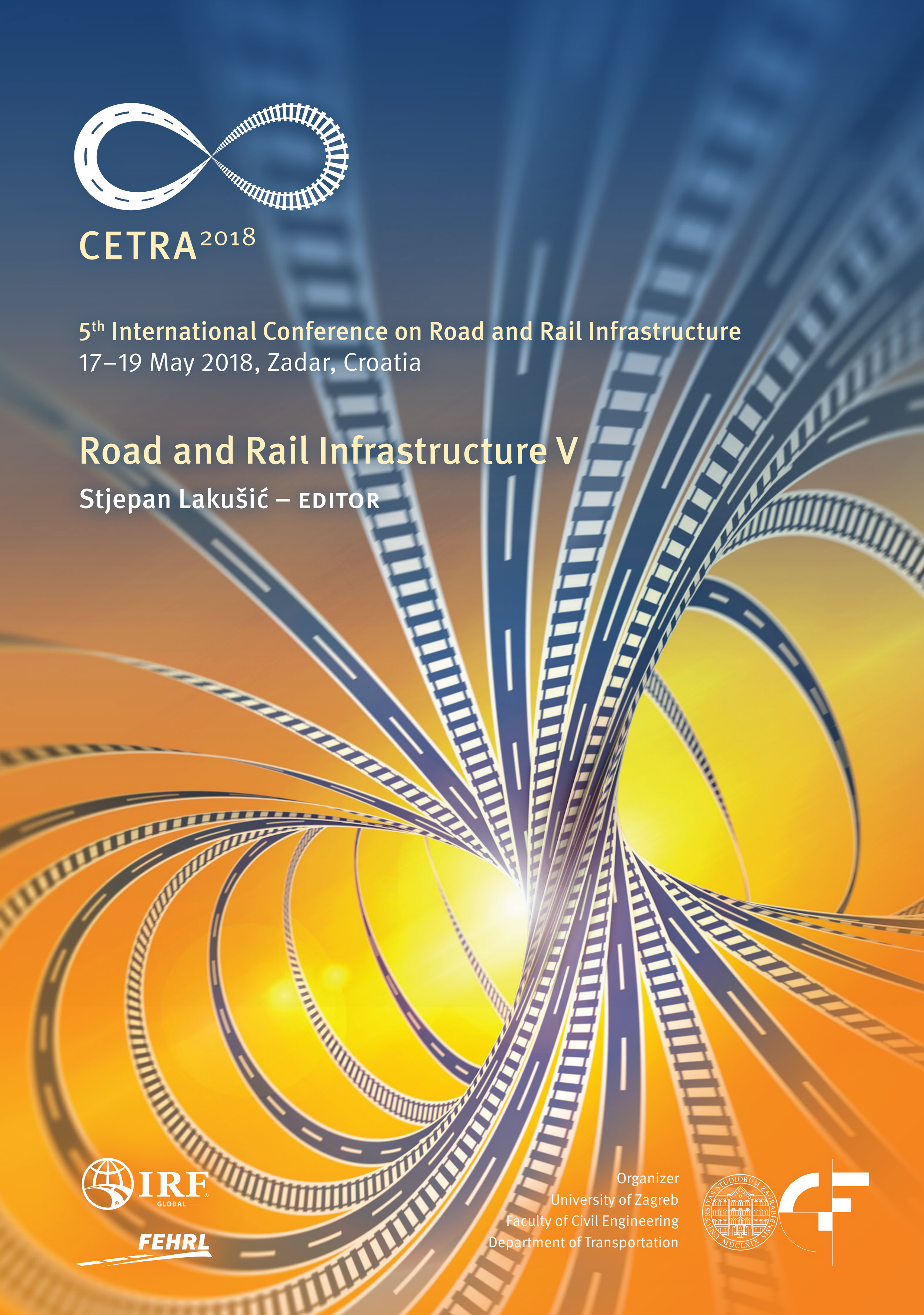

CETRA^{2018}

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – **EDITOR**

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SMA MIXTURES WITH ELEVATED CONTENT OF RECLAIMED ASPHALT

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Abstract

The paper provides results from a research project and related trial section which was focused on assessment and mix design optimization if reclaimed asphalt is used in stone mastic asphalt mixtures in a content up to 50 %. Experimental testing focused on asphalt mixtures which were gained during paving of a trial section which was divided into several subsections. These subsections differed in used bitumen, RA content as well as in several types of additives used in the SMA mixtures. At the same time cores were taken after one year operation from the trial section and selected tests were repeated and compared to the mixtures gained during the paving. In both cases some of the test specimens were additionally aged in the laboratory as well. The performance characterization of the asphalt mixtures was focused mainly on stiffness and resistance to crack propagation. Selected results are discussed in this paper and some recommendations will be given with respect to potentials or threats related to use of reclaimed asphalt in SMA mixtures.

