SUSTAINABLE ASPHALT RECYCLATE BASE COURSE

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Abstract

In the construction industry nowadays, it is the concepts such as sustainability, recycling, emission and energy reduction which are coming to the fore. This article follows the same path, looking at the design of new, recycled road subbase layers. These layers are almost 100% composed of recovered reclaimed asphalt, crushed to the appropriate fraction. This reclaimed asphalt is either mixed with a suitable binder, heated to a low temperature, or a combination of both effects occurs. The research described in this paper is partially related to the newly developed standard ČSN 73 6147 Cold recycling of pavement structural layers [1]. The aim of this research is to economically and environmentally reuse reclaimed asphalts of lower quality, specifically in the subbase layer of pavements. Otherwise, this precious material is mainly used for the backfilling of roadsides.

Keywords

Reclaimed asphalt, subbase layer, cold recycling, warm recycling, bitumen emulsion/cement bonding

1 INTRODUCTION

The research presented in this paper builds on previous work on the use of reclaimed asphalts in pavement construction layers [2]. Specifically, the previous work involved the use of higher amounts of reclaimed pavement asphalt (RAP) – 35 wt.% or more – in asphalt concrete for pavement layers. The goal was to increase the amount of reclaimed asphalt pavement used in hot mix asphalt pavements, which, according to Fig. 1 below, was quite successful. Unfortunately, this is still a lower percentage of usage of this economically and technologically suitable material for re-use in structural layers. Thus, a large proportion that is not suitable for use in hot mix asphalt ends up as inferior material for sidewalk base courses, road shoulder backfills or as unpaved surfaces on lightly loaded private roads. For this reason, it was decided to initiate a research on the design and development of mixtures for road subbase layers made of reclaimed asphalts, which according to TP 210, are unusable for hot mix asphalt [3], [4], [5].

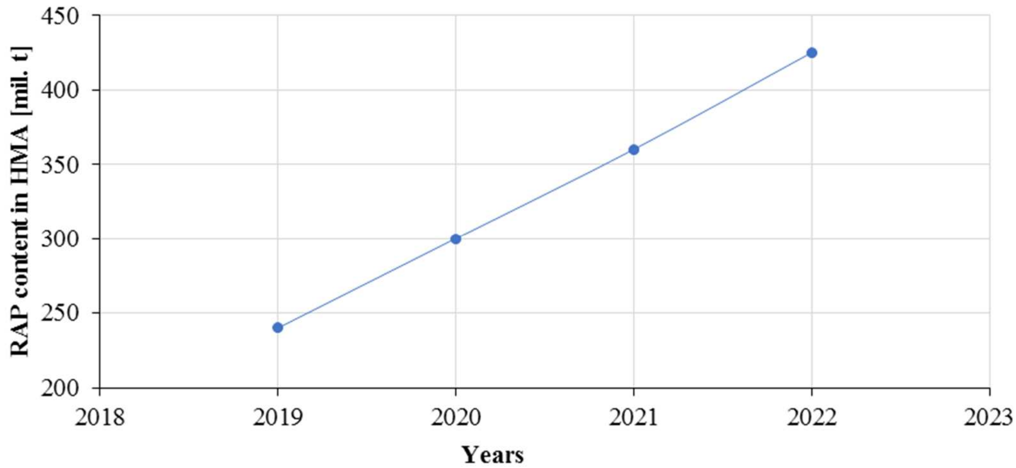

Fig. 1 RAP content in HMA in the Czech Republic [6], [7], [8], [9].

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2 METHODOLOGY

The research was partially based on the newly developed standard ČSN 73 6147 Cold recycling of pavement structural layers (effective from 1 June 2023), following the former technical specifications TP 208 Cold recycling of non-rigid pavement structural layers [1], [10]. The parameters which the results of the research are compared to, as well as the procedures used, are based on the above mentioned standard for cold recycling, as a standard describing the subject very close to the research conducted. The technical regulation dealing with warm recycling described below does not currently exist in the Czech Republic. The aim of the research was to examine various samples of commonly used reclaimed asphalts and to design their easy, widely applicable and economically viable treatment for their further use as subbase layers of Czech pavements, especially on local roads.

In the first phase, a significant number of suitable test samples of the materials were collected. As the research focuses mainly on the subbase of the second and third class roads, cooperation was established mainly with the road management and maintenance centres in the individual regions which often manage this material. A total of 5 different types of commonly used reclaimed asphalts up to a maximum particle size of 32 mm or 45 mm were collected from these centres and the surrounding asphalt mixing plants. Apart from the maximum particle size and a water content of up to 5 % (to ensure good workability and compactability under laboratory conditions), no other requirements were applied to the recyclate [11].

