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Asphalt concrete mixture containing 40 % reclaimed asphalt – comparison of initial testing and trial section control tests

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Abstract

The reuse of reclaimed asphalt (RA) is becoming more and more a common practice in many European countries. Long-term experience with high rates of RA already exist for various mixtures e.g. in Germany and the Netherlands. The Czech Republic has been moving towards recycling with specifications and equipment set up in recent years. To bring recycling to an advanced level, the use of rejuvenator is considered by some asphalt producers for increasing the RA content in new asphalt mixtures, or if the RA binder is showing increased level of ageing (low penetration and high softening point values), or if it is needed to improve the processing at the mix plant and during paving where mixtures containing RA are considered to be used. While there are already numerous studies and/or research projects at lab scale evaluating the benefits of rejuvenators, it still requires at local level to provide practical validation as well as to compare mix design expectations and laboratory mix performance with on-site mixtures and their particular characteristics. This paper presents results of full scale asphalt plant production for asphalt concrete and pavement application of such mixture containing 40 % RA. Two different rejuvenating agents have been used and compared with a reference mix with no additives as well as additionally with a softer bitumen as an alternative known technical option. In the first stage mix design was provided and for all later used variants volumetric as well as performance-based characteristics were determined. In the second stage asphalt mixtures from a trial section were sampled from the plant production for further laboratory evaluation. The outcomes show that with locally available RA and current plant processes mixtures with 40 % RA and a suitable rejuvenator can perform similarly to traditional asphalt concrete without RA not harming the long-term durability and improve resistance to rutting.

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1. INTRODUCTION

Over the years, road transportation has contributed significantly to air pollution and consequently to the global warming and climate changes. Therefore, the asphalt industry, as a part of this complex manmade problem, is making efforts to find solutions with the only target to reduce pollutants and to offer sustainable and still cost effective products. One of the very important solutions in asphalt pavement industry is the use of Reclaimed Asphalt (RA) in the production of new asphalt mixtures. Hence, this method is known for many years and has repeatedly shown a considerable savings in virgin material resource, energy, cost and waste disposal occupation. [7, 10, 14]

The maximum content of RA in asphalt pavements is usually limited by national standards, technical conditions, technical abilities and public willingness to reuse as much material as possible. It also differs for individual pavement layers. In parallel, among the last years, the roads community has increasingly reconsidered the environmental and economic benefits of using higher RA contents in asphalt mixtures. Nevertheless, the elevated amount of RA in asphalt mixtures has shown several problems, such as potentially worsen fatigue resistance, worsen thermal induced cracking resistance, partial blending, etc. [3, 4, 12].

In order to overcome the problems cited above, many research works and studies have shown that the use of additives or special bituminous binders allow to the aged bitumen regain its initial properties. In fact, the use of rejuvenators, allows a significant balance in the chemical composition of the aged bitumen. The correct dosage of rejuvenator can significantly improve the low temperature properties of asphalt mixtures (too stiff and brittle mixtures are predisposed to cracking in low temperature). On the other hand, the overdosing of rejuvenator can wosen the resistance of permanent deformation. Finding of optimum rejuvenator content is crutial for correct mixture design. [2, 6, 12]

Several studies have been presented to evaluate the performance of bituminous binder rejuvenators. Zaumanis et al. reported that the addition of five rejuvenators have increased the indirect tensile strength, hence, have improved low-temperature performance in the mixtures [13]. Shen et al. revealed that the rejuvenator percentage affect meaningfully the properties of bituminous binders. The researchers agree that this percentage decrease the rutting resistance parameters, yet, it improves the fatigue resistance parameters [8]. Tran et al. concluded that the use of rejuvenators in the recycled mixtures improved the resistance to crack propagation of asphalt mixtures with RA content with decreasing the water susceptibility or rutting. [9]

Similarly, the addition of polymer modified bitumen (PMB) as a binder can significantly improve the performance of asphalt mixtures. In fact, studies have shown that PMBs helps in increasing the softening point and improving the resistance to permanent deformation, moisture resistance and decreased fatigue damage [8].

To sum up, the use of rejuvenators and polymer modified bitumen has facilitated the use of high RA content in asphalt mixtures. These solutions, if used and designed in the mixture properly, offer a promising result that neither researchers nor practitioners can neglect.

2. ASPHALT MIXTURE VARIANTS

In this case study ten variants of AC_{bin} 16 with 40 % RA (asphalt concrete used in binder layers with maximum aggregate size 16 mm) are presented. Six (6) variants were produced in laboratory within the initial type testing procedure and four (4) variants were sampled on the asphalt plant during the mix production for a trial section.

