and life expectancy of the pavement.

Table 6: Results of bore sample mix analysis (extracted on September 2014)

Mix	Layer thickness [mm]	Residual binder content [%]	Fine particles [%]	Bulk density – SSD [g/cm^3]	Bulk density – dimensions [g/cm^3]	Maximum density [g/cm^3]	Voids content [%]
Section No. 1 (EAC 11)	55	6.2	13.1	2.224	2.164	2.537	14.7
Section No. 1 (EAC 16)	30	3.4	15.9	2.214	-	2.608	-
Section No. 3 (EAC 16)	65	4.9	9.9	2.388	2.327	2.668	12.8
Section No. 4 (EAC 16 + 30 % RAP)	45	-					
Section No. 5 (EAC 16 + 30 % RAP)	77	6.0	13.8	2.262	2.258	2.535	10.2

The fine particle content as discovered is quite sufficient to ensure good seal to bond the mix as such. On the other hand, such an increase if compared with designed mix (see Figure 3) will raise the specific surface and accordingly also the necessary quantity of bituminous emulsion. The residual bitumen content is insufficient for EAC16 samples from section 1. In the case of section 3, the content is on the threshold. Penetration and softening point were determined for section no. 1 with the extracted binder (original 70/100) from the borehole samples. Binder hardening is probably caused by oxidising processes due to higher voids content in the tested mixtures tested [4] (see Table 7).

Table 7: Parameters of bituminous binder after 2 months curing (section no. 1)

Mix	Penetration [mm^{-1}]	Softening point [ºC]
EAC 11	57	49.8
EAC 16	57	49.4

Similarly to the results presented in Table 6, the results of the voids content determined for the borehole samples document higher values achieved during the paving and compaction of individual EAC mixes within the test section completion. Again, it can be noted that in comparison to the type original mix design, voids content is about 20 % higher. In the case of the EAC mixes in section 1 and 4, the voids content determination could not be documented due to the problems in dimension definition (lack of cohesion of the material during drilling) for the borehole samples extracted from mixes EAC16 and EAC 11 + 30 % RAP. This also applies to strength and deformation parameters presented in the following Table 8. The strength characteristics presented for mixes EAC16, in comparison to the results indicated in

Table 5, have an increasing trend; this supports a gradual consolidation of the pavement layer as such. This is fully compliant with our expectations stipulated for this type of mix. The opposite trend is obvious in the stiffness modulus values where the slower increase is probably due to higher moisture content.

Table 8: Results of borehole sample mix analyses (extracted September 2014) - 2 months of curing

Mix	Indirect tensile strength [MPa]	Stiffness modulus [MPa]	Thermal susceptibility [-]	Fractural toughness (0°C) [N/mm$^{3/2}$]	Fractural toughness (-10°C) [N/mm$^{3/2}$]
Section No. 1 (EAC 11)	0.37	960	4.9	7.5	12.3
Section No. 1 (EAC 16)	-				
Section No. 3 (EAC 16)	0.44	1080	9.1	9.1	18.5
Section No. 4 (EAC 16 + 30 % RAP)	-				
Section No. 5 (EAC 16 + 30 % RAP)	0.57	1340	6.4	13.5	18.4

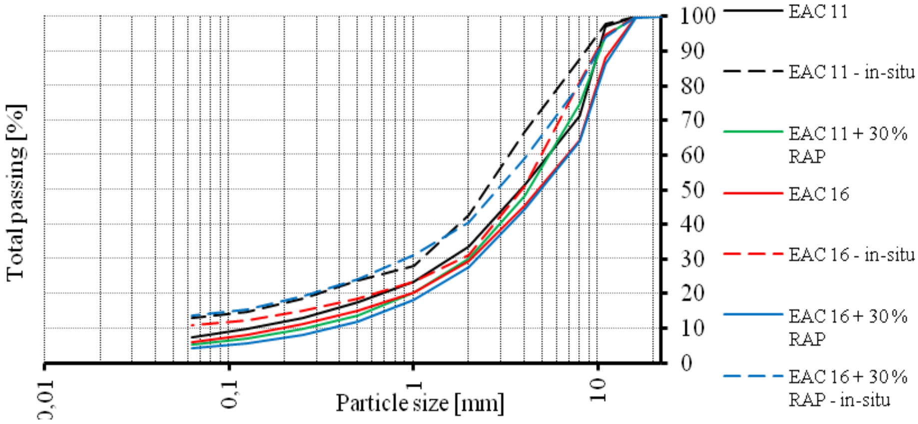
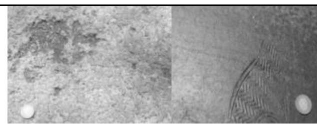


Figure 3: Grading curves for EAC mixes

Visual monitoring was conducted after 2 and 12 months from paving. The inspections detected the following defects listed in Table 9.