In the second phase, standard tests were carried out on both the recyclate itself (sieve analysis) and the extracted binder (bitumen binder content, penetration, softening point) to establish basic information on the samples taken. These tests confirmed the previously expected different origins and properties of the reclaimed asphalt, ensuring a wide range of choice between the materials used, from the lowest quality to very suitable reclaimed asphalts.

The third stage involved the actual design and production of the reclaimed asphalt subbase layers. A total of 9 test sets were created for each recyclate tested. In the first stage, a series of reference reclaimed asphalt specimens were created at a laboratory temperature of + 30 °C. Then, in order to maximise the potential of the residual bitumen binder content in the recyclate, 3 further sets of test specimens were created at 60 °C, 90 °C and 135 °C. The temperatures were chosen for the following reasons:

- 30 °C – reference temperature of the reclaimed asphalt under standard conditions,
- 60 °C – temperature at which the softening point of the commonly used bitumen binder in the country is normally reached or exceeded; it is also the temperature at which the bitumen emulsion is usually heated and can be generated in the heating drum used at some road maintenance centres,
- 90 °C – temperature at which the softening point of the bitumen binder is 100% exceeded and no water evaporation from dosed bitumen emulsion occurs,
- 135 °C – heating temperature of the reclaimed asphalt pavement at the asphalt mixing plant when added to hot asphalt mixes (to avoid burning of the bitumen film on the surface of the grains).

In the next stage, a small amount of binder – 1,5% polymer modified cationic bitumen emulsion 60% (KAE C60 BP5) – was dosed into the reclaimed asphalt to improve the bond and strength characteristics of the layer. For this amount of emulsion, 4 sets of specimens were formed and compacted again at the above-mentioned temperatures. The emulsion was always dosed at the standard mixing temperature of 60 °C.

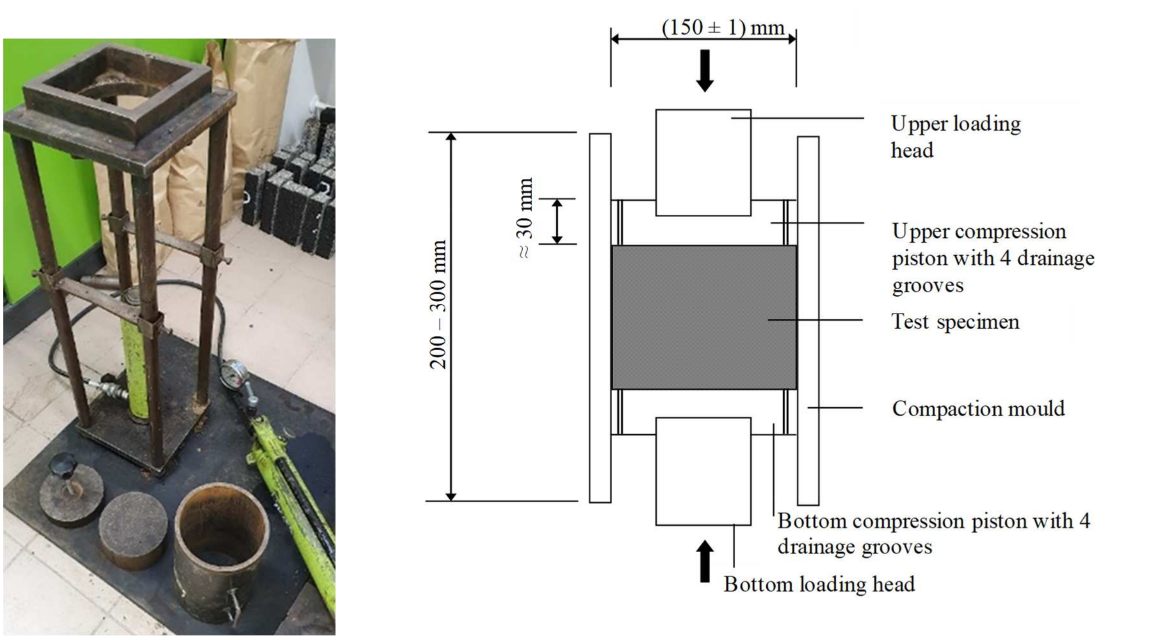
The last, ninth set of specimens was compacted only at a reference temperature of 30 °C and contained the addition of a binder in the form of 1,0 % CEM II 32,5 R Portland blended cement (CEM). This set was specifically designed to investigate the effects of the cement binder primarily on the stiffness of the reclaimed asphalt which contained the most aged binder. The softening point of this binder was so high that it had to be heated to at least 90 °C for its bonding function [12], [13].