This study covers asphalt mix variants containing either rejuvenator (2 types) or an alternative binder solutions and one reference asphalt mix with use of traditional bituminous binder. The study covers commonly used bituminous binder, as well as soft bitumen, bituminous binder specially modified by polymers for mixtures with elevated RA content (commonly described as PMB RC), and selected rejuvenators.

All the mixtures had the same grading composition and same binder content of added virgin binder. The recycled material was used in two different fractions – 0/8 mm and 8/16 mm. The finer RA fraction 0/8 mm was dosed in a ratio of 10 % and the coarser RA fraction 8/16 mm with 30 %. The intension to use two RA fractions was to have better control of grading curve and bitumen content in the final mix. These two fractions are regularly used by the collaborative asphalt plant partially also because of the used double-coated drum.

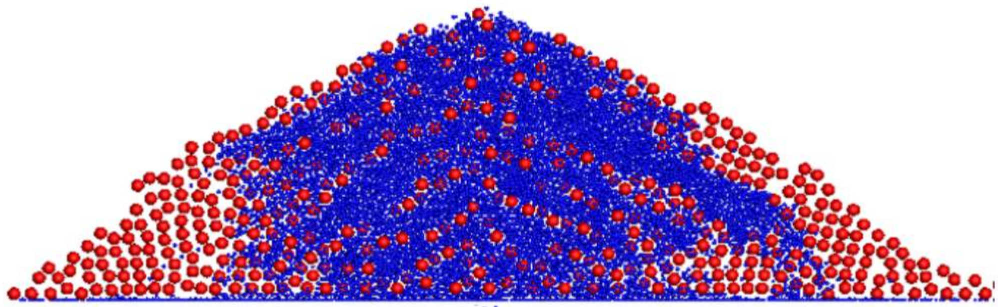

Figure 1: Illustration of segregation of aggregate with wide fraction [14] ~~[6]~~

The RA which is crushed and sorted to more narrow fractions is less susceptible to segregation during storage, for example in comparison to wide fractions like 0-16 mm. In wide fractions coarse and fine particles are segregated and it can result in greater dispersion in results during control tests (factory production control) of asphalt mixtures.

The aim of the research study was to compare the properties of asphalt mixtures from laboratory designs and choose the best solution for the trial section. Further aim was to compare the properties of laboratory designs and control mixtures from realized trial section.

The used bituminous binders were:

- paving grade bitumen 50/70 (the most commonly used bitumen in the Czech Republic);
- softer paving grade bitumen 70/100;
- soft paving grade bitumen 160/220;
- PMB 25/55-55 RC (special polymer modified binder used in asphalt mixtures with elevated RA content);
- paving grade bitumen 50/70 combined with rejuvenator REJU R;
- paving grade bitumen 50/70 combined with rejuvenator REJU S.

REJU R is an oil based additive, which should according to the manufacture improve the aged binder's flexibility, reduce the susceptibility of binder to fatigue, improves the permanent deformations and restores the self-healing properties of the aged binder.

REJU S is a vegetal based additive which, according to the manufacturer improves the workability of bituminous mixtures with a high proportion of RA, improves resistance to crack formation, water and frost resistance and resistance to permanent deformation.

Both rejuvenators were dosed according to laboratory settled nomogram for penetration-rejuvenator content functionality using the extracted bituminous binder from used RA.

Special RC polymer modified binders is a product developed for asphalt mixtures with high RA content used for many years mainly in Germany. The binder contains higher amount of elastomer modifier, but on the other hand the softening point of RC binders is usually not that high as for example for highly modified binders (HiMA). The aged binder in RA has usually high softening point, so it is not necessary to use high softening point binders.

3. TRIAL SECTION

The trial section was realized in September 2018. The total length of the section was almost 3 km and covered three variants of asphalt mixture in binder and in wearing course. In binder layer AC_{bin} 16 with 40 % RA with softer paving grade bitumen 70/100 and paving grade bitumen 50/70 with both types of selected rejuvenators were used. For all mixture variants the same mix design was used as presented in Table 1. It was not assumed to run specific optimization for each mix option even if it was assumed that mainly rejuvenators can have some effect on compaction and therefore also on resulting air voids. For the same reason laboratory compaction temperature was kept the same as well. With the same assumption the production on mixing plant was realized as well.

In wearing course AC_{surf} 11 with 20 % RA and application of same binders was used *(not presented in this paper)*. Additionally, to this, the mix variant with paving grade bitumen 50/70 was manufactured on the asphalt plant to be used as a referential mix. The soft bitumen 160/220 and PMB RC variant were not included in the trial section and tested only during the initial stage of experimental mix assessment.

