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INCREASING THE RATE OF RECYCLED ASPHALT: AN EXPERIMENTAL STUDY

Summary. Asphalt is material that can be recycled. In particular reclaimed asphalt (RA) contains aged binder, which limits the reuse of RA. In this study the rate of recycled asphalt was increased by adding a rejuvenator containing paraffin.

The authors investigated the effect of the rejuvenator in laboratory and in plant prepared samples of asphalt mixture. In laboratory samples with different percentage of RA (0%, 10%, 30%, 50%) and rejuvenator were prepared. In asphalt plant only asphalt mixture with highest amount of RA and rejuvenator and control mixture without RA were prepared. On samples were conducted different tests, e.g. determining softening point, Fraass breaking point, penetration, indirect tensile strength.

Results on extracted bitumen showed increase in softening point and decrease in Fraass breaking point with increasing percentage of RA and rejuvenator, meaning that service temperature of binders increased. Asphalt samples prepared in asphalt plant were laid on test field. Asphalt with RA and rejuvenator was built in at lower temperature (round 100 °C). Mixtures with RA and rejuvenator have better low temperature properties confirmed with Thermal Stress Restrained Specimen Test (TSRST) method, but are less resistant to compaction and less sensitive to water than control mixture. For comparison of long term behaviour wheel tracking test was performed on mixtures built in test field. A week after paving, the control mixture showed better properties, but one year later the results were opposite, asphalt containing RA and rejuvenator was more resistant to rutting.

From the results of this experimental study the following was concluded: the amount of RA can be increased by using rejuvenator and the quality of such asphalt mixture is in most cases equal or even better than asphalt mixture made of virgin materials. By using RA we preserve nature, reduce usage of virgin raw materials, but it is cost effective only if recycling degree is high enough and is a daily practice.

ZWIĘKSZENIE WSKAŹNIKA RECYKLINGOWEGO ASFALTU: STUDIUM EKSPERYMENTALNE

Streszczenie. Asfalt jest materiałem, który można poddać recyklingowi. W szczególności destrukt asfaltowy (RA) zawiera stare spoiwo, które ogranicza ponowne wykorzystanie RA. W badaniu wskaźnik recyklingowy asfaltu zwiększono przez dodanie substancji odmładzających zawierających parafinę.

Autorzy badali wpływ substancji odmładzających w laboratorium oraz w warsztacie na przygotowane próbki mieszanin asfaltu. W laboratorium przygotowano próbki z różną procentowo zawartością RA (0%, 10%, 30%, 50%) oraz z substancją odmładzającą. W asfaltowni przygotowano jedynie mieszanki z najwyższą zawartością RA i substancją odmładzającą oraz mieszankę kontrolną bez RA. Na próbkach przeprowadzano różne testy, np. określenie temperatury mięknienia, punktu łamania Fraassa, penetrację, pośrednią wytrzymałość na rozciąganie.

Wyniki na wyodrębnionym bituminie pokazały wzrost temperatury mięknienia i zmniejszenie punktu łamania Fraassa wraz ze wzrostem procentowym RA i substancji odmładzającej, co oznacza wzrost temperatury pracy spoiwa. Próbki asfaltu przygotowane w asfaltowni zostały położone na polu testowym. Asfalt z RA oraz substancją odmładzającą został zbudowany w niższej temperaturze (ok. 100^{o}C). Mieszaniny z RA oraz substancją odmładzającą mają lepsze właściwości niskotemperaturowe, co potwierdzono metodą Testu Próby Ograniczonego Naprężenia Termicznego (TSRST), ale są mniej odporne na zagęszczanie i mniej wrażliwe na działanie wody niż mieszanka kontrolna. Dla porównania przeprowadzono test długoterminowego zachowania toru ruchu na mieszaninach zbudowanych na polu testowym. Tydzień po położeniu nawierzchni mieszanka kontrolna wykazywała lepsze właściwości, lecz rok później wyniki były odwrotne – asfalt zawierający RA i substancje odmładzające był bardziej odporny na koleinowanie.