Finally, all the manufactured specimens were tested in an indirect tensile strength test. This was carried out on both saturated and dry bodies in accordance with ČSN 73 6147 and both their minimum indirect tensile strength and the ratio of wet to dry strengths were monitored [1].

Although the standard requires the preparation of 6 test specimens (3 dry and 3 wet ones) for each proposed mix, this has not yet been achieved [1]. Due to the physically challenging compaction system, the limited number of test moulds and the high number of compacted solids (Fig. 2) from various recyclates (more than 60 specimens in total), only one, maximum two specimens were produced for each variant. After evaluation of the results obtained so far, the best and most cost-efficient subbase designs will be selected. For these selected designs the remaining required solids will be compacted and tested to specify the final results.

Fig. 2 Test specimens after indirect tensile strength test.

Compaction was carried out using a manual hydraulic press, as shown in Fig. 3, which ensured that the material was compacted evenly on both sides. The compaction force applied to the specimen was set at 88,5 kN ± 0,5 kN according to ČSN 73 6147, which corresponds to a contact stress of 5 MPa in the compaction mould [1].



a) b)

Fig. 3 Manual hydraulic press a), scheme of cylindrical mould with compacting pistons b) [1].

To produce the test specimens, a special compaction press had to be built during the research because the Proctor modified impact compaction test used for laboratory compaction of test cylindrical specimens is not suitable for elastic-plastic reclaimed asphalt. A scheme of the compaction press is shown above in Fig. 4.

3 RESULTS

This chapter presents selected results of the tests performed. These include both tests on bitumen binders extracted from reclaimed asphalts and tests carried out on the reclaimed asphalts themselves. Coning and quartering were performed on the material prior to the sampling. The results of the bulk density test for all test specimens are available upon request from the authors of the paper and will not be published here.

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Bitumen binder tests

Tab. 1 shows the penetration and softening point values of the various bitumen binders extracted from the reclaimed asphalts and the amount of bitumen binder contained in the reclaimed asphalts. These values are used to evaluate the degree of ageing and the quality of the bitumen binder, or rather the quality of the reclaimed asphalt itself.

Tab. 1 Softening point and penetration values of bitumen binders extracted from reclaimed asphalt.

	1 (0/32)	**2 (0/32)**	**3 (0/45)**	**4 (0/32)**	**5 (0/32)**
Softening point [°C]	*61.8*	*67.9*	*85.9*	*60.8*	*62.5*
Penetration [0,1 mm]	*26.6*	*17.3*	*4.8*	*19.4*	*33.9*
Bitumen content [%]	*5.8*	*5.1*	*5.3*	*5.1*	*5.1*

Sieve test analyses

The following Fig. 4 shows the sieve test analyses performed on the used reclaimed asphalts, including the grain size limits. The values of these limits are only recommended for in-situ recycling.

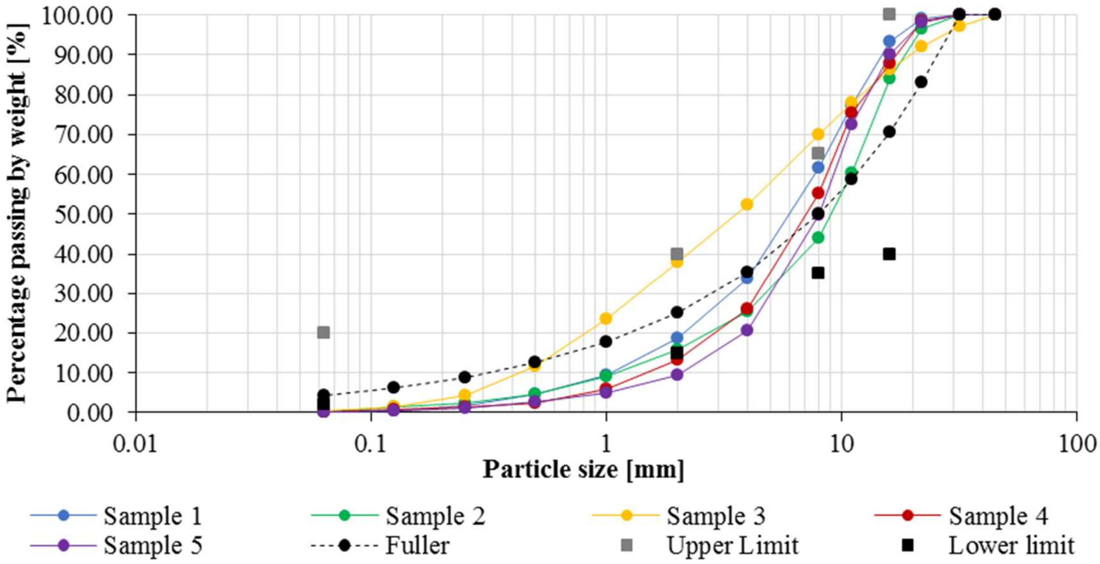

Fig. 4 Sieve test analyses – reclaimed asphalts.