The optimized content of used rejuvenators was set during the initial mix designing. From the used reclaimed asphalt several bitumen samples were recovered and tested on penetration and softening point. Based on this and on the knowledge of the basic bitumen characteristics fro paving grade 70/100 and 50/70 the amounts of added rejuvenators was fixed and kept the same also later during the plant production. There was no re-check for the rejuvenator content before plant production

Table 1. Asphalt mix grading curve (AC_{bin} 16)

Mix component	Virgin aggregate				Reclaimed asphalt		Filler	Virgin bitumen
	11/16	8/11	11/16	8/11	11/16	8/11		
Content (%)	19,6	8,7	10,5	17,0	30,0	10,0	1,5	2,7

4. TESTING OF AC_{BIN} ASPHALT MIXTURES

For evaluation of influence of tested variants, the following tests were performed and evaluated:

- **volumetric characteristics** (EN 12697-5, EN 12697-6, EN 12697-8);
- **water susceptibility** (EN 12697-12)
- **stiffness modulus** (EN 12697-26, method IT-CY) at test temperature of 0 °C, 15 °C a 27 °C;
- **resistance to permanent deformation** (EN 12697-22) on small test device in air bath at test temperature of 50 °C;
- **flexural strength** determined by three-point bending beam test at a test temperature of 0 °C (Czech Technical Specifications TP 151);
- **fracture toughness** determined according to SCB test (EN 12697-44) performed on 100 mm diameter semi-cylindrical specimens with a loading rate of 2,5 mm/min as a modified procedure used for several years in the Czech Republic.

4.1. Volumetric characteristics

The volumetric characteristics were compared with the limits required in the national application annex to the product standard EN 13108-1:2008. The standard limit and threshold values for the initial type tests are highlighted for the mixtures in Figure 2. The volumetric characteristics were determined on test specimens compacted according to EN 12697-30 at temperature of 150 °C (for paving grades) and 160 °C (for PMB RC).

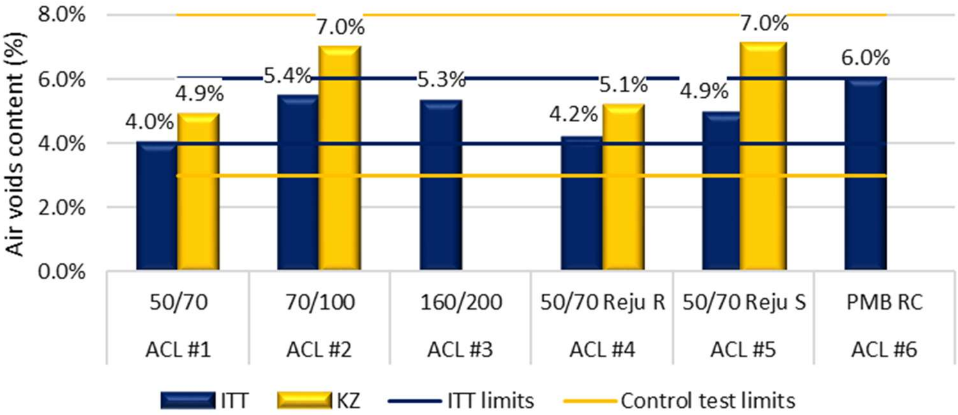

Figure 2: Air voids content of asphalt mixture AC_{bin} 16 40% RA

The design of all tested mix variants was the same as given in Table 1 to reach better comparison of influence of used "modifications" or improvements reached by used additives or bitumen variants. Based on this it was realized already during the laboratory stage of the study that the voids content variability is higher reaching the minimum limit given in the standard with 50/70 paving grade and the maximum allowed limit for variant with PMB RC. It has further to be emphasized that the used reclaimed aspahlt was from one dump which by far was not a single source, i.e. the dump contained site won asphalt from various roads and from wearing as well as binder courses of such roads. This approach was kept since it is common way how RA is treated and re-used in the Czech Republic. Most probably mainly this effect might influence the resulting voids content. It can at least explain the differente between type testing mixtures (ITT) and trial section samples (KZ) since there was a time difference of several months. Even if during the experimental stage and mix design reclaimed ashalt from one source was used, the identical reclaimed asphalt could not be guaranteed for the later plant production.

