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ASPHALT CONCRETE PRODUCED FROM REJUVENATED RECLAIMED ASPHALT PAVEMENT (RAP)

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The problem of recycled materials application in road construction is one of the key issues in contemporary road engineering. This article describes attempts to produce a hot mix asphalt (HMA) mixture entirely from processed reclaimed asphalt pavement (RAP) material. Due to the binder ageing process, rejuvenating agent was a necessary additive to the mixture. The mixture was tested to determine its parameters, including the content of voids, fatigue life, rutting resistance, stiffness and water sensitivity. The test results demonstrated that the rejuvenated RAP mixture is not inferior to fresh produced mixtures in terms of physical and strength parameters. Such results are, however, conditional on appropriate handling of the RAP material.

Keywords: reclaimed asphalt pavement (RAP), rejuvenator, hot mix asphalt (HMA), recycling

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1. INTRODUCTION

Problems with utilization of waste materials have been known for many years. They have to be dealt with in practically all industry sectors. Their sources include the quality of reclaimed materials which, for various reasons, are found unsuitable for new production or the lack of incentives from the Employers/ Contracting Authorities. The waste material that has been recycled on an increasing scale for use in road construction is processed RAP material.

It can be a used on its own for construction of unbound layers, although this form of recycling has been prohibited in quite a number of countries for environmental reasons. There is, however, a much greater potential for use of processed RAP as an ingredient of new HMA mixtures, the most commonly used road paving material. It can be used in the following technologies:

- cold process (for example in emulsion-mineral mixtures or mineral-cement-mineral mixtures) [1, 2, 3, 4, 5]
- half-warm and warm process (in mixtures containing foamed bitumen or with addition of chemical viscosity reducers) [6, 7]
- hot process (in HMA mixtures, generally as a supplement to fresh materials at quantities depending on the type of plant, for example black drum or double drum asphalt mixing plant) [8]

2. ISSUES OF UTILIZATION OF RECLAIMED ASPHALT MATERIAL

The processed RAP material to be used for production of new HMA mixtures must be uniform in terms of aggregate grading, binder content and its parameters as well. This is ensured by appropriately controlled milling, followed by sorting (including crushing) of the resultant RAP material. To use high amount of RAP in the HMA it is necessary to heat the RAP before introducing it to HMA. The most common method to preheat RAP is by using parallel drum. In the mixing plant there are two separate heating drums, one to heat aggregate second for RAP [31]. Thera are already many options of purchasing such drum, offered by producers of mixing plants.

While using high RAP amounts in the HMA particular attention should be paid to the parameters of the bituminous binder itself. The properties of RAP binder are affected by short- and long-term ageing to a degree depending on its location in the pavement layer, type of mixture in which it was originally used and service conditions. Thus increasing the quantity of processed RAP in new HMA mixtures can affect their performance characteristics.

The above-mentioned bitumen ageing processes are of both chemical and physical nature. Chemical ageing includes all the chemical reactions taking place in bituminous binder, oxidation and evaporation of volatile hydrocarbons being the most important ones [9, 10]. The chemical reactions increase the content of the heaviest and most polar bitumen groups and decrease the content of lighter and less polar fractions (mainly saturated and naphthalene aromatic hydrocarbons). The quantity of asphaltenes increases at the cost of aromatic compounds. The smallest changes occur in non-polar saturated hydrocarbons [11, 12].

Increased polarity of asphaltene groups aggravates physical ageing which involves interaction between polar particles. In this way agglomerates (micelles) are formed, which have an additional effect on binder structuring. Instead of the sol-gel state the bitumen is brought in the sol state in which interaction of micelles increases the viscosity and stiffness of bitumen [13].

The ageing processes in bituminous binders take place both during production (in HMA mixing in particular) and over the service life of the pavement. These processes are referred to as short-term and in-service (long-term) ageing respectively, with the former occurring during HMA production and placement. This phenomenon has been documented in the literature on the subject [14, 15, 16]. The conditions of the production process (high temperature, access of oxygen) which initiate changes occurring in bitumen can be simulated under laboratory conditions in the RTFOT test, according to EN 12607-1. In-service ageing can also be simulated and the PAV test, according to EN 14769 is used for that. This type of ageing is generally limited to the thin crust layers (ca. 0.5-1.5 cm in thickness) leaving the deeper part unaffected [17]. In these layers the binder is exposed to the effect of UV radiation and oxidation by atmospheric oxygen. Conversely, in-service ageing processes can possibly occur in deeper layers yet only in the case of higher air void content in the mixture (for example gap graded BBTM or porous asphalt mixtures). Summing up, we can assume that the properties of RAP bitumen should approximate the properties of bitumen after RTFOT (lower layers of the pavement) or RTFOT+PAV test (reclaimed wearing course material). It is estimated that the service life reflected by the RTFOT and PAV results is ca. 5 -10 years [18].

