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IMPACT OF MULTIPLE RECYCLING ON PERFORMANCE CHARACTERISTICS OF ASPHALT MIXTURES

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ABSTRACT

Recycling of asphalt pavements is widely applied and established standard in road construction practice for many years. However, in this connection stronger attention has so far not been paid to evaluate the possibility re-using again once recycled material in the form of multiple recyclability approach of cold recycled mixes. Within the European project CoRePaSol this process was evaluated in order to determine the multiple-recycling characteristics and limits. At the CTU in Prague, selected types of cold recycled mixtures were designed, which differ in the type of used stabilizing agent/binder. All designed mixtures were observed in terms of the evaluation of the ageing effect and the influence of environment where the specimens were stored. The aged material was quickly frozen and immediately crushed and then used like a multiple recycled material in cold recycled mixes. Differences in the characteristics of mixtures were compared with the evaluation of the ageing impact and increased bitumen content in the final mixture.

Keywords: Ageing, Cold Recycled Mixture, Multiple Recycling, Recycling, Stabilizing Agent

I. INTRODUCTION

The recycling of asphalt pavements in cold recycling mixtures is a widely applied and mostly approved procedure for full-depth rehabilitation measures. Whereas the mix design procedures for optimising the properties of cold recycled mixtures are well researched, the end-of-life strategies for these types of pavement layers are not known so far. However, the design of modern pavement materials has to consider end-of-life characteristics of the material in order to avoid costly and environmental hazardous disposal of these materials in the future. In order to assess the recyclability of pavement layers composed of cold recycled materials, a laboratory campaign was conducted on newly produced cold recycled mixtures. After the accelerated aging of the materials in laboratory their applicability in new road materials was evaluated.

II. LABORATORY-SIMULATED RECLAIMED COLD-RECYCLED MIXTURES

Cold recycling is a term used for re-use of a material from existing pavement without heating the recycled material or any of added binders, as is common for traditional hot asphalt mixes. Group of these technologies became, not only in the Czech Republic but mainly abroad, a trend particularly in case of in-place cold recycling. This group of techniques is well-established standard described e.g. in Czech Technical Specifications of the Ministry of Transportation TP 208. It offers broad possibilities of application; from reconstruction of thin pavement layers to full-depth recycling of a pavement structure. With respect to evaluation of the possibility to re-use again once recycled material 4 different types of cold recycled mixtures were designed. They differ in the type of stabilizing agent/binder and their variable content in the mix as shown in Table 1.

Table 1: Design of Assessed Cold-Recycled Mixes

Mix	RAP 0/22 Stredokluky	Stabilizing agent content			Water
		Cement	Bituminous emulsion	Foamed bitumen	
A	91.0 %	3.0 %	3.5 %	-	2.5 %
B	90.5 %	3.0 %	-	4.5 %	2.0 %
C	94.0 %	-	3.5 %	-	2.5 %
D	93.5 %	-	-	4.5 %	4.6 %

2.1 Input Materials

For the design and experimental production of cold recycled mixtures reclaimed asphalt material (RAP) 0/22 mm from the Stredokluky asphalt plant was used. Properties and composition of the RAP were analyzed in the laboratory and it included determination of bitumen content as well as of physical properties. Visual evaluation of the material allowed to determine if the RAP is active or inactive. This means assessment whether the RAP has definite own cohesion thanks to the contained binder. Extraction of the bituminous binder was done according to ČSN EN 12697 to reclaim aggregate from the RAP and to determinate the soluble binder content. Determination of the softening point is stated in the ČSN EN 1427 standard. The penetration test is defined in the ČSN EN 1426 standard. It is a very simple, but widely used empirical test which describes basic characteristics of bituminous binders. The needle penetration gives us one of the technical parameters of bitumen classification. Therefore the penetration test was used for the binder extracted from the used RAP. Gained characteristics of the RAP 0/22 mm, which were used for further mix designs are shown in Table 2.

Table 2: Characteristics of the RAP 0/22 mm from the Stredokluky asphalt plant.