Some of the mixtures behaved differently than it was expected. It was e.g. assumed that use of softer bitumen (160/220) will lower the air voids content. This did not appear and the air voids content increased by almost 1.3 %. The same phenomenon occurred for the mixture with 70/100 paving grade. Such increase can be caused by the heterogeneity of reclaimed asphalt. Even though same RA source was used for the whole project, reclaimed asphalt remains partly an unpredictable material, especially in elevated content due to its heterogeneity. Both fractions of RA were sampled at asphalt plant. The material there was crushed, sorted and separately stored. The material was several times homogenized and then sampled for the laboratory testing. Use of higher content of RA can unfortunately result in inconsistent test data, especially in laboratory conditions. On the other hand, the standard deviation of maximum densities was 0,010 g/cm^3 for laboratory manufacture (type testing) and 0,009 g/cm^3 for asphalt plant production (control tests), which shows very close results and therefore indicates quite good homogeneity of the mixtures (used materials).

It has to be further accentuated that – according to chapter 3 – the ontent of both rejuvenators was set at the beginning without any additional adjustments later during the laboratory testing or plant production. Already in the experimental stage it was visible that the effect of rejuvenator R lead most probably to slightly improved compactibility resulting in lower voids content. For the experimental stage the voids contents of variants #2, #3 and #5 are in terms of voids content more or less same. The higher voids content value for #6 is most probably related to the reduced workability which would need additional increase in compaction temperature. The result for mixture #1 is for us still unaccountable.

Very unexpected was the poor result of PMB RC binder. It was expected, that PMB RC binder will improved the workability of mixture and therefore lower the air void content.

All the control test specimens evinced increased air voids content in comparison to its laboratory manufacture equivalents. The bitumen is during the mixing process in asphalt plant exposed to increased temperatures (up to 180 °C) and pressures. The virgin binder is accordingly aged (short-time ageing) and the already aged binder in RA is partly further aged. The workability of the asphalt mix therefore decreases. The increase was approximately 25 %, excluding the mix variant with rejuvenator REJU S – in this case the increase was the highest (more than 40 %).

4.2. Water susceptibility

The determination of water immersion was performed in accordance with EN 12697-12. For each mix variant a set of 6 Marshall test specimens was compacted according to EN 12697-30 by 2x25 blows by impact compactor. These specimens were divided into two groups. Dry specimens were stored at room temperature and at normal relative humidity. Specimens marked "EN" were subjected to a water saturation procedure according to EN 12697-12, when the specimens were saturated and stored in a water bath at 40 °C for 72 hours.

As can be seen from Figure 3, the indirect tensile strength of the virgin (“dry”) specimens decreases with addition of rejuvenator or if different binders are used. It is expected, because rejuvenators or soft bitumen softens the aged binder in RA and therefore lower the strength properties.

Nevertheless, this does not fully apply to the results of control tests. The mix variants ACL #1, #2 and #4 achieved almost identical results. This means that application of softer bituminous binder or rejuvenator REJU R had almost no influence of softening of aged binder in RA. For rejuvenator S the strength decreased by 15 % compared to the reference mix. From point of view of this characteristic and use of higher RA content, the rejuveator REJU S seems to be the best option.

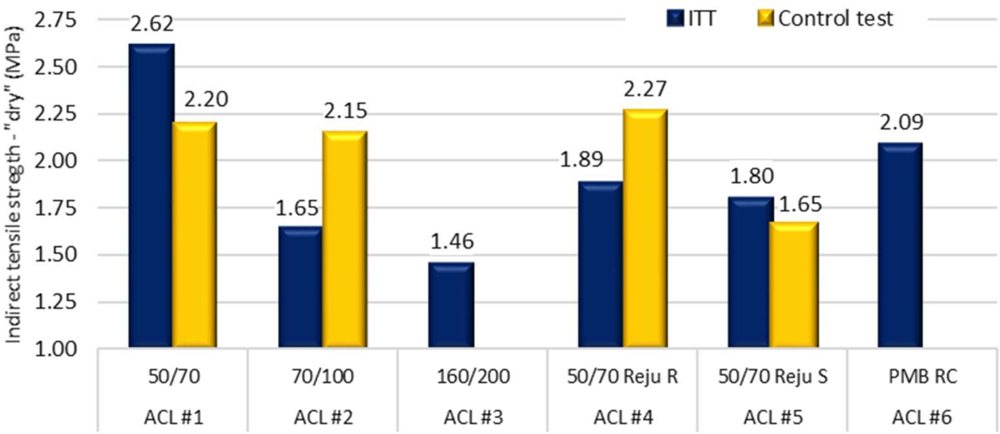

Figure 3: Indirect tensile strength (ITS) of AC_{bin} 16 asphalt mixture variants

The deciding results of this test is indirect tensile strength ratio (ITSR). This ratio shows the water influence on the specimen properties. As well known the lower the ratio, the more the mix is susceptible to water damage. It can be see, that ITSR value is improved by use of different binders or use of a rejuvenator (type testing). The best results as expected are reached by the mixtures with PMB RC binder. For the mixture containing PMB binder interesting phenomena occurred. The indirect tensile strength of saturated specimen is higher than for referential specimens. It is not possible that water would improve the properties. The results are more likely influenced by the averaging of the values or insufficient tempering of the specimens before the test procedure. Even 1 °C difference in the temperature can cause a relevant difference in the results.