All the above-mentioned processes make the bitumen harder, more brittle and susceptible to both low-temperature and fatigue cracking. In pavements constructed using high-RAP mixtures there is a higher risk of premature cracking [19] as compared to fresh mixtures without processed RAP addition. The existing research results are not conclusive as to the content of aged binder (recovered from processed RAP material) at which it actually affects the performance properties of HMA mixtures [20].

A number of products have been developed to avoid this undesired effect by complete or at least partial restoration ("rejuvenation") of the initial properties of aged RAP binder. Products of this kind should include oil and resin fractions to restore the proportion of functional groups typical of new bitumens. At the molecular level, these products increase the distance between the micelles, reverse the physical processes (reorienting the molecules), and decrease the viscosity of the bitumen. As a result, it is possible to mitigate (at least partially) the negative effects of ageing. The chemical effects of rejuvenators have been investigated in a number of research projects. The method of combining rejuvenators with aged RAP binder is presented in article [21].

The phenomenon of ageing and rejuvenation of bitumen, described by the change of the content of the respective bitumen components is illustrated in Fig. 1 [22].

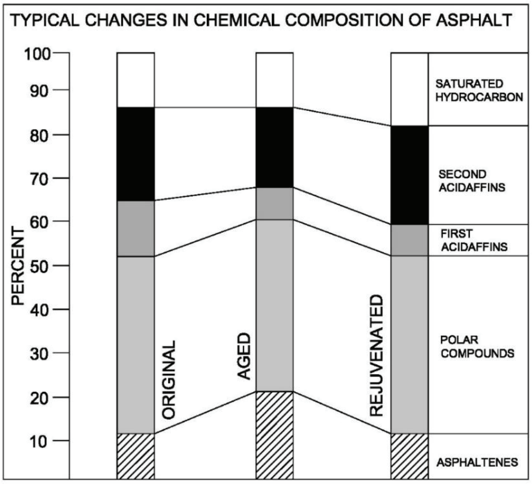

Fig. 1. Changes in the chemical composition of bitumen due to ageing and following rejuvenation [22]

The effectiveness of rejuvenators is being investigated at numerous research institutions [22, 24, 28, 29, 32]. These investigations concern the effect of addition of appropriate chemicals on the properties of both the bituminous binder and the HMA mixture. The results of experiments carried out to verify the influence of polymer-modified bitumen, soft bitumen and rejuvenators on the chemical and chemical-rheological properties of bitumen binders are presented in [23]. Experiments to investigate the effect of a RAP material content are also carried out on HMA mixtures. It is possible to use RAP material to which aggregate and rejuvenator (bio-agent) have been added, as long as attention is paid to possible increased water sensitivity of such mixture [24]. Addition of rejuvenators is not the only method of improving mechanical properties of high-RAP mixtures and other options are under research. In other research projects stable crumb rubber asphalt (SCRA) binder was found to improve some mechanical properties when added to the mixture in place of the conventional bituminous binder [25].

However, researchers face some problems concerning asphalt binder rejuvenation. It is connected with complexity of ageing processes and behaviour of asphalt binder and asphalt mix. Rejuvenation process depends on e.g. diffusion processes between rejuvenator and aged bitumen, which is a reason why proper thermal RAP treatment and adequate rejuvenators choice is of high importance. Thus, there is need for ongoing research in the field of asphalt rejuvenation.