Bitumen content (% by mass of RAP) according to the ČSN EN 12697-1	5.57 %
Softening point determined by the ring and ball method according to the ČSN EN 1427	77.4 °C
Penetration determined according to the ČSN EN 1426	14 dmm

Grading of the RAP from the Středokluky coating asphalt plant was determined according to the ČSN EN 933-1. A grading curve was plotted from the test results and the curve is shown in the Fig. 1 together with recommended requirements on grading envelope of cold recycled mixtures as specified in TP 208.

In compliance with the technical specifications TP 208 a cationic bituminous emulsion C60B7 was used for cold recycled mix design and its production, respectively. The straight-run bitumen 70/100 was used for production of foamed bitumen according to the ČSN EN 12591. Further on, Portland cement (specified as CEM II/B-M (V-LL) 32.5 R), manufactured in compliance with the standard ČSN EN 197-1 was used as a hydraulic binder. Portland composite cement containing total amount of silica ash (V) and limestone (LL) between 21 % and 35

% by mass was selected. It belongs in the 32.5 strength class and is characterized by its fast development of initial strengths (R).

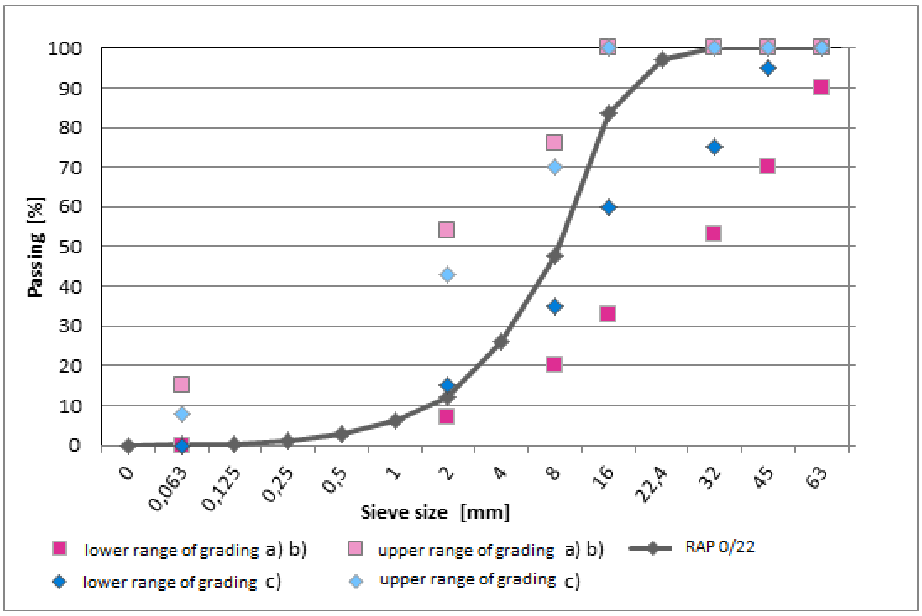

Figure 1: Grading curve of RAP 0/22. Note: a) cement or other hydraulic binder, b) cement + bituminous emulsion/foamed bitumen, c) bituminous emulsion/foamed bitumen)

2.2 Manufacturing of Test Specimens and Curing Conditions

Requirements set for production of cold recycled mix specimens differ country by country according to existing national technical specifications. Usually, a static pressure or gyratory compactor is used for compaction; Marshall hammer is used rarely in Europe. The differences in manufacturing do not concern just the equipment used, but more likely size of the test apparatus, number of revolutions, number of strokes etc. Results presented further assume that all specimens were manufactured by using a static pressure compaction. In compliance with the Czech specifications TP 208, a mixture is compacted by two pistons moving against each other. The pressure on a specimen is 5.0 MPa. When the load is applied, the vertical force needs to be balanced until it stabilizes at the value of 88.5 ± 0.5 kN for 30 seconds (for test specimens with 150 ± 1 mm diameter). Cylindrical test specimens with 150 ± 1 mm diameter and 60 ± 5 mm height were manufactured for each mixture using the mentioned compaction method. Bulk density was determined for each of the specimens (calculated from dimensions and weight of the specimen) in order to get the rate of compaction.