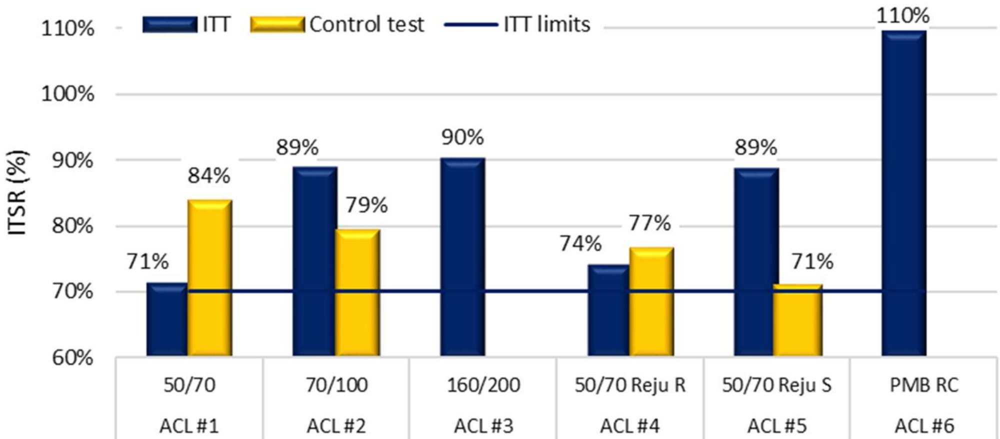

Figure 4: Indirect tensile strength ratio (ITSR) of AC_{bin} 16 asphalt mixture variants

The type testing results show an improvement of the ITS characteristics for all tested variants. The control test results show another phenomenon. The best results from control test group were obtained for reference mixture with bitumen 50/70 and all other variants showed worsen results. The lowest ITS ratio was achieved by the mix variant ACL #5 with application of rejuvenator REJU S. On the other hand, this variant achieved the best results of softening of the aged binder (reduction of ITS value of "dry" specimens). With application of soft bituminous binder or REJU R a nearly identical decrease in strength was achieved.

4.3. Stiffness modulus

The stiffness modulus was determined on Marshall test specimens by IT-CY test method according to EN 12697-26 (non-destructive repeated indirect tensile stress test) at three selected test temperatures: 0 °C, 15 °C and 27 °C, which are common for countries like the Czech Republic or Slovakia. Additionally, to that the aged specimens were tested at temperature of 15 °C and 0 °C for control test specimens. The specimens were laboratory aged according to one of the methods described in EN 12697-52 – storing of compacted specimen in the oven with forced air circulation at temperature of 85 °C for 5 days.

The stiffness modules of type testing specimens follow similar trend like ITS – the stiffness of mix with 50/70 paving grade reaches the highest value and softening of the aged bitumen contained by the reclaimed asphalt (by rejuvenator or soft bitumen) causes decrease in the strength properties.

Another trend is visible for control test specimens – the stiffness of some testspecimens from control tests at some test temperatures increased compared to the reference mix. The decisive design temperature for the Czech Republic is 15 °C. At this temperature the asphalt mix variant with REJU R evinced slight increase in stiffness compared to the reference mix value. The rest of the variants reached lower values. Compared to laboratory production, the stiffness of mix variants with rejuvenators increased by about 60 %. For other variants with common pavng grade bitumen, there was also a visible increase, but not as sgnificant. The asphalt plant production uses higher temperatures than those used in laboratory production. The rejuvenators were dosed (sprinkled) on the RA material on a conveyor belt before entering the drying drum. It is possible that during drying of the material (passing of RA through the drum), the rejuvenator partially leaked out. This would explain the increase in the air voids content and the significant increase in stiffness modulus. Regrettably, it is not possible to determine the exact amount of rejuvenator in the mixture. Nor can be the amount of rejuvenator reliably determined from tests of the extracted bituminous binder.