1 Introduction

Use of reclaimed asphalt (RA) in road constructions is nowadays a standard in most countries that can be characterised as advanced with respect to road infrastructure development. Recycling of construction materials saves direct primary costs like new material purchasing, material disposal, transportation and others. Those factors are also connected to environment-friendly approaches, like reduction of emission and greenhouse gas production, disposal and quarry expansion etc. The use of RA material in the production of new asphalt pavements leads to considerable economic and environmental benefits by transforming waste materials into a valuable resource. It is generally known, that bituminous binder exposed to climate and traffic conditions oxidized and becomes stiffer. The penetration of oxidized binder decreases and with it grows the potential risk of brittle cracking of asphalt mixtures. For this reason so called rejuvenators were discovers. The rejuvenator (rejuvenate agent) penetrates reclaimed asphalt and softens its bituminous binder. Rejuvenators have the ability to reconstitute the binder´s chemical composition [4] and partially restore its original properties. There are many types of rejuvenators used and sold all over the world. The most common ones are oil or bio-based. The problem of rejuvenators is long term testing. The asphalt mixtures with elevated content of RA and rejuvenator are usually control test during the manufacturing and compaction, but there is usually no further long term control, how the rejuvenator behave in the construction. If the ability of rejuvenator to restore the binder´s properties lasts or if the binder degrades the same way as it would without rejuvenator usage. For this reason this trial section was made. The mixtures were sampled from asphalt plant at the time of production and then the first cores were drilled after a year of operation. The continuing core drills and testing will follow to compare the changes in binder and mixture properties.

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2 Asphalt mixtures

In the presented research study there is a summary of analysis of control asphalt mixtures and cores from the trial section. The trial section was realized in autumn 2016 approximately 30 km from Prague (Czech Republic) on a regional rural road with a daily average of 934 heavy load vehicles [5] and its total length was almost 5 km. On the trial section 18 different types of stone mastic asphalt SMA 11S with variable amount of RA was used. Additionally there were used three kinds of asphalt concrete AC_{bin} 22S in binder layer with up to 60 % RA (these mixtures are not evaluated in this paper).

The SMA 11S mixtures differed in the percentage of used RA of fraction 0/11 mm, the origin of applied RA (common RA from various asphalt concrete mixtures and SMA RA gained strictly from SMA layers) and the used additives (rejuvenator or additive based on rejuvenator and crumb rubber). For easier evaluation of influence of given additives and RA content, the mixture variants were divided into logical groups according to percentage of used RA.

3 Input materials

There were 4 types of additives used in the presented asphalt mix variants. Three types of these additives should improve the properties of asphalt mixture containing elevated or high percentage of RA. The used additives were:

- cellulose fiber – labelled as “R” – this fiber is commonly used in the SMA mixture for prevention of bitumen drainage from aggregate – asphalt mix variants SMA #1 – #6
- cellulose fiber with special crumb rubber – labelled as “RE” – asphalt mix variants SMA #7
- cellulose fiber modified by rejuvenator – labelled as “RF” – amount of rejuvenator in cellulose fiber granules varied according to amount of used RA – asphalt mix variants SMA #10 – #13
- crumb rubber modified by rejuvenator – labelled as “SE” – asphalt mixture variants SMA #14 – #18

The purpose of cellulose fiber “R” is not to improve the properties of the mixtures with high RA content. The cellulose fiber is ordinary used to minimize the bitumen drainage. Asphalt mixtures with cellulose fiber “R” in this study served more likely as “reference” asphalt mix in the test group. In the first phase of the project, mixtures SMA #1 – #6 were not provided from the manufacturer, so the testing of “reference” mixtures from the first phase of the project is missing. Mixtures SMA #8 and #9 combine the cellulose fiber “R” and the crumb rubber modified by rejuvenator “SE”.