Z wyników eksperymentalnego badania wywnioskowano, co następuje: ilość RA może zostać zwiększona przez użycie substancji odmładzających oraz jakość takiej mieszanki asfaltowej jest w większości przypadków nawet lepsza niż mieszaniny z materiałów pierwotnych lub im równa. Dzięki zastosowaniu RA chronimy naturę, redukujemy wykorzystanie surowców pierwotnych, ale jest to opłacalne jedynie w przypadku, jeżeli stopień recyklingu jest wystarczająco wysoki i jest praktykowany codziennie.

1. INTRODUCTION

Asphalt is a composite material made of stone aggregate, air voids and binder, which is usually bitumen. Asphalt mixtures are common for constructing and maintaining roads, parking areas and also play- and sport areas. At the end of road service lifetime, when road is too damaged for traffic, road has to be repaired. We can choose to use virgin material or we can reuse materials from used asphalt, namely because asphalt is material that can be entirely recycled. RA may be used as a constituent material for bituminous mixtures in accordance with the specifications for those mixtures [1]. At first, asphalt recycling was considered as an option in the seventies during the oil crisis, when the prices of bitumen greatly increased. Initially, recycled asphalt materials were primarily used in road maintenance and construction of low-trafficked roads. Today, recycling methods are also considered for heavy trafficked roads, and recycling ratio may be close to 100% [1].

We need to take into account, that during road service life, the old binder has been aged and the aggregate degraded. Also the reclamation process may contribute to the inhomogeneity of the recycled pavement material [2]. In general bitumen ageing is divided in two stages: short-term and long-term ageing. Short-term occurs during construction, when bitumen is exposed to hot air at temperatures ranging from 135 to 163 °C. Short-term ageing results in increase in viscosity and changes in complex shear modulus and the adhesion. During service (long-term) bitumen progressively ages and hardens through various mechanisms. Age hardening during construction and service has been associated with six major mechanisms: oxidation, volatilization, polymerization, thixotropy, syneresis and separation [3], [4]. Aging process can be divided in two types. The main aging mechanism is an irreversible one, characterised by chemical changes of the binder. These processes are oxidation, loss of volatile components and exudation. The second mechanism is reversible process called physical hardening [4]. As asphalt binder reacts and loses some of its components during the aging process, its rheological behaviour will naturally differ from virgin materials [3]. Bitumen becomes harder, more brittle, its viscosity increases which results in loss of adhesion, ductility and in the end chip loss and cracking of asphalt layers [5]. Additive called rejuvenator can be added to asphalt made from recycled material, so asphalt can reach the required technical standards. Purpose of rejuvenator is to return aged bitumen its original properties by reconstructing the chemical composition of the aged bitumen [6]. Rejuvenators are designed to soften the existing bitumen on surface of the RA. They are often included in cold mixture and hot mixture recycling processes. Commonly bitumen becomes less viscous, more ductile and its coating properties are restored [7]. New technologies for the production of recycling asphalt considered in the article [28].

Due to different step of technological development and public awareness asphalt recycling rate in Europe vary from 90% to less than 10% [8]. In Slovenia only some asphalt plants recycle asphalt. The asphalt plants that use RA are not equipped with additional technology such as parallel drum enabling usage of more than 30% RA in new asphalt mixture. Our experimental study was oriented to increase RA percentage in new asphalt with minor adaptations of existing technology.

2. MATERIALS AND METHODS

Case study consisted of two parts. In first part asphalt samples were prepared in laboratory and in second part asphalt samples were prepared in asphalt plant. In laboratory samples with different share of RA (10%, 30%, 50%) and rejuvenator were prepared. Properties of mixtures were compared to control mixture, which was made from virgin materials and without rejuvenator. In asphalt plant only sample with highest amount of RA (almost 50%) and control mixture without RA and rejuvenator were prepared and tested.

2.1. Materials

In laboratory 7 kg of each mixture with target bitumen content 5% (by mass) was prepared. RA and rejuvenator were not heated and were added as last component in laboratory mixer. For preparation of laboratory samples RA with properties listed in and was used. The characteristics of RA such as gradation, type and properties of the residual bitumen play a fundamental role in the mix design phase. Other characteristics such as homogeneity, foreign matters and water content significantly influence the quality of the production [9].