The following Fig. 5 shows the sieve test analyses performed on the used reclaimed asphalts after extraction of the bitumen binder. The values of these limits are only recommended for in-situ recycling.

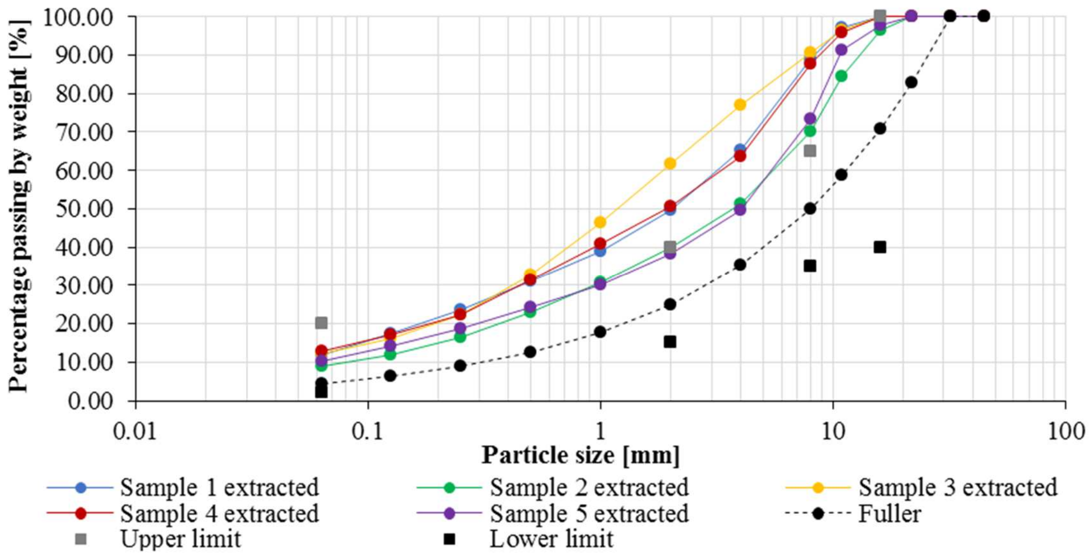

Fig. 5 Sieve test analyses – reclaimed asphalts after extraction.

Determination of indirect tensile strength and water resistance

The following figures show the results of the indirect tensile strength test (Fig. 6) and the indirect tensile strength ratios for the water resistance test (Fig. 7). All test specimens used in the above-mentioned tests met the requirements of ČSN 73 6147 for mass (4700–5000 g) and height (125 ± 20 mm) and were prepared and tested according to the relevant standard [1].