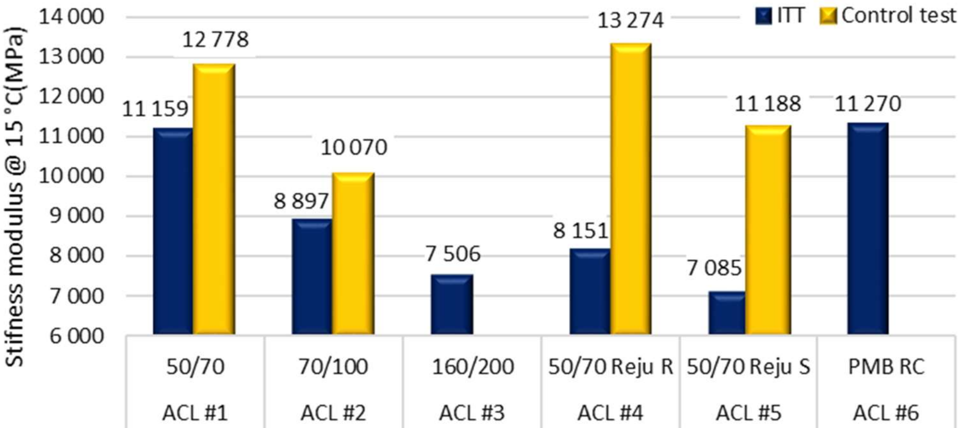

Figure 5: Stiffness modulus at 15 °C of AC_{bin} 16 asphalt mixture variants

Furthermore the thermal susceptibility was calculated as a ratio of stiffness modules at 0 °C and at 27 °C. The lower the thermal susceptibility, the less sensitive to temperature changes the asphalt mix is with respect to its deformation characteristics. The lower the value is, the better will the mix resist to climatic changes.

The thermal susceptibility of type testing specimens was in quite wide range – from 3.8 to 9.7. The lowest susceptibility was reached by the mixture with PMB RC binder. The elastomeric polymer in this binder improves the mix properties and therefore helps with resistance to changes in atmospheric temperatures. The highest was reached by using soft bitumen 160/220. Even thought there was used 40 % RA in the mixtures, bitumen 160/220 seems to be too soft for being used in asphalt mixtures.

From point of view of thermal susceptibility, the results on control tests were very consistent. There were not noticeable differences between the mixtures.

The aging index as an additional indicator could be one of the easy ways of comparing the durability of asphalt mixtures. In general, the closer the aging index is to 1.0, the less the aging process affects the properties of the asphalt mixture. On the other hand, the higher the index is, the more the aging of mixture (especially binder) influences the properties of asphalt mix and such a mixture may degrade sooner. It can be said with a certain extent of caution that the closer the aging index is to 1.0, the more durable the asphalt mixture will be, i.e. it can be expected to have a longer service life.

In case of strength characteristics, there is always an increase in strength properties due to aging of bituminous binders. The binder oxidizes (ages) due to increased temperature and oxygen presence. It decreases its penetration and elasticity, and on the other hand increases its brittleness and risk of distress (degradation) due to sudden load or temperature changes. Surprisingly the reference mixture with 50/70 binder reached the best results in terms of the aging index. Both rejuvenators showed similar values in control tests, but the mixtures with REJU S achieved worse results in the type test results.

Table 2. Stiffness modulus at 15 °C of AC_{bin} 16 asphalt mixture variants

Asphalt mixture			Stiffness modulus (MPa)							
			virgin			Thermal susceptibility	aged 5 days	Ageing index	aged 5 days	Ageing index
			0 °C	15 °C	27 °C		0 °C		15 °C	
Type testing	ACL #1	50/70	22 158	11 159	4 793	4,6	-	-	12 990	1,16
	ACL #2	70/100	19 455	8 897	3 111	6,3	-	-	11 280	1,27
	ACL #3	160/200	19 018	7 506	1 958	9,7	-	-	9 641	1,28
	ACL #4	50/70 Reju R	17 474	8 151	2 887	6,1	-	-	9 651	1,18
	ACL #5	50/70 Reju S	14 565	7 085	2 206	6,6	-	-	9 170	1,29
	ACL #6	PMB RC	20 705	11 270	5 399	3,8	-	-	13 520	1,20
Control testing	ACL #1	50/70	21 587	12 778	6 199	3,5	23 636	1,09	15 292	1,20
	ACL #2	70/100	18 053	10 070	4 418	4,1	24 890	1,38	14 139	1,40
	ACL #4	50/70 Reju R	21 041	13 274	5 713	3,7	24 457	1,16	15 396	1,16
	ACL #5	50/70 Reju S	17 546	11 188	4 841	3,6	21 192	1,21	13 783	1,23

4.4. Resistance to permanent deformation

The resistance to permanent deformation was determined in accordance with EN 12697-22 in a small test device using air bath with a test temperature of 50 °C. The national requirements based on product standard EN 13108-1 set maximum values for the two test parameters – PRD_{AIR} and WTS_{AIR}. For the average rut depth (PRD_{AIR}) the maximum value for ACL 16+ mixtures is 0,06 mm and for the increment of rut depth (WTS_{AIR}) the required threshold value is 4,0 %.