Table 1

Sieve curve of used RA

Sieve opening [mm]	Passing [% by mass]
0.063	11.0
0.25	16.5
0.71	25.8
2	44.2
4	60.8
8	79.9
11	91.0
16	98.8

Table 2

Properties of bitumen in RA

Content of bitumen [% by mass]	3.8
Softening point [°C]	78.0
Penetration [1/10 mm]	11.8

Composition and properties of asphalt mixtures prepared in laboratory are shown in.

Table 3

Composition of laboratory prepared asphalts

RA [% by mass]		0	10	30	50	30 without rejuvenator
RA	kg	0.0	0.701	2.106	3.5	2.106
0.63 mm	% by mass	12.3	12.07	11.05	9.5	11.05
0.25 mm	% by mass	14.11	13.97	13.24	12.18	13.24
0.71 mm	% by mass	20.0	19.45	17.76	14.86	17.76
2 mm	% by mass	34.0	32.97	30.13	24.79	30.13
4 mm	% by mass	50.84	51.19	49.05	44.84	49.05
8 mm	% by mass	69.85	70.3	68.26	64.67	68.25
11 mm	% by mass	81.85	82.49	80.91	78.1	80.9
16 mm	% by mass	98.85	100.0	99.98	100.0	99.98
Rejuvenator	kg	0.0	0.0103	0.0309	0.0515	0.0
Fresh bitumen	kg	0.35	0.3131	0.2393	0.1655	0.27
Bitumen content	% by mass	5.0	5.0	5.0	5.0	5.1

In asphalt plant we prepared asphalt mixture with 48.5% RA and rejuvenator and control mixture without RA and rejuvenator. In following sieving curve is presented.

Table 4

Sieving curve of asphalt samples

Sieve opening [mm]	Unit	Plant mixture without RA	Plant mixture with RA	Laboratory mixture with RA
0.63	% by mass	8.6	9.5	8.8
0.09	% by mass	9.0	10.0	10.0
0.25	% by mass	13.0	14.0	14.0
0.71	% by mass	21.0	22.0	21.0
2	% by mass	39.0	40.0	35.0
4	% by mass	54.0	56.0	49.0
8	% by mass	76.0	78.0	71.0
11	% by mass	92.0	90.0	87.0
16	% by mass	100.0	96.0	100.0
22.4	% by mass	100.0	97.0	100.0

Conventional binder with following properties was used as a virgin material.

Table 5

Properties of used fresh bitumen

Property	Unit	
Penetration	1/10 mm	94
Softening point	°C	46.1
Fraass breaking point	°C	-19.0

2.2. Methods

All asphalt samples were prepared in accordance with European standard [10]. Laboratory asphalt samples contain different percentage of RA (from 0% to 50%) and rejuvenator. All sample's properties were compared to properties of control mixture, which was prepared only with virgin materials and did not contain any RA. On samples were performed different tests according to European Standards. Tests showed properties of extracted bitumen and properties of asphalt mixtures.

Bitumen was extracted from asphalt mixtures by dissolving bitumen using trichloroethylene as a solvent and then distilling the solution to recover the bitumen [11]. On extracted bitumen softening point was determined using a ring and ball method [12]. Consistency of bitumen was checked with standard needle penetration test [13]. Fraass breaking point was determined in accordance with European standard [14].

Basic information about asphalt samples was gained by determining void content [15], bulk density [16], maximal density [17] and indirect tensile test [18]. On asphalt samples prepared in asphalt plant more tests were conducted. Marshall test was used to determine stability and flow [19]. Water sensitivity tests were made according to [20] to evaluate the effect of moistures. Asphalt mixture produced in asphalt plant was compacted in form of slab [21] from which specimens were cut out. On these specimens TSRST tests [22] were carried out for characterizing the resistance against low temperature cracking.

Asphalt mixture prepared in asphalt plant was also laid on test field. A week after paving samples was taken in order to determine bulk density, void content and wheel tracking test [23]. After one year other samples were taken from test field and the tests were repeated.