3. MATERIALS USED IN THE EXPERIMENTS

The article presents the results of testing of the effect of rejuvenating additives on the properties of hot mix asphalt containing 100% processed (granular) RAP material. The tests were carried out on a representative sample of homogenous RAP obtained from a road designed for heavy traffic load (KR6 category according to the Polish classification system). The RAP material was obtained by milling pavement trafficked for 11 years. Asphalt layers were removed one by one. The pavement was free from damage or patch repairs. The material obtained for testing was protected from dirt, precipitation and solar radiation. The material used in the tests came from the base course layer (AC 22 P 35/50 – asphalt concrete for base course construction, 22 mm grading limit, 35/50 bitumen). The effectiveness of reclaimed bitumen rejuvenation was tested for four different rejuvenating agents.

Test cores were drilled from the pavement prior to removal of the pavement layers in order to carry out preliminary testing. The determinations included grading and content of bitumen and air voids, maximum and bulk specific gravity of cores. The test results are compiled in Table 1 below.

Table 1. Properties of base course HMA mixture sampled as RAP material for the main tests

Property	Unit	Reference standard	Value
Grading	-	EN 12697-2	0/22.4
Bitumen content	%	EN 12697-1	3.5 ± 0.3
Maximum specific gravity	Mg/m^3	EN 12697-5	2.642 ± 0.012
Bulk density	Mg/m^3	EN 12697-6	2.484 ± 0.017
Void content	%	EN 12697-8	6.0 ± 0.3

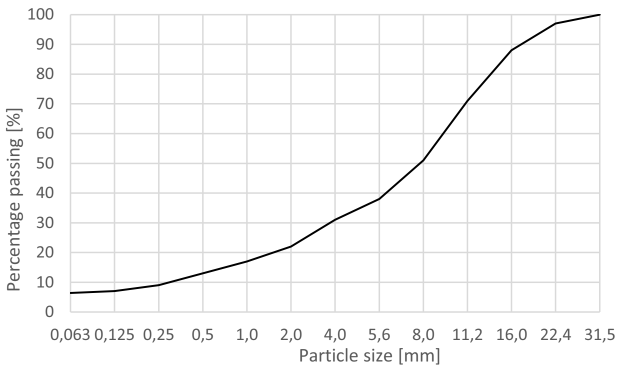

Fig. 2. Particle size distribution of the HMA mixture sampled from base course layer as RAP material for the main tests as per EN 12697-2

In the next step the parameters of the binder extracted from RAP material were determined. A comparative evaluation was performed for the binder parameters, based on the existing technical documentation and performance grading tests ($T_{R\&B}$, PEN) carried out at the construction stage (Table 2). It was determined that 35/50 PEN grade bitumen was used in base course mixture production. The tests performed on bitumen extracted from the RAP material obtained from the pavement trafficked for 11 years as per EN 12697-3:2013 showed a quite significant increase in the bitumen hardness value (Table 2).

Table 2. Test results for bitumen extracted from RAP vs. original values

Property	Standard	Original binder (used to produce the mixture in 2006)	Reclaimed binder (from pavement trafficked for 11 years)	Original binder after RTFOT (according to [30])	Original binder after RTFOT+PAV (according to [30])
Penetration (PEN), (25°C, 100 g, 5 s) [× 0.1 mm]	EN 1426:2015-08	45	25 ± 2.1	31	18
Softening point (TR&B), (5°C/min) [°C]	EN 1427:2015-08	54	60 ± 0.4	59	69

In the research, four types of rejuvenating additives were used. They differed primarily in terms of origin and degree of liquidity (different physical states at room temperature). Specifically, the applied rejuvenators were:

- a re-refined oil distillate based agent (designated D1),
- a plant resin based agent, composed exclusively of natural environmentally compatible ingredients (designated D2),

- very soft asphalt V6000 used mainly for production of mixtures designated for lightly trafficked roads (designated D3),
- imidazoline, an animal fat derivative (designated D4).

4. THE MAIN TESTS PROGRAM

In the preliminary part of research, the influence of the respective rejuvenators on the properties of asphalt binder was determined. This resulted in estimating their content in in the mixture in proportion to processed RAP content. For the sake of this comparison 100% RAP specimens were also produced. The scope of analyses included estimation of changes to the HMA mixture properties defining its performance characteristics caused by the respective rejuvenators added at different rates.

Considering the properties of rejuvenators (in relation to the changes in the properties of bitumen to which they were added) the following contents have been determined in the specimens containing RAP (in proportion to the processed RAP weight). The values obtained are as follows:

- D1: 0.2%, 0.3% and 0.4%;
- D2: 0.2%, 0.4% and 0.6%;
- D3: 0.2%, 0.3% and 0.4%;
- D4: 0.1%, 0.2% and 0.4%.