All four designed mixtures were observed to evaluate the effect of curing period and influence of environment where the specimens were stored. The curing conditions of cold recycled mix specimens are described in the TP 208 specifications. The document provides temperature, relative humidity and time necessary for storing test specimens. Using mixtures stabilized by bituminous emulsion or foamed bitumen (C and D mixture), test specimens are stored at 90–100 % relative humidity and temperature of (20±2) °C for 24 hours and then exposed to the so called accelerated curing. This means that the specimens are moved to a heating chamber which keeps temperature of 50 °C for 72 hours. After elapsing this period the specimens are stored at 15 °C for at least 4 hours and then immediately tested for stiffness modulus. In the following cycle, the test specimens are exposed to ageing process in a heating chamber which keeps temperature of 85 °C for 9 days and then tested for

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stiffness modulus including indirect tensile strength at temperature of 15 °C (conditioning again for at least 4 hours). The ageing protocol was selected unanimously for the whole CoRePaSol project. In the case of cold recycled mixtures bound with cement and bituminous emulsion (A mixture), the test specimens were stored at 90-100 % relative humidity and temperature of (20±2) °C for 24 hours. Then the specimens cured at dry conditions with relative humidity of 40-70 % and laboratory temperature for additional 14 days. After this period the specimens are conditioned at 15 °C for at least 4 hours and tested for stiffness modulus. Another ageing cycle follows like for C and D mixtures; the specimens are heated at temperature of 85 °C for 9 days, then the stored for 4 hours at 15 °C and immediately tested for stiffness modulus and indirect tensile strength.

Table 3: Laboratory curing condition and impact of ageing on test specimens. Note: 90-100 % of relative humidity can be simulated by storing test specimens in sealed plastic bags. Relative humidity 40-70 % represents a humidity of a test specimen at regular atmospheric conditions in the laboratory (unsealed).

Options of cold-recycled mixture	1st cycle	2nd cycle
	Laboratory curing condition of the test specimens	Used ageing of test specimens
Mix A	24 hours at 90-100 % relative humidity and 20 ± 2 °C, 14 days of curing in dry conditions	9 days at temperature of 85 °C
Mix B	24 hours at 90-100 % relative humidity and 20 ± 2 °C, 14 days of curing in dry conditions	
Mix C	24 hours at 90-100 % relative humidity and 20 ± 2 °C, 72 hours accelerated curing at 50 °C	9 days at temperature of 85 °C
Mix D		

Testing procedures including the ageing process in case of all prepared cold recycled mixtures enable simulating conditions of recycled pavement material at the end of its life-time. The test specimens, exposed to the curing process, were further quickly frozen and immediately crushed using a laboratory jaw crusher. This laboratory aged RAP was then used like a multiple recycled material in cold recycled mixes with reduced content of newly added bituminous binder as well. An illustration of multiple aged and crushed RAP is presented in the Fig. 2.

Figure 2: Multiple aged and crushed RAP.

2.3 Results for Design Cold-Recycled Mixtures

Results gained for assessed cold recycled mixes containing bituminous emulsion/foamed bitumen or variations where also hydraulic binder is used, are described in following sub-sections. Table 4 summarizes basic physical properties of cold recycled mix with the comparison of three assessed variations of aged cold recycled mix. Bulk density and maximum density are important parameters, whereas the bulk density was later selected as a characteristic to which the most of the other properties are related. As is obvious, maximum densities for cold recycled mixtures containing bituminous emulsion and cement, as well as mixes containing only emulsion have similar values. Mix A and C shows slightly increased value. On the other hand maximum density for mix B and D where foamed bitumen and combination with cement were used, reaches lower values.

With respect to the voids content it is not possible to see any logical trend within the tested mixes. Highest voids content is reached for mix C where bituminous emulsion without hydraulic binder was used with an average value of 11.4 %-vol. Mixes A and D reach nearly same results. In case of mix A the voids content is 10.0 %-vol. and in case of mix D 10.3 %-vol. Mix B reaches lower values, 9.2 %-vol.