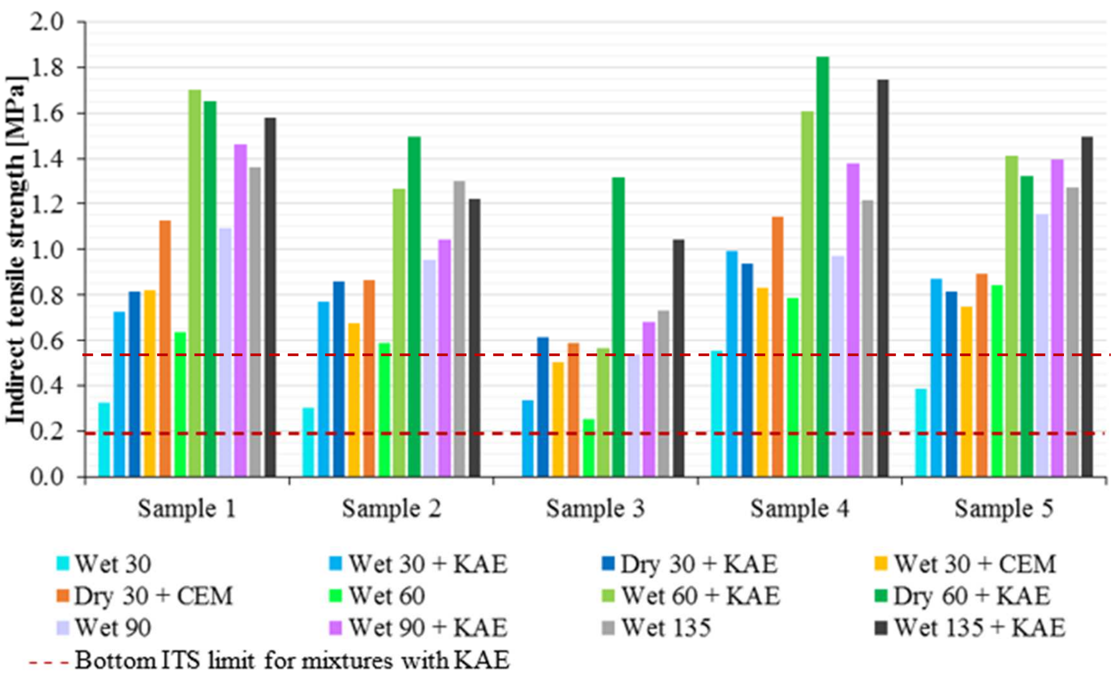

Fig. 6 Indirect tensile strength – all values.

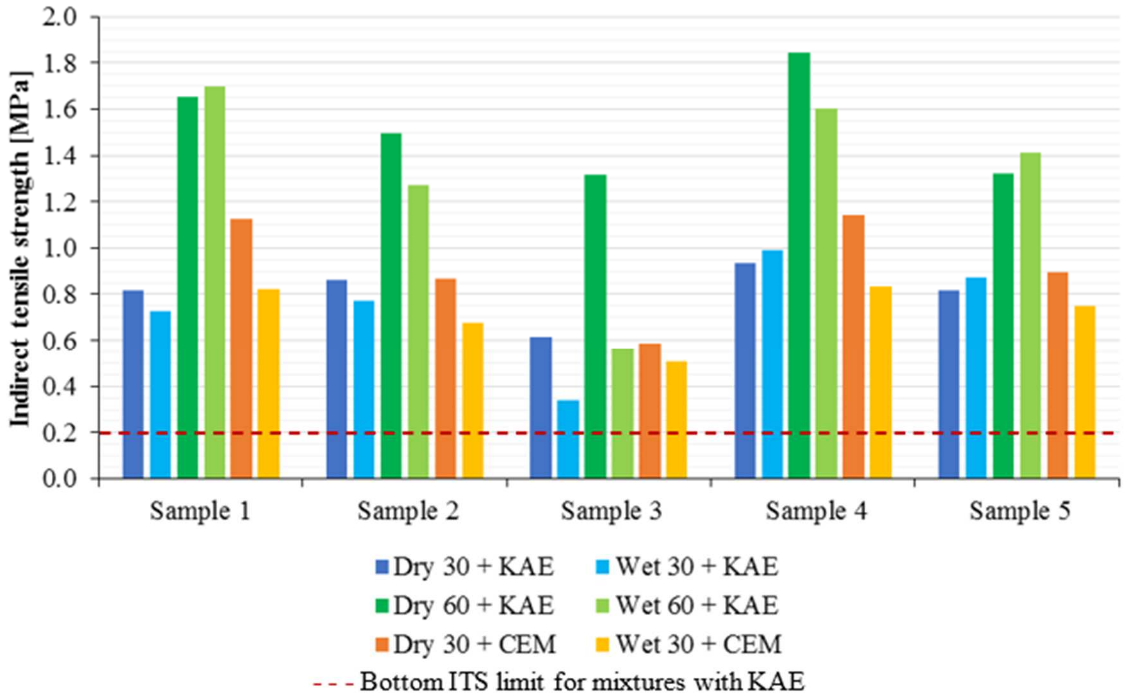

Fig. 7 Indirect tensile strength ratio.

4 DISCUSSION

This chapter describes and evaluates the measured values presented in the "Results" chapter and compares them with the requirements of the relevant standards [1], [14]. This part is divided into several sections so that the subsections correspond to the content of the 'Results' chapter.

Bitumen binders and bitumen emulsion

First of all, the measured values of penetration and softening point by the ring & ball method were compared with the values specified in the ČSN 73 6141 Requirements for the use of reclaimed asphalt pavement in asphalt mixtures [14]. According to the requirements of the standard, the conditions for use in asphalt mixtures are fulfilled by 4 out of 5 tested reclaimed asphalts (under the conditions of their modification into reclaimed asphalt pavement, compliance with the prescribed granularity and compliance with the classification into quality grades ZAS T1 to ZAS T3) [15]. However, only samples 1 and 5 are sufficiently distant from the limit values required by the above-mentioned standard (penetration ≥ 15 p.u. and softening point ≤ 70 °C) and could probably be used for the production of hot mix asphalt. The other samples are unsuitable for hot mix asphalt but can be used in road subbase layers.

A 1,5% of polymer modified bitumen cationic emulsion 60% (KAE C60 BP5) was dosed into almost all designed subbase mixtures. This emulsion was chosen because of its frequent use, among others, at road management and maintenance centres in the Czech Republic. The amount of emulsion was chosen according to expert estimation, taking into account the costs of the designed mixtures. Changing the amount of bitumen emulsion added and changing the type of emulsion or binder in general are other options that are planned to be compared in the continuation of this research.