Preparation of HMA mixtures from processed RAP material (both with and without rejuvenator addition) and moulding the laboratory specimens involved the following steps:

1. conditioning of processed RAP material for 24 hrs to air-dry state (drying process at ca. 50-60°C),
2. heating up the RAP material to 150°C for 4 hours with limited access of air,
3. mixing in an automatic laboratory mixer for HMA mixtures for 180 seconds (time was set in order to obtain material optically similar to HMA (black colour of the whole mix),
4. dosing of the rejuvenator (in a precisely determined amount in relation to the binder weight, addition directly to the mixer)
5. re-stirring in the automatic laboratory mixer for HMA mixtures for 180 seconds,
6. conditioning of the mixture for two (2) hours at 130°C in order to simulate technological ageing process,
7. heating up the mixture to 150°C,
8. moulding and compacting the specimens.

Presented procedure was proposed by authors on the basis of observations as the rejuvenation process differs from standard HMA production.

The first stage tests were carried out in advance of the main tests. These tests included determination of the physical properties of HMA on Marshall specimens. The determinations included:

- maximum density as per EN 12697-5, method A, in water,
- bulk density as per EN 12697-6, method B,
- air voids content as per EN 12697-8.

Slightly different amounts of rejuvenators were added in the first stage of research. These amounts were in the range of 0.0% - 0.8% of the weight of the processed RAP material so as to enable variation of the physical properties of the moulded specimens.

The maximum density of the HMA mixture was 2.642 Mg/m^3. The bulk density and air voids content varied depending on the amount of rejuvenator added to the mixture. The relationship between the air voids content and the amount of rejuvenator is presented in Fig. 3. A detailed analysis of the test results is presented in [27].

Results of air void content test show that increase of rejuvenator content results in decrease of air void content to certain level. Above this level it seems, that the air void content growth is stopped or even reversed (rejuvenator D1). The only exception to this rule can be observed with rejuvenator D3, which may not be cooperating with the binder of RAP. This may cause such differences between the rejuvenators. It is also possible that different viscosity of applied rejuvenators has an impact of obtained results.

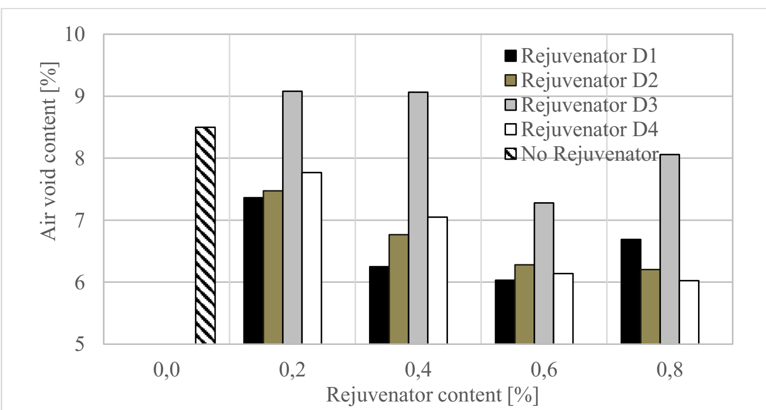

Fig. 3. Air voids content determined on Marshall specimens

The main tests procedures comprised production of laboratory specimens and determination of the performance properties of the tested HMA mixtures, i.e.:

– rutting resistance as per EN 12697-22:2008 - 10 000 passes of a wheel in temperature of 60°C,
– stiffness as per EN 12697-26:2012 – test carried out in 4 point bending beam apparatus in 10°C with frequency of 10 Hz and micro strain 50,
– resistance to fatigue as per EN 12697-24:2012 – test carried out in 4 point bending beam apparatus, in 10°C with frequency 10 Hz and micro strain 130,
– water sensitivity as per EN 12697-12:2008 – quotient between indirect tensile strength carried out on dry conditioned samples and wet conditioned samples.

All the tests results were compared to the control mixture. The control mixture was made of 100% RAP material, without addition of any rejuvenators, and the specimens were prepared according to the same procedure, including thermal conditions. The subsequent specimens had different contents of the discussed rejuvenators.