Used reclaimed asphalt originated from two sources. The RA originates from different asphalt concrete mixtures form different sites. Usually wearing and binder course were milled in one step. When the cold milled asphalt material arrived at the mixing plant it was screened and partly crushed to get standardized grading of 0/11 mm. The average penetration of the bitumen from RA was 19 dmm, the softening point R&B was between 66 °C and 69 °C. The control testing is done regularly at least once a week. The binder content in the RA was in average 5.5 %. The second type of reclaimed asphalt SMA RA originates from a trunk road where SMA was in service for more than 10 years. In this case the material was selective cold milled and stored separately. The original SMA mixture contained a PMB (similar to presently used PMB 45/80-55). The binder content in SMA RA was 5.4 % and its penetration was 24 dmm with a softening point higher then 64 °C.

Asphalt mixtures were designed with the most possible similar granularity and the production and paving of trial section was done in one day.

4 Asphalt mixture testing

The test performed on all tested and assessed mix variants were:

- volumetric characteristics (EN 12697-5, EN 12697-6, EN 12697-8);
- stiffness modulus (EN 12697-26, method IT-CY) at temperature of 0 °C, 15 °C a 27 °C;
- fracture toughness and fracture energy – SCB test (EN 12697-44) performed on modified semi-cylindrical specimens.

The tests were performed on Marshall test specimens compacted by impact compactor according to EN 12697-30 from control mixture samples and Marshall test specimens recompacted from cores. The cores were cut from the construction after one year of operation. From each test section 2 samples of 150 mm diameter were cored.
In the further presented evaluation the results of control mixtures are labelled as "MS", the results of recompacted cores are labelled as "MS_{core}" and the results performed on the cores are labelled as "core".

5 Volumetric characteristics

The volumetric characteristics of the asphalt mix variants were compared with the requirements of standard EN 13108-5 for control mixtures and ČSN 73 6121 for cores (Czech technical standard for Road Construction: Compacted asphalt mixtures). The air voids content results including the standard limits are summarized in the Figure 1.
Two sets of Marshall test specimens compacted from control mixes exceeded the upper standard limit. Both of the mixes consist of 20 % RA. The last remaining variant with 20 % RA (SMA #15) fulfil the standard criterion, but it has the third highest air voids content of them all. Three SMA mixtures with 20 % RA have almost the highest air voids contents. This can be caused primary by the poor design of granularity of the mixtures.
For cores and recompacted core the results are exactly opposite. Air voids contents of recompacted cores ("MS_{core}") were with exceptions lower than for control mixes ("MS"), but higher than for cores ("core"). The lower standard limit was not exceeded by more than half of the cores and on contrary two of them were getting close to the upper limit.