Table 4: Test results for initial cold recycled asphalt mixes

Options of cold recycled mixture	Maximum density [g/cm³]	Bulk density [g/cm³]	Voids content [%]	ITS [MPa]		Stiffness modulus [MPa]	
				After 1st cycle	After 2nd cycle	After 1st cycle	After 2nd cycle
Mix A	2.403	2.162	10.0	0.76	1.12	3736	6539
Mix B	2.345	2.130	9.2	0.76	1.29	3406	7086
Mix C	2.416	2.140	11.4	0.67	0.99	2105	4775
Mix D	2.358	2.116	10.3	0.60	1.09	2487	5160

Fig. 3 illustrates results of indirect tensile strength test. If it would be assumed to compare ITS results with the requirements given for cold recycled mixes in Czech technical specifications following conclusions can be made. Technical specifications TP 208 prescribe requirements according to used stabilizing agent. For cold recycled mixes where bituminous emulsion or foamed bitumen is used the minimum indirect tensile strength after 7 days is set as R_{it} = 0.3 MPa. In case of mixes where bituminous binder is combined with cement, this required value has to be within the range of 0.3 MPa and 0.7 MPa, whereas the upper limit is selected with respect to avoid the risk on micro-cracking. In both cases the ITS is determined at 15 °C. Results of gained ITS values, were assessed also on aged test specimens, and compare with results on specimens after first cycle of laboratory curing. The quality of the asphalt cold recycled mix is therefore proven by reached required value of particular indirect tensile strength, eventually stiffness modulus. From the results it is obvious, that the highest values of gained ITS after cold recycled mix ageing are reached for mix B - value of 1.29 MPa, mix A and mix D – in average 1.10 MPa. In comparison to that mix C shows only strength values around 0.99 MPa.

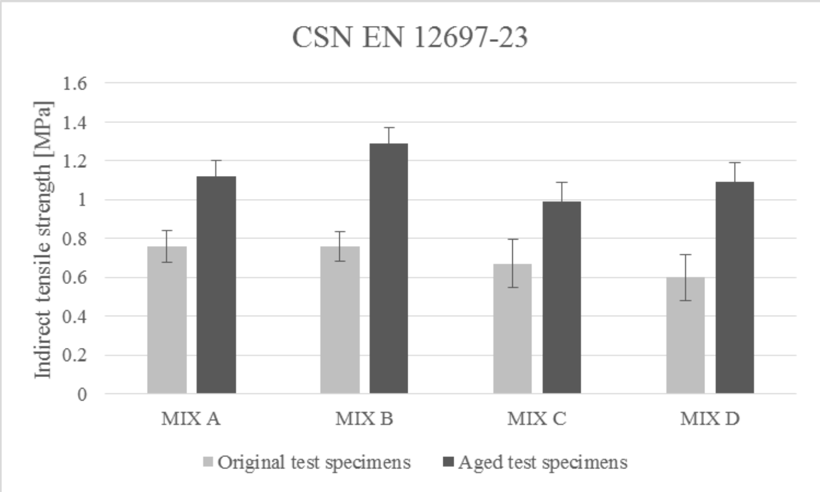

Figure 3: Indirect tensile strength results of experimentally designed cold recycled mixes

For all four designed mix types stiffness modulus after first ageing cycle of test specimens was determined as well. The ageing effect depends on the assessed cold recycled mix type. For mixes with use of hydraulic binders the stiffness was determined after 15 days curing, in case of mixes without cement this was determined already after 5 days (accelerated curing). Further the effect of test specimen ageing was reflected simulating material behaviour in the pavement structure which is for a certain time in operation. At the end of ageing the stiffness modulus was determined again and finally the indirect tensile strength was tested. Despite of the fact that Czech technical standards do not require the check on stiffness for this type of material and there is no minimum required threshold value, it is presented as a very important characteristic, which has a good predictability for describing cold recycled mix behaviour in a pavement similarly to the destructive testing of indirect tensile strength. At the same time stiffness represents an important parameter from the viewpoint of pavement structural design. Therefore for all mixes with unaged and aged material stiffness was always determined at the temperature of 15 °C by applying the IT-CY test method.