Table 3. Resistance to permanent deformation of AC_{bin} 16 asphalt mixture variants

		WTS_{air} (mm)		Limit	PRD_{AIR} (%)		Limit
		Type testing	Control testing		Type testing	Control testing	
ACL #1	50/70	0,019	0,011	*0,060*	2,7	1,4	*4,0*
ACL #2	70/100	0,019	0,022		2,2	1,9	
ACL #3	160/200	0,029	-		2,7	-	
ACL #4	50/70 Reju R	0,022	0,009		2,3	1,3	
ACL #5	50/70 Reju S	0,015	0,010		2,2	1,5	
ACL #6	PMB RC	0,013	-		1,4	-	

All tested variants fulfil the standard criterions. As it was expected the mix variant with bitumen 160/200 had slightly worsen values than the other variants. But it is necessary to emphasise that reached values are still significantly below the limits required by the standard. The best results were reached by the mix variant with PMB RC binder, which seems to have very good influence on asphalt mix properties.

The control test results are slightly better than figures gained during type testing. It corresponds with the previous data, when control test specimens reached higher strength values.

4.5. Resistance to crack propagation

The resistance to crack propagation was tested in accordance with EN 12697-44. The testing process was modified with respect to the available laboratory equipment, i.e. instead of gyratory compactor Marshall impact compactor was used. Contrary to the standard procedure cylindrical test specimens with diameter of 100 mm were used. The reason was that the same test specimens were firstly used for stiffness testing and later for crack propagation test. The required specimen thickness of 50 mm was achieved by cutting of specimens on laboratory saw. The essence of the test is a three-point bending of semi-circular specimens with a defined notch of 10 mm depth in the middle of bottom specimen face. The test procedure was always performed on at least 6 semi-circular test specimens at a temperature of 0 °C applying a loading rate of 2.5 mm/min. This is again modification from the recommendation given by the European standard.

For the test itself it can be generally said that the higher the value of fracture toughness is, the better resistance to thermal induced cracking can be reached. Also usually the higher the stiffness modulus is, the lower the fracture toughness is. But this second rule cannot be generalized and is not always true.

The problem which was during last years repeatedly identified is, that fracture toughness itself does not provide sufficient parameter which would be able to effectively explain the tested behaviour. The CTU in Prague therefore uses in parallel procedure which comes partially from AASHTO TP 105-13 and includes fracture energy as another characteristic to explain the cracking behaviour. The energy is calculated from the load-displacement diagram as an area under the loading curve. The fracture energy is determined in two stages – until the maximum force and then as a total fracture energy including the unloading part (not presented in this paper). In our opinion, using both parameters (i.e. the European and and the American approach) gives us more information about the asphalt mix behaviour in the range of low temperatures. The reached values of fracture toughness were quite similar for type testing and control test specimens. The only major difference was for variant with REJU S (ACL #5), where type testing specimens reached 44 $N/mm^{3/2}$, but control test only 29 $N/mm^{3/2}$ (almost 35 % drop in the value). It is true, that there was visible major increase in stiffness modulus for control test mixtures, but it was also visible for ACL #4, which reached identical fracture toughness values. It was expected that mixture with PMB RC binder will reach the best values, but unfortunately reached one of the lowest.

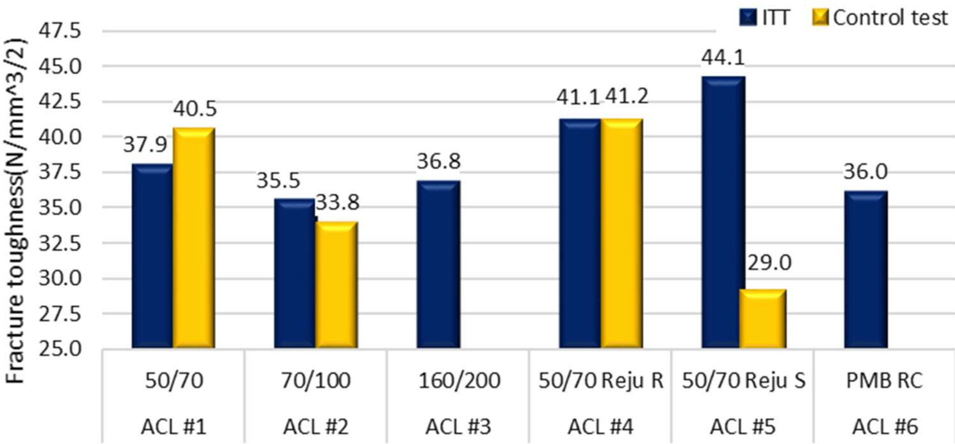

Figure 6: Resistance to crack propagation of AC_{bin} 16 asphalt mixture variants – fracture toughness