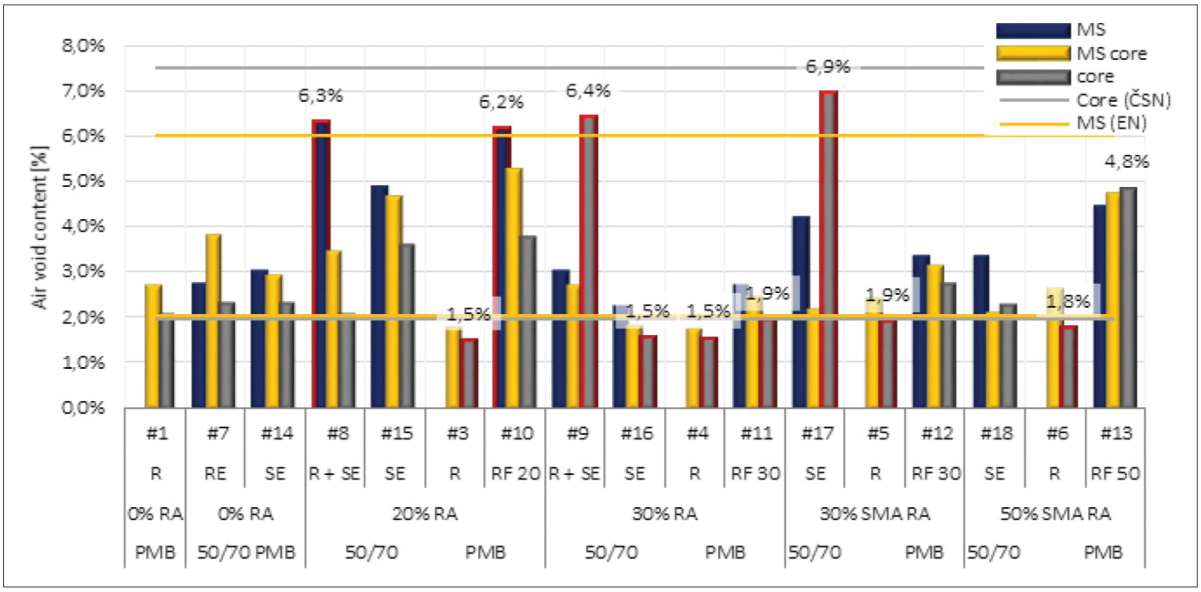

Figure 1 Air void content of SMA mixtures

The recompacted core were with 3 exceptions in the standard limits. The air voids content of recompacted cores were very close to the lower limit. If the voids content of the asphalt layer is below the standard limits, the pavement is usually more susceptible to rutting. The bituminous binder is expanding due to climate changes and road traffic, therefore on the other hand if the voids content is too low, the binder does not have any spare room for expanding and it can cause the squeezing of the asphalt mixture under the wheel loading and will result usually in rutting (formation of permanent deformations). If the voids content is too high, the water can easily permeate through the pavement structure and can cause cracking and destruction of particular layers.

Low voids content of cores and recompacted test specimens from cores can be caused by partial crushing of the aggregate during paving and compaction of asphalt layers. If the aggregate does not have sufficient strength, it can break during the compaction and therefore change the granularity and voids content of the mix.

6 Stiffness modulus

The stiffness was determined by IT-CY method according to EN 12697-26 (non-destructive repeated indirect tensile stress test) at three selected test temperatures usually used for typical seasonal conditions in the Czech Republic: 0 °C, 15 °C and 27 °C. The results of recompacted specimens were compared with control mix specimens. It is necessary to emphasise that recompacted specimens were always only 2 of its kind, due to lack of additional material, even if standard methodology requires at least 3 test specimens for each test. From this reason it is desirable to consider this in the evaluation process.

Asphalt mixture from recompacted cores was submitted to approximately one year ageing (exposure to one year of regular operating traffic conditions). It can be assumed that the stiffness will reach a higher values than control mix test specimens. Bituminous binder ages in road construction (due to climatic and traffic changes) and becomes stiffer and therefore to some extent it increases strength properties. In addition the recompacted specimens had a lower voids content, which again indicates assumed higher stiffness modules.

Table 1 Stiffness results for assessed asphalt mix variants

		Additive	**0 °C**			**15 °C**			**27 °C**		
			MS	**MS_{core}**	**Δ**	**MS**	**MS_{core}**	**Δ**	**MS**	**MS_{core}**	**Δ**
0% RA	#1	R	-	14 464	-	-	5 150	-	-	1 710	-
	#7	RE	17 827	18 408	+3%	9 148	8 681	-5%	3 264	3 492	+7%
	#14	SE	18 212	16 147	-13%	6 760	6 074	-11%	2 490	2 407	-3%
20% RA	#8	R+SE	14 747	16 791	+12%	6 665	6 712	+1%	2 159	2 582	+16%
	#15	SE	16 861	15 311	-10%	6 093	6 402	+5%	1 917	2 478	+23%
	#3	R	-	15 560	-	-	5 502	-	-	1 972	-
	#10	RF 20	12 115	13 489	+10%	3 914	4 323	+9%	1 486	1 507	+1%
30% RA	#9	R+SE	16 656	17 378	+4%	7 806	7 193	-9%	2 768	2 753	-1%
	#16	SE	14 577	18 530	+21%	7 603	6 383	-19%	2 843	2 236	-27%
	#4	R	-	14 715	-	-	5 375	-	-	1 978	-
	#11	RF 30	14 244	14 668	+3%	4 179	5 332	+22%	1 598	2 007	+20%
30% SMA RA	#17	SE	15 571	17 468	+11%	7 279	6 601	-10%	3 054	2 212	-38%
	#5	R	-	15 996	-	-	5 229	-	-	1 903	-
	#12	RF 30	13 967	12 525	-12%	5 065	4 169	-22%	1 766	1 583	-12%
50% SMA RA	#18	SE	15 004	16 322	+8%	7 077	6 360	-11%	3 029	2 393	-27%
	#6	R	-	15 769	-	-	6 351	-	-	2 365	-
	#13	RF 50	14 171	16 288	+13%	5 412	6 923	+22%	2 042	2 540	+20%