Table 6

Test carried out in research

Samples	Test	European standard
Extracted bitumen	Soluble binder content	SIST EN 12697-1:2006
	Softening point	SIST EN 1427:2007
	Penetration test	SIST EN 1426:2007
	Fraass breaking point	SIST EN 12593:2007
All samples	Determining void content	SIST EN12697-8:2004
	Bulk density	SIST EN 12697-6:204+A1:2007
	Maximal density	SIST EN 12697-5:2010
	Indirect tensile test (ITS)	SIST EN 12697-23:2004
	Sample preparation	SIST EN 12697-30:2004+A1:2007
In plant prepared samples	Marshal test (stability and flow)	SIST EN 12697-34:2004+A1:2007
	Water sensitivity tests	SIST EN 12697-12:2009
	Slab compaction	SIST EN 12697-33:2004+A1:2007
	Uniaxial tension test	prEN 12697-46:2010
	Wheel tracking test	SIST EN 12697-22:2004+A1:2007

3. RESULTS AND ANALYSIS

In the following Table 7 and are given the results of this study. Firstly results for asphalt samples prepared in laboratory (Table 7) will be presented and then results for asphalt samples prepared in asphalt plant

Rejuvenator was added last, directly into the laboratory mixer. During the production of asphalt mixture in laboratory we had to prolong the mixing time to get suitable homogeneous mixtures. Void content was not determined.

Table 7

Characteristics of extracted bitumen and properties of laboratory prepared asphalt samples

RA [% by mass]		0	10 with rejuvenator	30 with rejuvenator	50 with rejuvenator	30 without rejuvenator
Softening point	°C	48,4	50.6	63.2	75.4	53.4
Penetration	1/10 mm	65	63	63	54	44
Fraass breaking point	°C	-11	-12	-15	-18	-11
ITS (2 x 50 blows, 25°C)	[MPa]	0.93	0.97	0.91	0.91	1.23
Temperature of compaction	°C	150	155	160	165	160

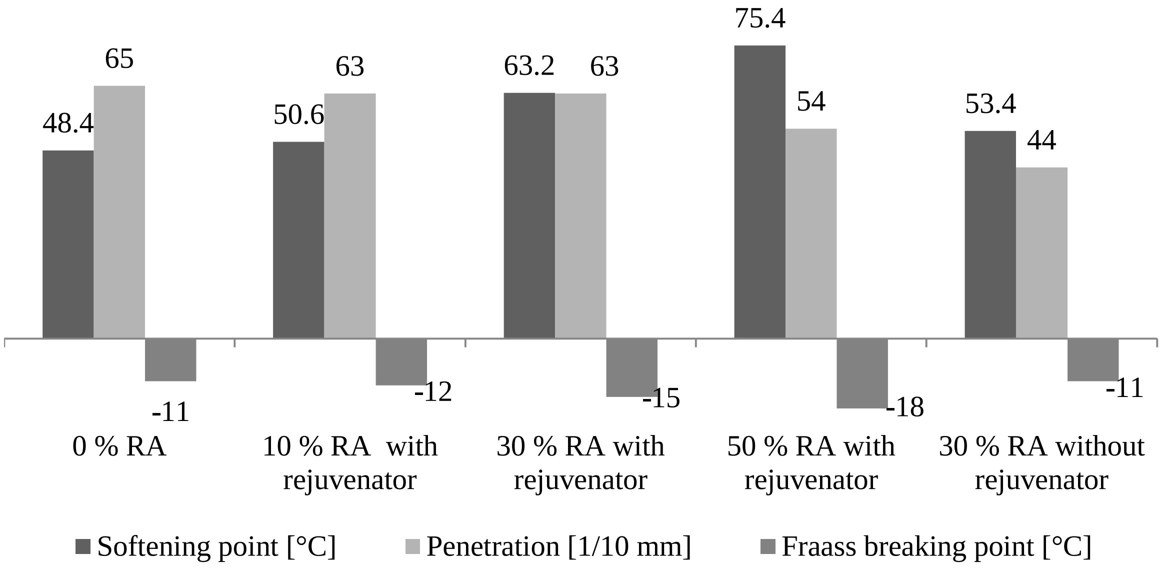

Fig. 1. Characteristics of extracted bitumen from laboratory prepared asphalt mixtures with different percentage of RA and with or without rejuvenator