Table 9: Visual inspection of the test section

Section no.	Visual inspection 2 months	12 months	Photographic evidence
1	Open texture of the surface is visible; a loss of coarse particles from in the wearing course all over the section. This might be result of compaction when large particles partly stuck to the steel wheel of the roller. The failure is accompanied by short transverse cracks which, again, occurred during the compaction.	A significant development in overall ravelling in the wearing course. Potholes and longitudinal waves have started to occur in some places.	 
2	The test sections have a single-layer surface dressing according to the national technical regulations [5]. Damage to the dressing is obvious – local aggregate loss either due to	Areas with binder bleeding and areas with loss of aggregate from the coating occur on a larger scale. No permanent deformations in the pavement surfacing due to traffic load appear.	

	inappropriate choice of aggregate, insufficient cleaning of the surface or use of unwashed aggregate and probably unsuitable binder, or poor quality of the emulsion. Another failure is the overlapping of surface dressing between traffic lanes, specifically in section 3. This largely contradicts the applicable technical regulations where the method of proper execution of surface dressing is pointed out and emphasised.		
3		-	
5		Areas with binder bleeding and with loss of aggregate from the coating occur on a larger scale. No permanent deformations due to traffic load appeared so far.	
4 5	No failures or defects were detected during the visual inspection.		

From the point of view of permanent deformation of the pavement due to traffic loads, no problems are detected in any of the sections. Unfortunately, the aforementioned failures caused by errors during construction can have a negative impact on the perception of the emulsified asphalt concrete technology itself.

7. LABORATORY TESTING OF EAC MIXTURES

There is currently no "widely accepted" design method for cold asphalt mixtures in the world. Besides the lack of unified laboratory methods and evaluation thereof, particularly in the early curing stages, it is difficult to generate reliable correlations between experimental findings and test results described in literature by various experts. One of the specific issues within the field of EAC mixtures is finding a correlation between laboratory [6] and in-situ [7] compaction. Some sources specify compaction of cold emulsified mixtures in the laboratory by means of an impact compactor [2], hydraulic press [8] or gyratory compactor [9]. Based on the methods applied in France, the voids content achieved during paving corresponds with gyrator compaction if 60 revolutions with the pressure of 600 kPa are applied. According to French methodology [9, 10, 11, 12], the gyratory revolution number is determined by the layer thickness and mix type regardless of the traffic load. The 60 revolutions correspond with a layer thickness of 5-10 cm. This comparison (see Table 10) follows the requirements of [9] in relation to the gyratory compactor. We should accent that the presented compaction values achieved in-situ are not absolutely relevant for the comparison due to the aforementioned problems in completion, or the differences between the laboratory mix design and the in-situ mix.

Table 10: Comparison of the voids contents achieved through different compaction methods

Mix	Voids content		
	Hydraulic press 5.0 MPa	**Gyrator 60 rev., 1.25°, 30 rpm, 0.6 MPa**	**In -situ compaction**
EAC 11	10.1	8.8	14.7
EAC 11 + 30 % RAP	9.2	9.4	-
EAC 16	11.8	10.3	12.8
EAC 16 + 30 % RAP	11.9	11.4	10.2

Within the framework of laboratory design of cold emulsified asphalt mixtures, voids contents of the mix for 60 revolutions must fall within the range of 5-12 %-vol. and, at the same time, exceed >12 % under 10 revolutions of the gyrator in compliance with the requirements of the standard [13]; the value represents a quality parameter of compactability during paving. Table 11 presents a comparison of the aforementioned compacting equipment and the resulting volumetric, physical, mechanical and deformation parameters of the selected emulsified mix.

Table 11: Comparison of the parameters of mix EAC 11 depending on the compaction method

EAC 11	Gyrator 60 rev., 1.25°, 30 rpm, 0.6 MPa	Hydraulic press 5 MPa	Observed change in the parameter (%)
Bulk density (kg.m^{-3})	2231	2211	99.1
Voids content (%)	8.8	10.1	114.8
Indirect tensile strength – 7 days air curing (MPa)	0.61	0.53	86.9
Indirect tensile strength – 14 days curing (7d+7w) (MPa)	0.53	0.39	73.6
Stiffness modulus – 7 days air curing (MPa)	1 727	1 880	108.9
Stiffness modulus – 14 days curing (7d+7w) (MPa)	1 199	800	66.7