The general assumptions were not confirmed by the performed tests. For a number of tested mix variants (see Table 1) there was an unexpected decrease in stiffness modules. For some asphalt mixtures, the stiffness decreased by more than 20 %. This phenomenon might be partly caused by the crushing of coarse aggregate during the paving and compacting of the asphalt layer. If the aggregate do not have sufficient strength, it can break during the paving process and the asphalt mixture can lose its rigid skeleton. In stone mastic asphalt (SMA) the coarse aggregate forms a crucial rigid skeleton and the fine fractions together with the bituminous binder fulfil only the function of the mastic. If the coarse aggregate is crushed, the stiffness of the layer can be reduced and the properties change. This hypothesis is partially confirmed by the result of air voids contents. The voids contents of cores and recompacted cores are considerably lower than those for control mixes, which were not expose to paving and compaction process.

For almost 40 % of the compared measurements (12 variants at 3 test temperatures), the stiffness of the test specimens MS_{core} decreased, Figure 2. For mixtures with additives “SE” there was a decrease for almost all measurements. The largest deviation found was a decrease of almost 40 % (SMA # 17 at 27 °C).

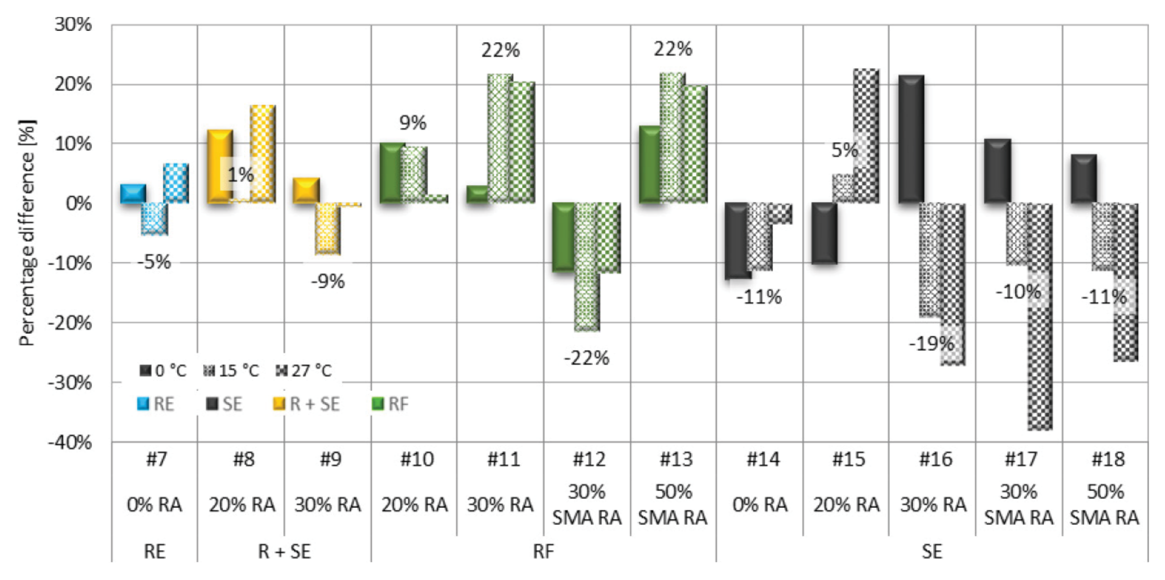

Figure 2 Percentual difference of stiffness modulus of MS and MS_{core}

From the results it might be obvious that additives “SE” softens the asphalt mix long-termly, which could be a positive phenomenon for asphalt mixtures with high RA content. In that case it would be necessary to determine the resistance to permanent deformation even from the point of view of the long-term effect of the additive. Unfortunately, this phenomenon may have a more practical explanation and that is the crushing of aggregate described above. The natural aggregates crushed in quarries and aggregate in RA used in this trial section were most likely not that strong as it was expected (even though the natural aggregate fulfil the standard requirements for aggregate for asphalt mixtures as stated in the type testing protocols). This fact could only be evaluated by extraction of the asphalt mixture, but it was not done because of too limited amount of cored material.