4.1. RUTTING RESISTANCE TEST

The function of rejuvenators is to interact with old binder to reduce the softening point and increase the penetration value. However, one should expect an undesired effect of decreased resistance to permanent deformation of the finally produced HMA mixture.

The permanent deformation test was performed in accordance with PN-EN 12697-22:2008 in a small-size device, method B (in air) at 60°C. The effect of different rejuvenators on the rutting resistance is presented in Fig. 4 and Fig. 5. The grading parameters are the mean values relating to the proportional rut depth (PRD_{AIR}) and the wheel-tracking slope WTS_{AIR}. The WTS and PRD values were determined according to PN-EN 12697-22.

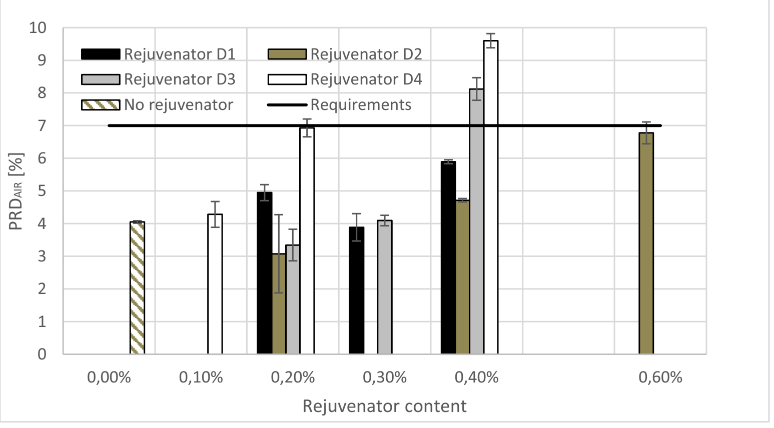

Fig. 4. PRD_{AIR} value depending on the rejuvenator type and content

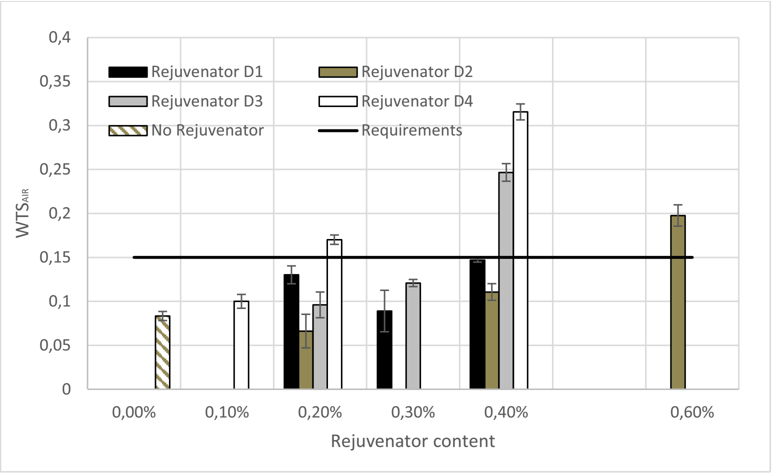

Fig. 5. WTS_{AIR} value depending on the rejuvenator type and content

The rutting resistance decreased with the increase in the amount of rejuvenator, which is in line with the initial assumptions. The variation in the rutting resistance depended on both the type and amount of the rejuvenator added to the mixture. For rejuvenators D3 and D4 the maximum acceptable rutting values (as per the design manual WT-2:2014) were exceeded at 0.4% content of the rejuvenator. The same content of the two other additives (D1 and D2) satisfied the rutting resistance requirement of the mixture. The rutting resistance test enabled determination of the maximum (limit) amounts of rejuvenators. The maximum acceptable PRD_{AIR} value was taken at 7% and the maximum acceptable WTS_{AIR} value at 0.15 mm/1,000 load cycles. Both values are in accordance with the requirement of the Polish design manual WT-2:2014 for HMA base course mixtures for heavily trafficked roads (KR5-KR7 categories). [26]

4.2. STIFFNESS TEST

The stiffness test (4 PB-PR) was performed according to the method defined in PN-EN 12697-26:2012 on 65×65×460 mm beam specimens. The specimens were cut out from 500×180×100 mm slabs produced of HMA mixture. The mixture was compacted in the asphalt slab roller compactor to achieve relative compaction in the region of 99% ± 1%. The preliminary tests, carried out during preparation of specimens comprised determination of the maximum density, bulk density and air voids content.