Following the penetration and softening point values measured for specimen 3, it was decided to create one set of test specimens using cement as a binder instead of bitumen emulsion. It is the cement that could be used for reclaimed asphalts in which the bitumen binder no longer performs the bonding function. In terms of design, it would be a cement-bound mixture with a specified strength (SC C $R_{k,cyl}/R_{k,cyl/cube}$). Since the use of cement to improve larger quantities of reclaimed asphalt could be significantly uneconomical, it would be appropriate to use this material only for shoulder backfill or as a replacement of unbound material.

Sieve test analyses

In terms of the grain size limits of the recyclate processed in-situ, the ČSN 73 6147 standard states recommended values [1]. In the case of preparation in a mixing centre or a laboratory, the percentage passing values required by the standard for the 0.063 mm, 2 mm, 8 mm, 16 mm sieves (31.5 mm only for the 0/63 fraction) should be respected [1]. Even the first value of the required percentage passing of at least 2% on the 0,063 mm sieves is very questionable. Reclaimed asphalts, whose grains, as the name implies, are bound with a bitumen binder, will hardly achieve a percentage passing of more than a few tenths of a percent on the 0,063 mm sieve under standard conditions. Fig. 8 shows the average percentage passing of the 4 recyclates used (sample 3 was discarded for the reasons given above). The value of percentage passing on a 0.063 mm sieve is 0,07% and it would therefore be advisable to focus on adjusting these values (for reclaimed asphalt) in a future revision of the standard.

A similar problem is that the standard specifies a requirement for the granularity of the mixture to be "probably" (not specified in words) before extraction [1]. Under these conditions, it is usually not possible to achieve the required high percentage passing rates even for a 2 mm sieve (for reclaimed asphalt). These particles are contained within the recyclates, but even after they are milled out of the pavement, they are still largely bound by the bitumen binder into larger particles, as shown in Fig. 8.

The final consideration of this subsection is the effect of temperature on the granularity of reclaimed asphalt. In the case of cold recycling, which is the subject of this standard, the problem does not occur. If the temperature of the reclaimed asphalt is raised above the softening point, which is what this research focused on, the bonding between the particles is loosened and the sieve analysis of the cold recyclate does not match the actual conditions. For this reason, the average sieve analysis before (with binder content) and after extraction (without binder content) are shown in Fig. 8. Their average sieve analysis (average of averages) is shown in the same figure. It can be assumed that the actual sieve analysis for reclaimed asphalt heated to 60 °C would be somewhere close to this average of averages.

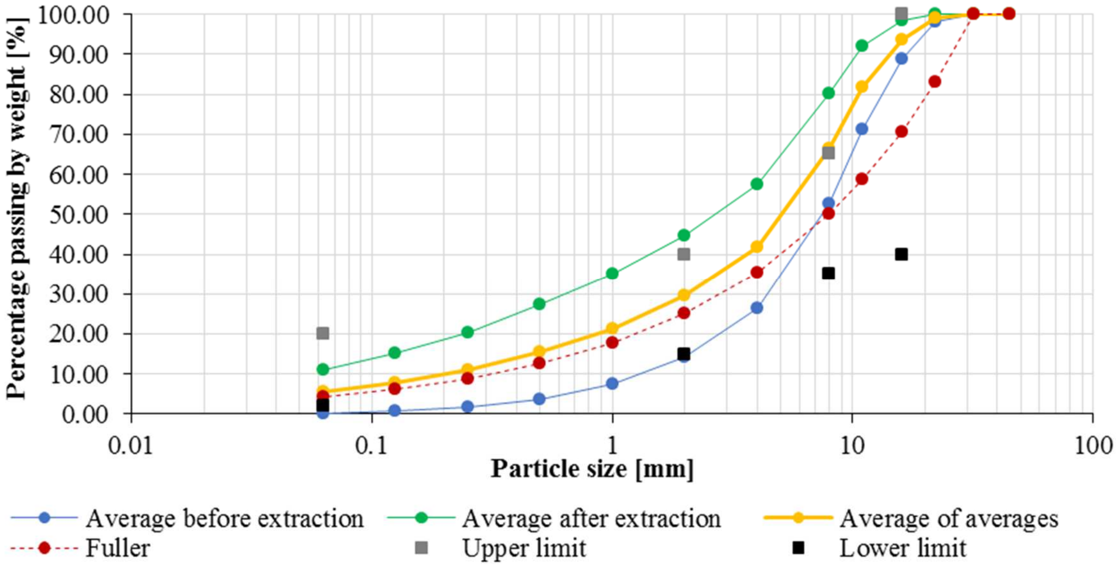

Fig. 8 Sieve test analysis – average values.