Another important issue affecting the ultimate EAC mix properties is the effect of curing conditions. The laboratory testing involved research of the effect of curing conditions on the stiffness modulus development (15°C) in time, specifically for mixtures EAC 11 and mixtures extracted during in-plant preparation of EAC 16 + 30 % RAP. Fig. 4 shows five methods of test specimen curing where the first method follows the standardised conditions according to the preliminary technical conditions, i.e. dry curing at (20±2)ºC with humidity of 40-70 %. The second method involved humidity of 100 % and temperature of (20±2)ºC. The third method examined the effect of accelerated curing where each specimen was cured for 4 days after production in standard conditions and, subsequently, put in a drier for 3 days at (50±2)ºC and then back for air curing with humidity of 40-70 %. The fourth option involved test specimen curing in water straight after production; the fifth method was a combination of cyclic air curing for 21 days at (20±2)ºC with humidity of 40-70 % followed by 7 days water curing. EAC mixtures are developing materials. Besides temperature or ageing of the bituminous binder, the development of deformation or strength characteristics of these mixtures is also fundamentally influenced by the mix moisture content, as illustrated by Figure 4 [14, 15]. The relationship between the laboratory and in-situ conditions is also noticeable; this discrepancy can be attributed to the differences in preparation and compaction in the laboratory and in-situ as described above, and the different humidity settings for curing.

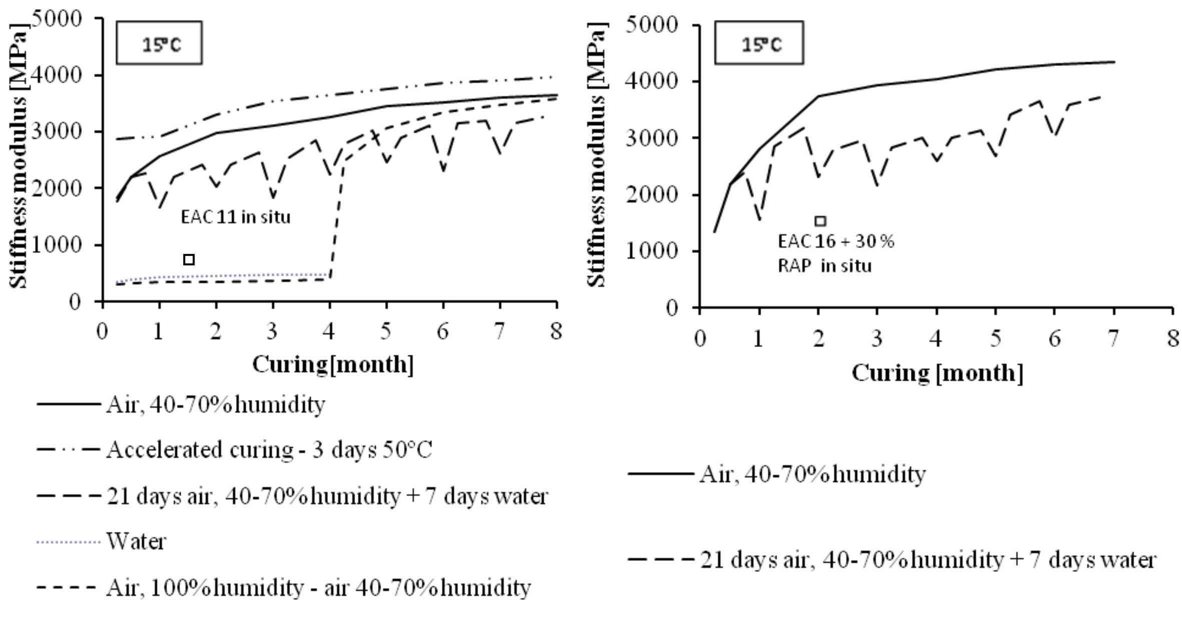


Figure 4: Curing conditions for mixes EAC 11 and EAC 16 + 30 % RAP

Cold emulsified asphalt mixtures are a multi-phase system of many components some of which also have a complex internal structure characterised by high thermal sensitivity. Basically, these are the components of irregular aggregate grains with slightly higher binder content and a small proportion of the volume filled by air voids. Despite its complex structure, the material behaviour can be described by means of the visco-elasticity theory [16; 17; 18; 19; 20]. One of the linear visco-elastic parameters is the complex modulus. Dynamic complex modules were determined by the 4PB-PR method according to [21] in the -20°C to +27°C temperature range and with frequencies 0.1 Hz to 40 Hz after 28 days of air curing. The master curves (Figure 5) were compiled using the time-temperature superposition principle through shifts in both the horizontal and the vertical direction to determine the thermal dependence of the material's rheological behaviour and to extend the time and frequency range under the relevant temperature within the IRIS Rheo-Hub. The Wiliams-Landel-Ferry equation with parameters C_1=100.00, C_2= 1070.08 was used to describe the horizontal shift while a polynomial function with parameters a_0=0.964, a_1=1.553E-02, a_2=1.537E-04 described the vertical shift [17; 22]. If we look at the master curves from right to left, it is obvious that the material tends to behave in an almost elastic manner in the lowest temperature range and highest frequency range. The shift from visco-elastic to elastic behaviour is clearly visible in the values measured within the dropping imaginary part of the complex curve. With increasing frequency, the real part of the complex curve gradually increases while its derivation decreases and for last values almost touches 0. This phenomenon correlates with the shift of material properties towards the elastic area and with reaching the equilibrium point of the modulus, [17; 23]. As is obvious from the phase angle change, the cold emulsified asphalt mixes are highly thermos-mechanically sensitive materials in comparison to hot-compacted asphalt mixes.