Rys. 1. Charakterystyki wyodrębnionego bituminu z mieszanin asfaltowych przygotowanych w laboratorium z procentowo różną zawartością RA oraz z substancją odmładzającą lub bez niej

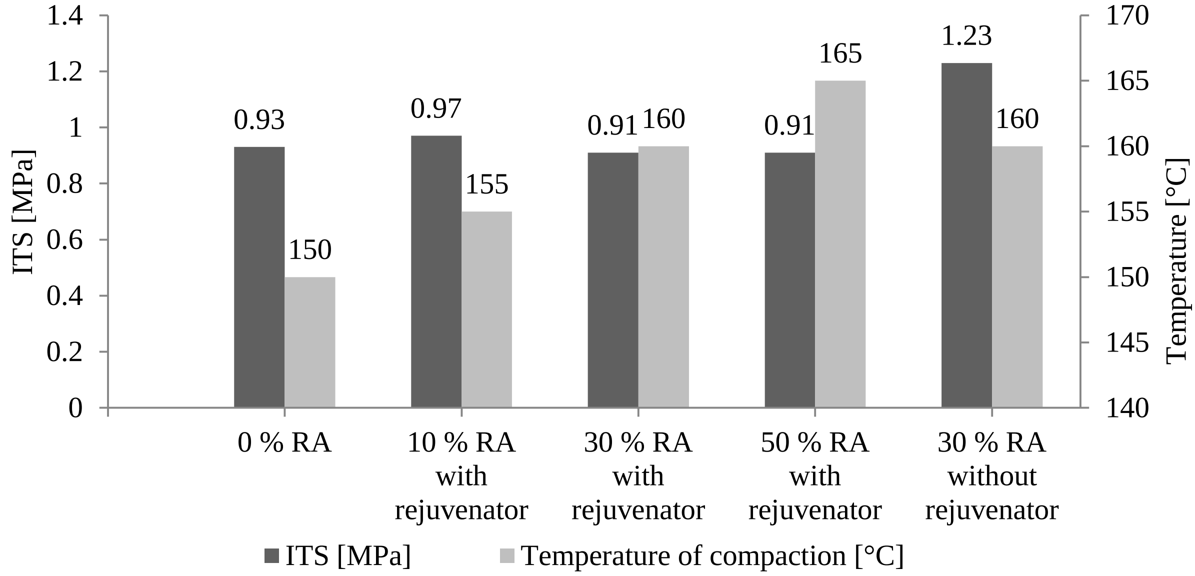

Fig. 2. Characteristics of asphalt prepared in laboratory with different percentage of RA and with or without rejuvenator

Rys. 2. Charakterystyki asfaltu przygotowanego w laboratorium z procentowo różną zawartością RA oraz z lub bez niej

Results showed that softening point increased with increasing percentage of RA and rejuvenator. Softening point of bitumen extracted from control mixture was 48.4°C and of bitumen from asphalt mixture containing 50% RA was 75.4°C. Fraass breaking point decreased as RA and rejuvenator was added. At first (for bitumen from control mixture) it was - 11°C and for bitumen from asphalt mixture with highest amount of RA it was -18°C. Increasing softening point and at the same time decreasing Fraass breaking point means the service temperature of bitumen increased. When only RA was added and no rejuvenator, the softening point increased comparing to control mixture, but when we compare it to mixture containing the same amount RA (30%) and a rejuvenator we notice the value of softening point is lower. In the last sample, 30% of RA and no rejuvenator, Fraass breaking point has the same value as measured for bitumen from control mixture. Penetration value was decreasing when we added RA, from 6.5 mm for control mixture, to 5.4 mm for the sample with 50% RA. Results show that penetration decrease less, when rejuvenator is added. Mechanical properties of asphalt mixtures tested according to [18] were almost uniform for all mixtures even when rejuvenator was added. Another studies report contradictory results about ITS [24], [25], [26]. The compaction temperature rose when we added RA. Comparing samples with RA and rejuvenator to the one with RA and no rejuvenator we can see that compaction temperature was the same.