Comparison of stiffness modulus values for cold recycled mixes before and after ageing is illustrated in Fig. 4. From the gained results following findings and conclusions can be made. Stiffness modulus of mix A and mix B where bituminous emulsion (or foam bitumen) is applied together with cement shows highest average values before ageing (3,736 MPa and 3,406 MPa). On the other hand mixes C and D reach approximately values of 2,250 MPa. It is therefore possible to demonstrate again the influence of hydraulic binder content, which improves stiffness and ITS values. Ageing leads to increase in stiffness of tested mixes and the values correspond again well with results of indirect tensile strengths which were determined after ageing as well. Mix A reaches in average stiffness values of 6,539 MPa, for mix B a value of stiffness 7,086 MPa was determined. This means an increase of about 75 % of original value before ageing procedure. In case of mix C it can be stated, that stiffness modulus results are in average 4,775 MPa what is an increase by more than 125 %. Highest relative increase after ageing is nevertheless reached for cold recycled mixes with foamed bitumen (mix D). In this case stiffness was raised by more than 140 %. In general this corresponds well with results gained for indirect tensile strength. Only in case of mix D the ITS reaches in average higher increase of measured values.

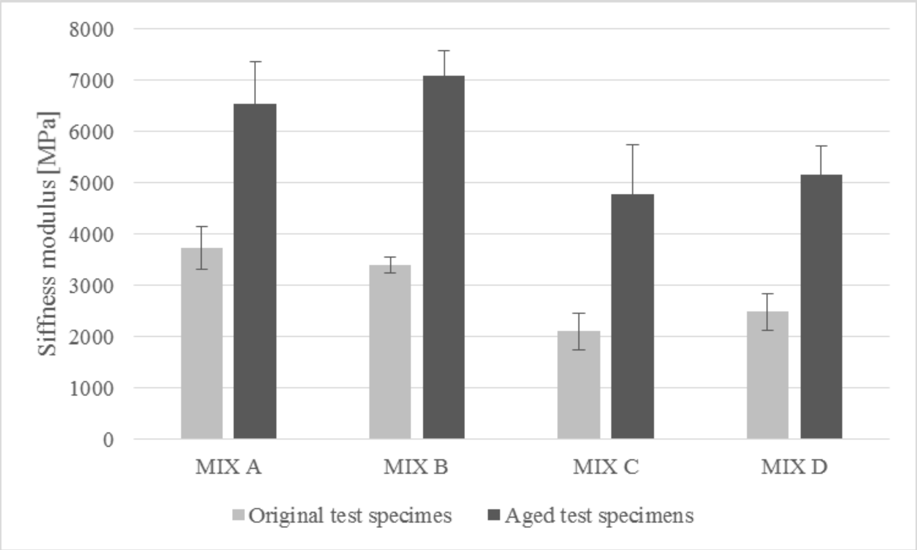

Figure 4: Impact of ageing shown on stiffness modulus values

III. MULTIPLE RECYCLED COLD MIXES

Aged material from cold recycled mixes described in chapter 2 was re-crushed by a laboratory jaw crusher and used for new design of cold recycled mixes. The selected mix designs are summarized in following Table 5. For each proposed experimental mix two sets of test specimens were produced and compacted. Test specimens were left for 24 hours in sealed conditions at laboratory temperature and then moved to a climatic chamber with unsealed conditioned at 50 °C for three days. After this time period the test specimens were measured on their dimensions, weighed and divided in two groups. First group of test specimens was left at standard laboratory conditions for three days, second group was water saturated and conditioned for 3 days in a water bath at 40 °C. After 7 days curing stiffness modulus was determined on all test specimens at 15 °C. Lastly indirect tensile strength was set at the same temperature.

Table 5: Design of multiple cold recycled mixes.