7 Fracture toughness (SCB-test)

Fracture toughness/resistance to thermal induced cracks was determined by the modified method defined in EN 12697-44 (2011) at the temperature of 0 °C. The standard method requires test specimens of 150 mm diameter compacted on gyrator. For this research the Marshall specimens of 100 mm compacted by impact compactor were used – the same test specimens

which were firstly used for stiffness determination. Most of the asphalt mixtures have increased the fracture toughness due to ageing – one year used in the road construction. Bituminous binder exposed to climatic changes ages and becomes to some extent stiffer. However, in the case of low-temperature tests, there is a higher risk of brittle fracture.
The reference mixture without RA and a selected modification (SMA # 1) reached almost the highest fracture toughness. These results confirm the assumption that a too high stiffness value leads to increased brittleness at low temperatures. The variants SMA # 7, # 9 and # 13 reached the highest stiffness modules and on the contrary reached the lowest fracture toughness as well. Since SMA mixtures are more exposed to climatic changes in wearing course, the higher fracture toughness is according to our opinion more important than a too high stiffness value. High stiffness modules are essential for binder or base layers where they distribute the traffic loads. Fracture toughness of asphalt mixture variants is shown at Figure 3.

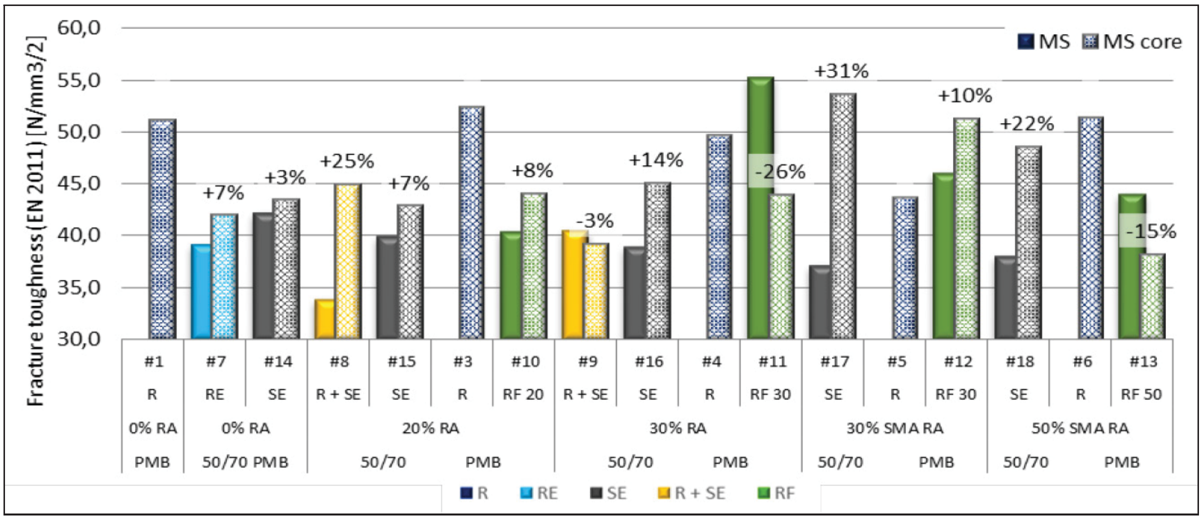

Figure 3 Fracture toughness of asphalt mixture variants

The fracture toughness of recompacted cores decreases with increasing amount of RA in the mixture. It applies with some exceptions for mixture with cellulose fiber “R”, “RF” and combination of fibers “R” and additive “SE”. But the variants of asphalt mixtures with only additive “SE” evince exactly an opposite result – the fracture toughness increased with increased RA content.