Indirect tensile strength

The ČSN 73 6147 standard requires 2 tests of the physical-mechanical properties to be performed on recycled bound mixtures – indirect tensile strength R_{it} after 7 days and minimum water resistance [1]. The required values are presented in Tab. 2.

Tab. 2 Requirements for physical-mechanical properties [1].

		Cement	**Bitumen emulsion**
All roads except highways	*Indirect tensile strength R_{it} (7 days)*	*0.30–0.70 MPa*	*min. 0.2 MPa*
	Minimal water resistance	*75% R_{it}*	*60% R_{it}*

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The minimum limit of 0,2 MPa specified by the standard was exceeded by all samples without the influence of temperature or type of bonding, except for sample 3 at the laboratory temperature [1]. In this sample, disintegration occurred before the actual test was carried out. The reason for the disintegration is described in the previous subsections. Since all samples, even without bonding, exceeded this limit, the adequacy of this standard value can again be questioned.

Since all bitumen emulsion bound specimens at laboratory temperature (except for specimen 3) achieved at least three times the value of the strength of the wet specimen than the value of the strength of the dry specimen required by ČSN 73 6147, a large part of the specimens was tested only in the saturated state to obtain a larger amount of data [1]. All bitumen emulsion bound specimens at laboratory temperature (except for specimen 3) achieved at least three times the value of the strength of the wet specimen than the value of the strength of the dry specimen required by standard. Thus, a large part of the specimens was tested only in the saturated state to obtain a wider range of data. Selected sets of specimens (30 °C + KAE, 60 °C + KAE and 30 °C + CEM) were then tested in both the dry and saturated states. For all saturated specimens bound with bitumen emulsion, minimum strengths of approximately 85% were achieved compared to the R_{it} strength, and for the saturated specimens bound with cement, minimum strengths of approximately 73% were achieved compared to the R_{it} strength. This slight deficiency compared to the standard requirement (min. 75%) could easily be solved by increasing the cement content [1]. However, in view of the strength results obtained on the bitumen emulsion bound specimens, the cement option becomes meaningless and appears to be less economical.

The most cost-effective and best quality option appears to be heating the reclaimed asphalt to a temperature around the softening point of the contained binder (approx. 60 °C) in combination with bonding with the cationic bitumen emulsion (1.5%). The average values of the indirect tensile strength R_{it} after 7 days were approximately about 1.6 MPa in the dry state and 1.5 MPa in the saturated state, which corresponds to approximately **eight times** the minimum required strength R_{it} [1]. At the same time, it can be observed in Fig. 6 that even with increasing temperature (less economical) or increasing temperature with the addition of emulsion, the indirect tensile strength is not achieved as high as at 60 °C + KAE. This phenomenon can be easily explained. While the binder in the recyclate softens with increasing temperature, the emulsion reacts more rapidly with the recyclate (or even the water in the emulsion evaporates immediately) and does not sufficiently coat and bond the grains.

5 CONCLUSION

From the above mentioned results, it can be concluded that all the set objectives were achieved. It has been demonstrated that the bonding of the reclaimed asphalts by bitumen emulsion achieves sufficient strength of the road subbase. At the same time, in combination with a slight heating of the bound mixture, the potential of the layer is much increased , thanks to the activation of the binder contained in the recyclate. This processing option is suitable for most reclaimed asphalts used in the Czech Republic which contain a binder with a softening point of around 60 °C.

In a follow-up research, it would be advisable to focus on the economy of these mixes, especially the ratio of increased cost due to heating the mix (to 60 °C) versus increased layer strength. It would also be interesting to address the practical feasibility of producing these mixtures on site, such as a mobile heating drum. However, this is not part of the objectives of this paper. Its main objective is the design of mixes for subbase courses made of reclaimed asphalt and the evaluation of the effect of the temperature increase and the addition of binder on its strength.

Due to the fact that in the Czech Republic, there are cold recycling (ČSN 73 6147) and hot recycling (ČSN 73 6148, dealing with temperatures higher than 120 °C) standards, yet there is no suitable standard describing warm recycling of non-rigid pavements the requirements for the designed mixtures were used from the most similar standard, which is ČSN 73 6147. [1], [16] According to the research carried out and the lack of standards for warm recycling, it would be advisable to either:

- add chapters on warm recycling requirements to standard ČSN 73 6147 [1],

or

- create a new standard or technical recommendations for warm recycling.