Mix	RAP	Stabilizing agent content			Water content
		Cement	Bituminous emulsion	Foamed bitumen	
SA	95.5 % - RAP A	-	2.0 %	-	2.5 %
SB	96.0 % - RAP B	-	-	2.0 %	2.0 %
SC	95.5 % - RAP C	-	2.0 %	-	2.5 %
SD	96.0 % - RAP D	-	-	2.0 %	2.0 %

For each reclaimed asphalt material its grading has to be declared, i.e. relative mix composition showing the total mass of particular particle sizes including its expression in form of a grading curve. For the later mix designs and use of aged recycled materials in cold and hot asphalt mixes grading curves of all applied re-crushed and aged options of reclaimed asphalt material were calculated and plotted.

Basic characteristics determined on test specimens of designed mixes are summarized in Table 6. From the results it is evident that voids content of the assessed mixes have similar trend like for cold recycled mixes produced and compacted before the artificial laboratory ageing. For mixes SA and SC resulting voids content is 13.4 % and 14.5 %, experimental mix with foamed bitumen as a binder shows lower value of 8.9 % and 9.6 %.

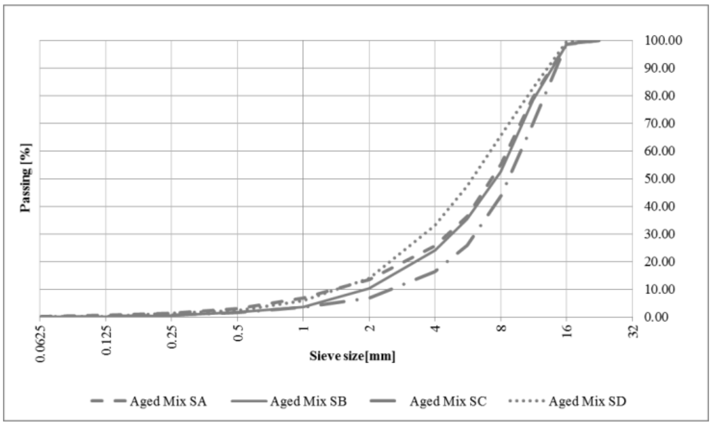

Figure 5: Grading curves of aged and re-crushed material from cold recycled mixes

Table 6: The basic empirical and mechanical characteristics.

Cold recycled mixture	Maximum density [g/cm³]	Bulk density [g/cm³]	Voids content [%]	ITS_{dry} [MPa]	ITS_{wet} [MPa]	ITSR [%]
Mix SA	2.328	2.017	13.4	0.796	0.666	83.8
Mix SB	2.290	2.088	8.9	0.745	0.755	101.4
Mix SC	2.407	2.059	14.5	0.798	0.546	68.8
Mix SD	2.300	2.078	9.6	0.834	0.526	63.9

If we focus on comparing results of gained ITS values and display them in Fig. 6, then it can be concluded, that slightly higher values of 0.83 MPa were reached for the mix SD containing foamed bitumen. Sets of test specimens of mixes SA and SC reach in average similar results around 0.80 MPa. Indirect tensile strength for mix SB is 0.75 MPa.