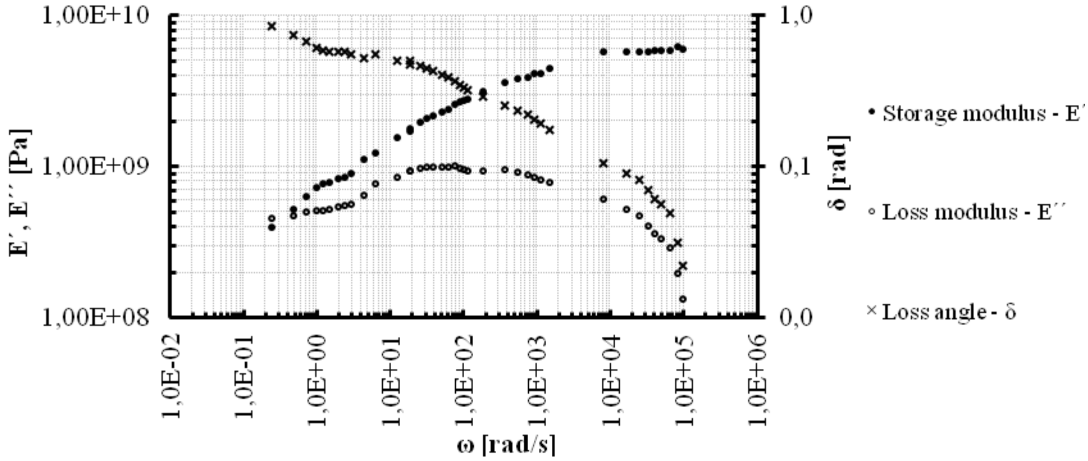


Figure 5: Master curves - EAC 11(Voids content 10.1 %)

With respect to permanent deformation standard rutting test was conducted in a small test device at 60 °C according to [24]. The test specimen was loaded by 10,000 cycles with a frequency of 0.44 Hz for each passing. The results achieved are not too reproducible (see Figure 6) since considerable deformation and damage to the test specimens occurred. The next stage should therefore be a discussion on whether the test conditions reflect the actual conditions (fluctuation of vehicle driving tracks, curing etc.). The fact does not restrict the options for exploiting the mixes in road construction because, based on French findings [7, 11] the tests of resistance to permanent deformation usually delivered poorer laboratory results, i.e. they never corresponded with reality in the pavement. So far, cold mixtures have always behaved better in-situ throughout their life. This is closely related to their curing in time.

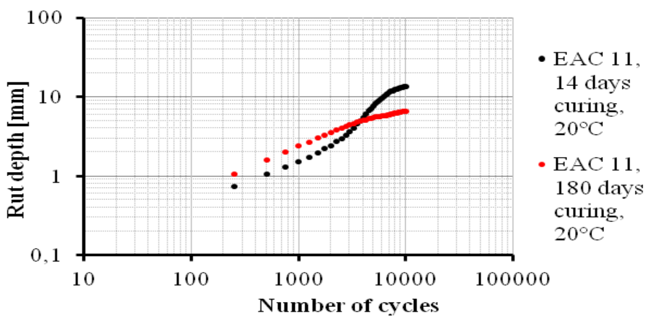


Figure 6: Occurrence of permanent deformation, cold mix EAC 11 (voids content 10.1 %)

8. CONCLUSION

This paper described the individual stages of the first trial section for cold emulsified asphalt mixtures which originally intended to verify the viability of this technology in the Czech Republic. The project was required to verify the design methodology, to confirm promising laboratory results and to acquire initial experience with the mix production and subsequent completion in-situ for the purposes of compilation of the “Cold Asphalt Mixes” technical specifications. Based on the presented results, we can state that the project has been successfully finished; the findings obtained will be utilised not only in the regulations but also in the formulation of arguments from the point of view of recommendations to the contractors and public administrators. The project faced a number of problems, of a technical nature in particular due to unsatisfactory planning and weak technical preparation of the contractor. However, even such problems and findings derived there from have their value for the future application of the technology forming lessons learnt for next application of this technique. There is nevertheless still a more difficult comparability with the experimental laboratory results which have been done before the trial section and later on materials obtained from the trial section.

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