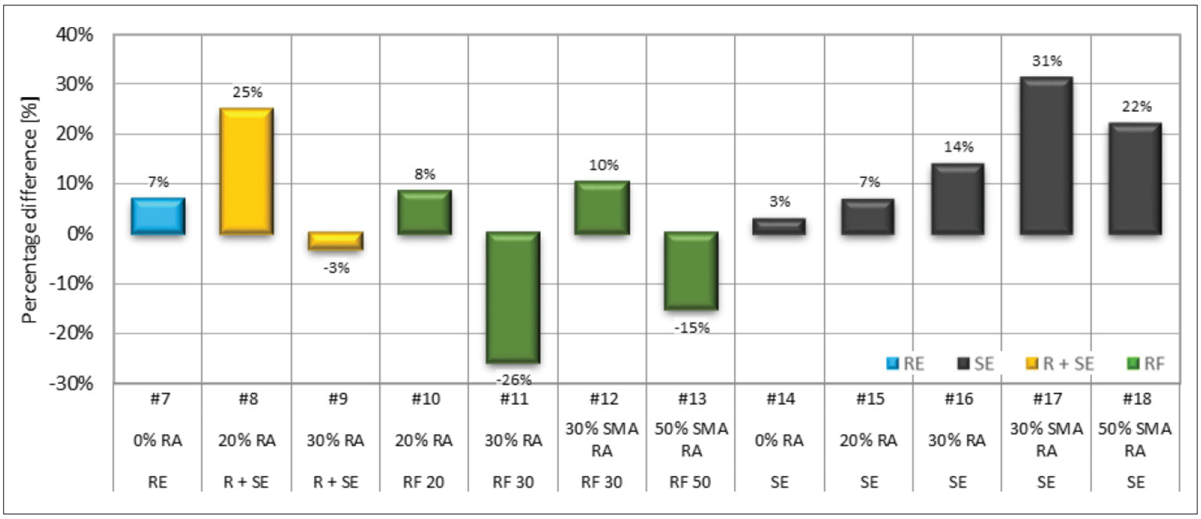

Figure 4 Percentage difference of fracture toughness of MS and MS_{core}

Percentage difference of fracture toughness of MS and MScore is shown at Figure 4. The “trend” of stiffness modulus – partly logical percentage decrease/increase in comparison to the value determined for control mixes and recompacted cores is not evident in the case of assessing fracture toughness results. In this test, the additives behave differently in different variants of asphalt mixtures. The trend works only for variants with “SE” additive. With increasing RA content and with increased additive content the percentual difference of determined fracture toughness value increases either.

8 Conclusion

Within this research project, 36 core drills (2 out of 18 test variants) from the trial section were evaluated. After determination of volumetric properties, the cores were recompacted by impact compactor to Marshall test specimens. On these specimens stiffness and fracture toughness were determined. The recompacted Marshall test specimens were compared with the results of the control tests sampled from the asphalt plant.

At the beginning of the research, there was an idea to compare properties of asphalt mixtures from site control testing and properties of asphalt mixture from cores after one year of traffic operation. An unexpected phenomenon occurred during the evaluation of the results, as the mixtures were more likely affected by the crushing of coarse aggregates than by the ageing of the bituminous binder exposed to climate changes in the road construction. The crushing of coarse aggregate caused the changes in voids content and therefore all other properties.

Even small changes in density (bulk as well as maximum density) have a significant effect on changes in air void content between compared variants. The largest changes in the voids content were up to 90 % (SMA # 17 – 92.3%, SMA # 8 – 83.2%). The voids content and the related granularity significantly influences the properties of asphalt mixtures and pavement layers made from them.

This phenomenon is noticeable especially in stiffness modules. It was assumed that the stiffness will increase due to the exposure of the mixture to climatic conditions. But the recompacted cores reached at nearly half of the determined values exactly opposite result – the recompacted cores had lower stiffness than control mix specimens. The decrease was approximately around 20%. The additive “SE” softened the SMA mixtures the most. The more additive was in the mixture (hand in hand with more RA content) the higher was the difference in determined stiffness modulus. Similar trend occur with fracture toughness. With increased RA content and amount of used “SE” additive the percentage difference of determined value increases as well. This phenomenon occurs only for “SE” additive (and still is not fully confirmed), the other additives are more influenced by the poor aggregate than the ageing of bitumen in the road construction.

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