In process of preparation asphalt mixture in asphalt plant RA was continuously added at the end of dryer drum, with dosing conducted visually by setting the speed of conveying belt. RA was heated indirectly with mineral mixture in hot elevator. To ensure proper mixing temperature, the mineral mixture had to be heated to higher temperatures. For proportion of 50% RA the temperature of stone aggregate mixture should be increased by at least 100°C (to at least 250°C), but technology did not allow such temperatures. With used additive, production temperature was decreased. Mineral mixture in the drum dryer was heated to 220-230°C and the production temperature of the asphalt mixture in a mixing drum was 110-150°C. Rejuvenator was added last, directly into the mixer. Beside the temperature correction also correction of the mixing time was required, to provide an even distribution of additive in asphalt mixtures. Mixing time was prolonged from 40 s to 48 s, but due to software limitations longer period was not possible. As a rule of thumb, higher the RA temperature before mixing, higher the amount of RA can be recycled. If cold and wet RA is added directly in the mixing drum, the virgin aggregates have to be superheated in order to ensure appropriate mixing temperature.

The excessive temperature of aggregates can cause the oxidation, or even burning, of the bitumen that can compromise the durability of final asphalt mixture [9].

Results on asphalt mixtures prepared in asphalt plant confirmed the results from laboratory. Softening point of extracted bitumen increased when we added rejuvenator. Comparing softening point of extracted bitumen from asphalt mixture with RA and rejuvenator produced in laboratory and in plant we show similarities, but the penetration values are more similar between plant mixture with RA and rejuvenator compared to plant mixture without RA. Volumetric properties are comparable for all three mixtures. Mechanical tests were conducted only on asphalt mixtures produced in plant and conclusions are that mixtures with RA and rejuvenator have better low temperature properties, which was confirmed with TSRST method, but resistance to compaction and sensitivity to water is lower than control mixture's.

Results on extracted bitumen extracted with Infratest asphalt analyzer (solvent trichlorethylene) showed increase in softening point and decrease in Fraass breaking point with increasing percentage of RA and rejuvenator, meaning that service temperature of binders increased. Mechanical properties of asphalt mixtures tested according to [18] were almost uniform for all mixtures even when rejuvenator was added. Comparing samples 30% RA with or without rejuvenator we notice increased softening point and penetration in samples with rejuvenator.

Table 8

Properties of asphalt samples without RA and asphalt samples from the plant or laboratory containing 50% RA and rejuvenator

Property	Unit	Plant mixture without RA	Plant mixture with RA 50% RA and rejuvenator	Laboratory mixture with 50 % RA and rejuvenator
Bitumen content	% by mass	5	4.9	5.1
Softening point	°C	52.5	77.6	75.4
Penetration	1/10 mm	42	42	54
Void content *	% by volume	2.2	1.8	1.9
Voids filled with bitumen*	% by volume	84.6	86.8	86.9
Bulk density*	kg/m^3	2462.6	2476.3	2485
Maximal density	kg/m^3	2517.5	2521.4	2532
Marshall stability at 60 °C*	kN	10.4	11.0	-
Marshall flow at 60 °C*	mm	2.6	3.3	-
Marshall stiffness at 60 °C*	kN /mm	3.9	3.4	-
ITS_d (at 25°C)	kPa	929.5 *(2x35 blows)*	769.1910 *(2x35 blows)*	910 *(2x50 blows)*
ITS_w (at 25°C) *(2x35 blows)*	kPa	888.3	773.6	-
Water sensitivity ITSR (ITS_w /ITS_d) *(2x35 blows)*	%	95.6	100.6	-
Compactibility C/0.0202 (at 148 ^{0} C)	°C	30.7	24.5	-
Failure stress	MPa	3.9	5.2	-
Failure temperature	°C	-27.5	-32	-

**(2x50 blows)*

Asphalt samples prepared in asphalt plant were laid on test field. Asphalt with RA and rejuvenator was built in at lower temperature (round 100°C). Tests on asphalt cores taken from field have confirmed appropriate compaction degree and void content of asphalt layers. Void content on test field is higher than in laboratory. For comparison of long term behaviour we used wheel tracking test on mixtures built in test field. A week after paving, the control mixture showed better properties, but a year after the results were opposite, asphalt containing RA and rejuvenator was more resistant to rutting.