The stiffness tests were carried out at 10°C, with 50 μm strain and 10 Hz loading frequency. Three tests were done, each including 100 measurements, taking the mean value of the last 50 measurements of each series as the test result. The stiffness test results are presented in Fig. 6 below.

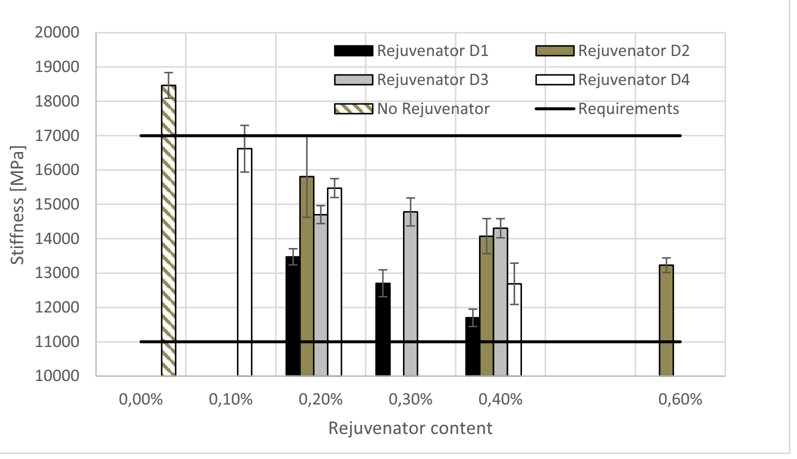

Fig. 6. Stiffness value depending on the rejuvenator type and content

The highest stiffness values were obtained on the control mixture specimens with no rejuvenators added. Increasing the amount of rejuvenator decreases the stiffness of the HMA mixture. The greatest decrease of stiffness was observed in the case of D1 rejuvenator. In the other cases the stiffness variation was comparable and the smallest effect on the mixture stiffness was noted in the case of D2 and D3 rejuvenators. This effect is most pronounced for 0.4% rejuvenator content. Based on the stiffness test results we can conclude that the appropriate range of rejuvenator content in the mixture for the processed RAP material used should be within the range of 0.2% to 0.6% of its weight. Requirements for stiffness test were set in accordance to combined requirements of polish manuals WT-2:2014 [26] and WT (2007) [33].

4.3. FATIGUE RESISTANCE TEST

The fatigue resistance test at constant strain consisted in performing a series of deformations of beam specimens 4PR-PB (four-point bend beam) at the constant strain of 130 μm with the 10 Hz loading frequency. The test temperature was 10°C. The test result was the number of cycles till the loss of 50% of the value of the modulus of stiffness determined during the initial 100 loading cycles (Fig. 7). The test was a modified version of the test presented in PN-EN 12697-24.

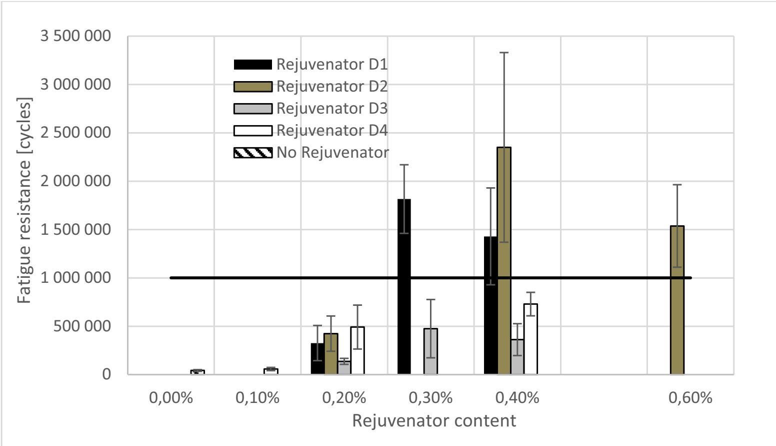

Fig. 7. The fatigue resistance level depending on rejuvenator type and content

The specimens made of the control mixture are characterised by the lowest fatigue resistance (ca. 42,000 cycles on average). Increased rejuvenator content resulted in increased fatigue resistance. In the case of the rejuvenator D3, fatigue resistance at the level of 500,000 cycles was obtained with the 0.3% rejuvenator content in proportion to the total mass of the mixture. For rejuvenator D4, the maximum value was 700,000 cycles with the rejuvenator content at the level of 0.4%. The best effects were obtained for rejuvenators D1 and D2, for which the fatigue resistance at the strain of 130 μm (and rejuvenator content above 0.3%) amounted to over 1,000,000 cycles.