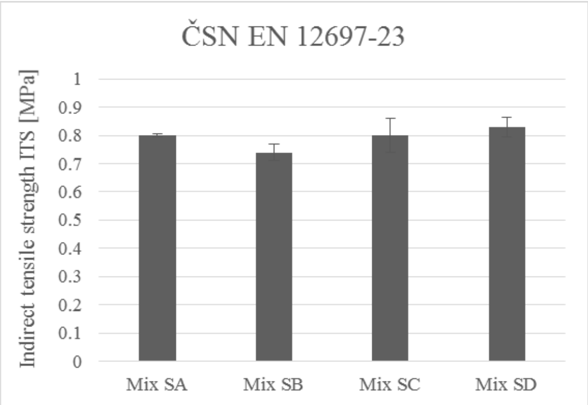

Figure 6: ITS values of cold recycled mixes made with re-crushed and aged RAP

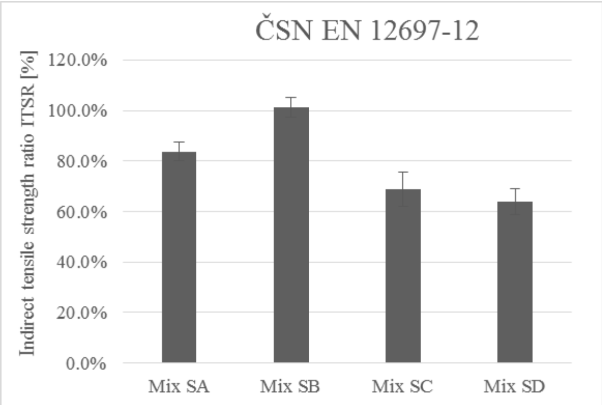

Figure 7: ITSR values of cold recycled mixes made with re-crushed and aged RAP

From the Fig. 7 where ratios of indirect tensile strength values are determined for dry specimen and water saturated specimen subjected to adverse impact of higher temperature of 40 °C it is obvious that there is a negative impact of water on the test specimens. From the results it is apparent that mix SA and SB containing combination with cement resist better the adverse effects of water if compared with the other two mixes. The mix is less water susceptible. Mixes SC and SD are reaching ITSR value lower than 70 %. Last but not least of the attention is paid to comparison of stiffness modules, the results confirm findings made for indirect tensile strength. Cold recycled mix SB resist again better negative impacts of water as against remaining three experimental mixes. Stiffness modulus of used dry test specimens for mix SA (3,161 MPa) and mix SB (2,991 MPa) and mix SD (3,185 MPa) –containing bituminous emulsion or foamed bitumen – show in average similar result, whereas mix SC (2,629 MPa) reached a lower value. In this case surprisingly the hydrated cement in the aged and re-crushed cold recycled material A and material B does not have any effect on the properties of newly produced cold recycled mix SA, the binder acts as a regular mineral part of the aggregates.

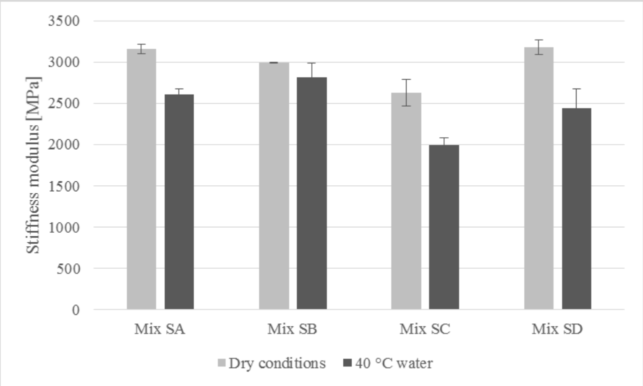

Figure 8: Stiffness of cold recycled mixes with re-crushed and aged RAP, including water susceptibility

IV. CONCLUSION

Multiple recycling of asphalt pavement layers is dependent on the ageing process during the life-time of this composite material which is used in the pavement structure and at the same time exposed to climatic conditions and effects of road traffic. Repeatedly use of reclaimed asphalt material is according to so far gained experience a possible and at the same time suitable approach for reduction of non-renewable sources exploitation (aggregates, bituminous binders). At the same time it is a possibility how to increase the environmental protection and securing savings of public budgets. This paper provided an assessment of impact of ageing if simulated for cold recycled asphalt mixtures which then where repeatedly recycled in the same type of mixture just with a reduced content of used binder. From the gained results it is visible, that the use of twice recycled asphalt material does not show worsening of determined characteristics even with respect to slightly increased content of bituminous binder in the mix. Multiple recycling therefore lead to satisfactory results, nevertheless it is important to consider certain limit for the bitumen content. This is mainly if the repeatedly recycled RAP will reach too high level of residual active binder and such material would be then unsuitable for an application in a new asphalt mixture.

V. ACKNOWLEDGEMENT

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