In conclusion, the research and its follow-up will be presented and consulted with the heads of road maintenance in the Czech Republic and Slovakia in the annual technical conferences and seminars. Hopefully, the technology will prove its worth in the construction, repair or maintenance of roads and this valuable material in the form of reclaimed asphalt will be used adequately.

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References

[1] ČSN 73 6147 Recyklace konstrukčních vrstev vozovek za studena (Pavement cold-in-place recycling). In: Prague: Czech Agency for Standardization, p. 20, 05/2023. Czech standard

[2] SPIES, Karel. Inovativní asfaltové směsi pro obrusné vrstvy s použitím vyššího množství R-materiálu. (Innovative asphalt mixtures for wearing course with a higher content of reclaimed asphalt pavement) Brno, 2020. 81 p., 31 app. p. Diploma Thesis. Brno Universitry of Technology, Faculty of Civil Engineering, Institute of Road Structures. Supervisor: Ing. Pavel Šperka

[3] PRADHAN, Sujit Kumar and BISWAL, Gurukalyana,. Utilization of reclaimed asphalt pavement (RAP) as granular sub-base material in road construction. *Materials Today: Proceedings*. 2022, pp. 288–293. ISSN 22147853. Available at: https://doi.org/10.1016/j.matpr.2021.12.564

[4] TAHA, Ramzi; ALI, Galal; BASMA, Adnan and AL-TURK, Omar. Evaluation of Reclaimed Asphalt Pavement Aggregate in Road Bases and Subbases. Transportation Research Record: *Journal of the Transportation Research Board*. 1999, pp. 264–269. ISSN 0361-1981. Available at: https://doi.org/10.3141/1652-33

[5] TP 210 Use of recycled construction demolition materials in roads. In: Brno: Brno University of Technology, Faculty of Civil Engineering, Institute of Road Structures, p. 23, 2011

[6] Overview of production and processing of pavement materials in 2019. [online], Vol. 11, no. 1 In: Prague: Road Construction Association, 2020

[7] Overview of production and processing of pavement materials in 2020. [online], Vol. 12, no. 1 In: Prague: Road Construction Association, 2021

[8] Overview of production and processing of pavement materials in 2021. [online], Vol. 13, no. 1 In: Prague: Road Construction Association, 2022

[9] Overview of production and processing of pavement materials in 2022. [online], Vol. 14, no. 1 In: Prague: Road Construction Association, 2023

[10] TP 208 Cold recycling of non-rigid pavement layers. In: Prague: Ministry of Transport - Department of Road Infrastructure, p. 27, 2009

[11] PLATI, Christina; TSAKO UMAKI, Maria and GKYRTIS, Konstantinos. Physical and Mechanical Properties of Reclaimed Asphalt Pavement (RAP) Incorporated into Unbound Pavement Layers. In: Applied Sciences [online]. 2023. ISSN 2076-3417. Available at: https://doi.org/10.3390/app13010362

[12] OGBO, Chibuike; DAVE, Eshan V. and SIAS, Jo E. Laboratory Performance of Stabilized Base with 100% Reclaimed Asphalt Pavement (RAP) Using Portland Cement, Bitumen Emulsion and Foamed-Bitumen. *Proceedings of the RILEM International Symposium on Bituminous Materials* [online]. RILEM Bookseries. Cham: Springer International Publishing, 2022, pp. 1257–1263. ISBN 978-3-030-46454-7. Available to: https://doi.org/10.1007/978-3-030-46455-4_160

[13] BLEAKLEY, Albert M.; COSENTINO, Paul J. a GKYRTIS, Konstantinos. Improving Properties of Reclaimed Asphalt Pavement for Roadway Base Applications through Blending and Chemical Stabilization. *Transportation Research Record: Journal of the Transportation Research Board*. 2013, pp. 20–28. ISSN 0361-1981. Available at: https://doi.org/10.3141/2335-03

[14] ČSN 73 6141 Požadavky na použití R-materiálu do asfaltových směsí (Requirements for reclaimed asphalt for bituminous mixtures). In: Prague: Czech Agency for Standardization. p. 20, 12/2020. Czech standard.

[15] Vyhláška č. 283/2023 Sb.: Vyhláška o stanovení podmínek, při jejichž splnění jsou znovuzískaná asfaltová směs a znovuzískaný penetrační makadam vedlejším produktem nebo přestávají být odpadem (Decree No. 283/2023 Coll.: Ordinance determining the conditions under which recovered asphalt mix and recovered penetration macadam becomes a by-product or ceases to be waste), In: Sbírka zákonů. no. 283, p. 9, 2023

[16] ČSN 73 6148 Recyklace asfaltových vrstev na místě za horka (Hot-in-place recycling of bituminous layers), In: Prague: Czech Agency for Standardization. p. 16, 05/2023. Czech standard.