4.4. WATER SENSITIVITY TEST

Water sensitivity and freeze-thaw resistance ITSR test was carried out in accordance with PN-EN 12697-12 and Appendix no. 1 - Design Manual WT-2 2014. It consisted in making 6 specimens for each of the tested contents of individual rejuvenators. Cylinder-shaped specimens (with 101.6 mm diameter and 63 mm height) were compacted using a Marshall compactor (2 x 35 hits per each specimen side). Three out of the total number of the specimens were subjected to the cycle of operation of water and low (below zero) temperatures, while other specimens were stored under constant temperature conditions, without the presence of water. As a result of the test the ratio of indirect tensile strength (ITS) of a specimen series conditioned in water (ITS_w) to the tensile strength of specimens conditioned without the presence of water (ITS_d) was obtained. Test results for various contents of 4 rejuvenators' are shown in Fig. 8.

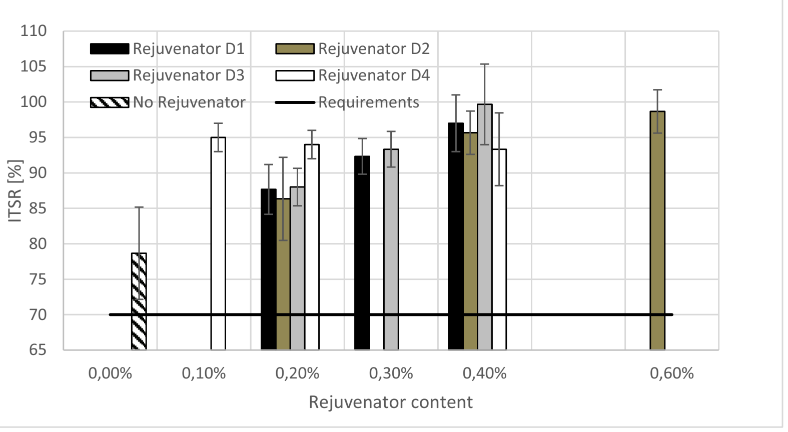

Fig. 8. Water sensitivity test result depending on rejuvenator type and content

Based on the results obtained it can be stated that the use of rejuvenators has a beneficial effect on the water resistance of the HMA mixture. Use of the rejuvenator resulted in improved water resistance of the HMA mixture, regardless of the type of rejuvenator. However, the most effective rejuvenator cannot be indicated as far as this property (ITSR) is concerned.

5. SUMMARY

The appropriate attitude towards obtaining the processed RAP material at the stage of old pavement milling and the precise analysis of the composition and properties of the aged bitumen allow to increase the proportion of the processed RAP material in new HMA mixtures (providing that appropriate equipment resources and processing technology are used in the process). Implementation of a production technology of HMA mixtures containing only rejuvenated processed RAP material cannot be also excluded. The study results corroborate the relevance of further research on the methods that would allow to compensate for bitumen ageing effects in HMA mixtures.

Four rejuvenators distinctly different from one another were used in the tests. Their use in HMA mixtures produced from processed RAP material results in:

– considerably improved fatigue resistance, however the rejuvenator content in the mixture should not be lower than 0.3% of the weight of the processed RAP material. The best effects were obtained when using rejuvenating agents D1 and D2, i.e., rejuvenators based on re-refined waste mineral oil and on plant resins;

- improved water and frost resistance (ITSR) – improvement in this parameter is evident for each of the applied rejuvenating agents. Already at the proportion as small as 0.1% a clear improvement in the resistance of the mixture to water and frost was noted. When the proportion at the level of 0.4% is applied, the values of the parameter become stable.
- increased susceptibility to permanent deformation and decreased stiffness of the tested HMA mixtures – changes in these parameters, however, are not indicative of an adverse effect of the rejuvenating agents on the mixture, as an excessive stiffness and hardness of the HMA mixture will result in premature pavement deterioration, mainly due to cracking. The results of the wheel tracking and stiffness modulus tests demonstrate that the optimum content of the additives in the mixture ranges at the level of 0.2-0.4% of RAP weight. A greater rejuvenator content could result in the pavement's increased susceptibility to deformation.
- the optimal content of rejuvenator is dependent on RAP and rejuvenator. As the research covered only one type of RAP, it cannot be stated that presented contents of rejuvenators would be optimal for any kind of RAP, which properties vary because of different gradation, binder content or binder's characteristics.