From point of view of fracture energy (till the maximum force) the differences between type testing and control testing results are more visible. The mixtures with standard paving grade biumen evinced improvement in these characteristics, but for the mixtures with rejuvenator showed decrease. These results are supporting hypothesis about partial evaporation of the rejuvenator during the asphalt plant production.

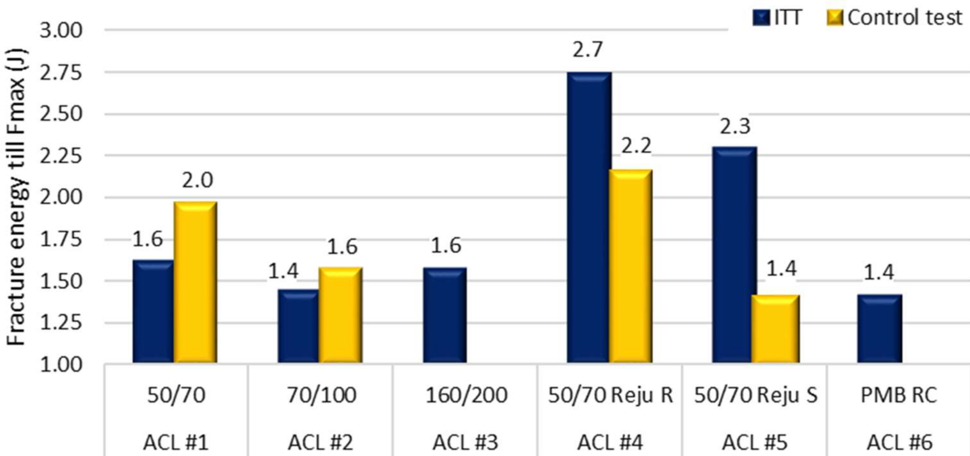

Figure 7: Resistance to crack propagation of AC_{bin} 16 mixture variants – fracture energy till maximum force

5. CONCLUSION

This study covers evaluation of design and control tests results of asphalt mixtures with elevated RA content. The variants contained reference mixtures with 50/70 paving grade bitumen, 2 types of rejuvenators, 2 soft binders and bituminous binder specially modified by polymers for mixtures with elevated RA content (commonly described as PMB RC). The design covered 6 mixtures for which type testing protcols have been prepared and the control tests from the trial section with selected and paved 4 mixtures.

The results showed that all the control test specimens reached increased air voids content in comparison to its laboratory manufacture equivalents. It was caused by the increased temperature (up to 180 °C) and pressures during the asphalt plant production. The virgin binder is accordingly aged (short-time ageing) and the already aged binder in RA is partly further aged. The workability of the asphalt mix therefore decreases.

The higher rate of ageing was confirmed by the rest of the results. Most of the variants from control tests reached higher values of strength properties (stiffness modulus, indirect tensile strength). Due to increase temperature and oxygen presence the binder oxidizes and hardens. The penetration decreases and the strength properties increases (to certain level). The hazard is that the brittleness of the bitumen steeply increases with ageing and the binder is susceptible to risk of distress (degradation) – damage due to sudden load or temperature changes.

Another phenomenon which can explain the increase of the strength properties is the expected evaporation of some volatile substances of the rejuvenators. Rejuvenators were dosed (sprinkled) on the RA material on a conveyor belt before entering the drying drum. It is possible that during drying of the material (passing of RA through the drum), some of the chemical substances forming rejuvenator partially leaked out. Regrettably, it is not possible to determine the exact amount of rejuvenator in the asphalt mix. Nor can be the amount of rejuvenator reliably determined from tests of the extracted bituminous binder. Some indication can be of course provided by chemical analyses like SARA or FTIR.

The results show that using elevated RA content do not have to have negative influence on the asphalt mix properties, but it is important to perform enough tests during the design. The low temperature properties or resistance to fatigue can be crucial for asphalt mixtures with RA. It is necessary to concentrate on such potential risks and avoid them. And of course to perform as many test as possible during the control tests, not only checking the air voids content and granularity.

ACKNOWLEDGEMENTS

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