Table 9

Properties of built in asphalt mixture with RA

Time after paving/ sample/ test temperature	Bulk density	Thic kness	Void conten t	Compacti on degree	Average rut depth	Proport. rut depth PRD_{AIR}	Rate of rut propagation WTS_{AIR}
	[kg/m^3]	[mm]	[%]	[%]	[mm]	[%]	[mm/1000]
1 week / with RA and rejuvenator/ 55°C	2388	62	5.1	97.0	6.22	10.0	0.28
1 week / without RA and rejuvenator/ 55°C	2407	60	4.5	97.2	4.17	7.0	0.13
1 week / with RA and rejuvenator on 50°C	2390	67	5.1	97.1	5.9	8.8	0.21
1 week / without RA and rejuvenator / 50°C	2418	68	4.1	97.6	5.05	7.4	0.1
1 year / with RA and rejuvenator / 55°C	2394	76	4.9	97.2	1.84	2.4	0.08
1 year / without RA and rejuvenator /55°C	2418	63	4.1	97.6	3.98	6.3	0.2
1 year / with RA and rejuvenator / 50°C	2381	74	5.4	96.7	1.02	1.4	0.04
1 year / without RA and rejuvenator/ 50°C	2417	63	4.1	97.6	2.96	4.7	0.1

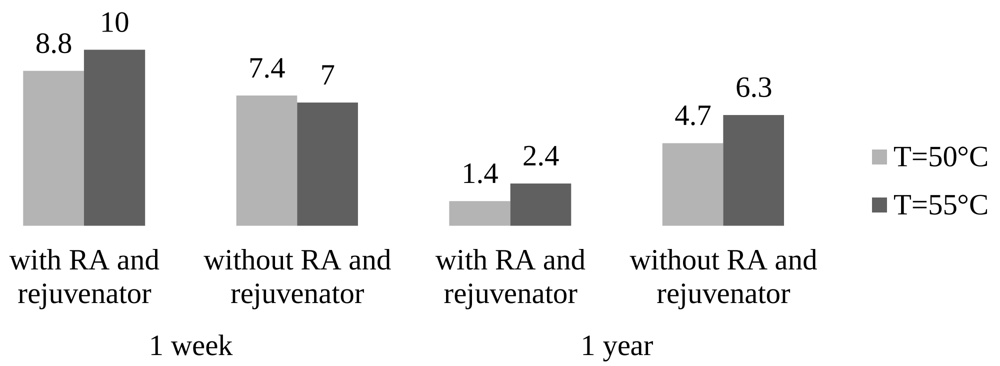

Fig. 3. Wheel tracking test – proportional rut depth, one week and one year after paving
Rys. 3. Test toru ruchu – proporcjonalna głębokość koleiny tydzień oraz rok po położeniu

Wheel tracking test have shown a slightly lower resistance to the formation of ruts for asphalt layer containing RA. All asphalt properties are within acceptable limits. From Table 6 it can be also seen that void content on test field is higher than in laboratory.

4. CONCLUSIONS

The tests proved that the amount of RA can be increased by using rejuvenator and the quality of such asphalt mixture is in most cases equal or even better than asphalt mixture made of virgin materials. Use of rejuvenators is cost effective, but it must be a daily practice, because if rejuvenators are used only occasionally, then such productions represent disturbance in regular production. Rejuvenator enables reuse of RA and at the same time improves the properties of asphalt mixture containing RA. By using rejuvenator we can lower the compaction temperature, which is cost efficient, saves energy and is more ecological. Lower compaction temperatures means longer transportation distance and time [27]. Rejuvenator prolongs life time of road surface [2].

Using RA means preserving nature, reducing usage of virgin raw materials and reducing waste.

Study showed that asphalt mixture prepared in asphalt plant containing about 50% RA was successfully produced in ordinary batch asphalt plant with no special hardware for RA addition like parallel drum. In spite of low temperatures after production (about 100°C) the asphalt mixture was also successfully laid and compacted as a wearing course in a test section.

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