Further research is required to determine the possibilities of restoring the original properties of hot mix asphalt mixtures from old pavements. Technological development (mainly in the organic chemistry field) is indicative of new possibilities and promotes the development of increasingly advanced rejuvenation agents. Nowadays we should seek to fully utilize production waste based materials in line with sustainable development goals and hence to facilitate effective management of non-renewable resources.

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LIST OF FIGURES AND TABLES:

BETONY ASFALTOWE Z ODŚWIEŻONEGO GRANULATU ASFALTOWEGO

Słowa kluczowe: destrukt asfaltowy, granulat asfaltowy, rejuvenator, mieszanki mineralno-asfaltowe (MMA), recykling,)

STRESZCZENIE:

Problem z wykorzystaniem destruktu asfaltowego jest jednym z najbardziej aktualnych zagadnień budownictwa drogowego. Problem ten dotyczy w szczególności krajów wysokorozwiniętych, gdzie występuje znacząca przewaga remontów i przebudów nad budową nowych odcinków dróg. Niezbędne jest zatem umożliwienie optymalnego przetworzenia destruktu asfaltowego.

Artykuł zawiera rozbudowaną część teoretyczną, w której wymienione zostały różne możliwości wykorzystania destruktu asfaltowego. Dalsza część przeglądu literatury dotyczyła wykorzystania destruktu asfaltowego w mieszankach mineralno-asfaltowych, reakcjom zachodzącym w asfalcie oraz możliwościom stosowania wysokich zawartości destrukty w nowych mieszankach mineralno-asfaltowych.

Kolejna część artykułu opisywała dobór materiałów do badań. Opisany został sposób poboru destruktu asfaltowego oraz zostały przedstawione jego badania. Finalnie została wykonana mieszanka mineralno-asfaltowa składająca się w 100% z wyselekcjonowanego destruktu asfaltowego. W dalszej części ta mieszanka była nazywana mieszanką referencyjną. Na tej mieszance wykonano badania zawartości wolnych przestrzeni, trwałości zmęczeniowej, koleinowania, sztywności oraz odporności na działanie wody.

Wyniki z badań mieszanki referencyjnej pozwoliły na ustalenie, iż mieszanka składająca się z samego granulatu asfaltowego charakteryzuje się zbyt wysoką zawartością wolnej przestrzeni, zbyt wysoką sztywnością oraz niewystarczającą trwałością zmęczeniową. Wyniki pozostałych badań mieściły się w oczekiwanych granicach. W celu przywrócenia mieszance odpowiednich parametrów dodawano do mieszanki składającej się z granulatu asfaltowego rejuvenatory – dodatki chemiczne umożlwiające odwrócenie efektów starzenia lepiszcza asfaltowego. Po zastosowaniu dodatków, przy odpowiednim doborze ilości i rodzaju rejuvenatora udało się uzyskać pożądane parametry mieszanki mineralno-asfaltowej w zakresie zbadanych właściwości. Dodatek rejuvenatorów powodował spadek odporności na koleinowanie, spadek sztywności, spadek zawartości wolnych przestrzeni, wzrost trwałości zmęczeniowej oraz odporności na działanie wody w stosunku do mieszanki referencyjnej.

Osiągniecie wymaganych parametrów nie oznacza zakończenia prac nad wykorzystaniem wysokich zawartości destruktu asfaltowego do nowych mieszanek mineralno-asfaltowych. Określenie możliwości przywracania pierwotnych właściwości mieszankom mineralno-asfaltowym ze starych nawierzchni wymaga jeszcze licznych badań. Badania te są obecnie istotnym zagadnieniem naukowym, ze względu na konieczność dążenia do pełnego wykorzystania materiałów stanowiących odpad produkcyjny, co wpisuje się w ideę zrównoważonego rozwoju, umożliwiając poprawnie zarządzać zasobami nieodnawialnymi.

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