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Evaluation of the quality of reclaimed asphalt originating from SMA mixtures containing neat and polymer-modified bitumens

Abstract: Hot recycling of asphalt mixtures in mixing plants belongs to methods that enable sustainable production of new hot-mix paving mixtures incorporating material reclaimed through milling of existing pavement layers. Whereas hot recycling of base and binder courses has become a typical solution, application of this technology to wearing courses has not yet been fully explored. Polish motorways and expressways constructed in 2010-2012, whose wearing courses generally comprise stone mastic asphalt (SMA) mixtures with polymer-modified bitumens, are currently nearing the stage of wearing course replacement. Primary issues related to hot recycling of asphalt mixtures include evaluation of reclaimed asphalt (RA) in terms of its quality and suitability for production of new hot-mix SMA mixtures for wearing courses. This pertains both to the composition of the RA material itself and to the quality of the aged binder it contains. The article presents the results of investigations performed under the RID II rSMA2 research project, whose aims included, among others, quality evaluation of 6 different RA materials originating from milling of SMA8 and SMA11 wearing courses. In five cases RA material contained polymer-modified bitumens; in one case RA contained neat paving-grade (unmodified) bitumen. Quality evaluation encompassed determination of RA composition and particle size distribution, as well as assessment of the extracted bitumen and recovered fine asphalt mixture material (FAM – a mixture of bitumen, filler and sand). The obtained results are analyzed in the article. Extracted bitumens were evaluated based on European and American procedures; recovered mineral mixtures were assessed using both "black" and "white" gradation curves. For the first time in Polish literature, FAMs were separated from RA and evaluated.

Keywords: fine asphalt mixture (FAM), hot recycling, reclaimed asphalt, relaxation, stone mastic asphalt (SMA).

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1. INTRODUCTION

1.1. INTERNATIONAL USE OF RECLAIMED ASPHALT IN SMA MIXTURES

Hot recycling of asphalt mixtures in mixing plants enables sustainable production of new asphalt mixtures using reclaimed asphalt (RA) from existing pavements. While hot recycling of base and binder courses is commonly used, application of this technology to wearing courses has not yet been fully investigated. Polish motorways and expressways constructed in 2010-2012, whose wearing courses generally comprise stone mastic asphalt (SMA) mixtures with SBS-modified binders, are currently on the threshold of necessary wearing course replacement.

Asphalt mixture recycling provides a wide range of economic and environmental benefits. However, usage of reclaimed asphalt in wearing course mixtures is relatively limited in Europe. In some countries application of RA in wearing courses is still not permitted [1-7], in others the acceptable content does not typically exceed 20% or 30% [8-10]. Concerns related to the potential acceptance of greater proportions of RA in wearing courses (similar to the proportions acceptable for lower pavement layers) are primarily based on the following reasons:

- stricter material requirements pertaining to wearing courses,
- permission to only use RA originating from wearing courses (due to material requirements),
- considerable environment-related aging of binders contained in existing wearing courses, additionally leading to concerns about affective blending of the aged binders with virgin binders during reuse,
- serious potential technical-economic consequences in the case of failure and premature distress of the new wearing course,
- lesser quantities of material reclaimed – in comparison to binder and base courses – due to lower thickness of wearing courses; combined with greater risk.

Hot recycling of SMA mixtures is a challenging issue, practically pertaining only to wearing courses, whose recycling is treated as riskier than that of other pavement layers [11-19]. Moreover, an SMA mixture itself exhibits properties that make the recycling process more complicated than in the case of asphalt concretes (AC) used in wearing courses. The basic factors that may cause additional difficulties include:

1. Greater binder content in SMA than in AC.
2. High viscosity of binder, combined with its increased content in SMA vs. AC.
3. Use of elastomer-modified bitumens.

Due to the factors mentioned above, the issue of effective blending of the old binder from SMA with the new bituminous binder becomes fundamental in the case of recycling of SMA wearing courses. It is necessary to evaluate the potential degree of activation of the binder contained in SMA, taking into account its increased content, high viscosity and the desirable homogeneous blending with new binders. If elastomer-modified binders are used, compatibility of the old and new binder is a significant issue.

Due to the abovementioned aspects, in the majority of countries use of RA originating from SMA is subject to greater limitations than general recycling of AC wearing courses. Some countries – e.g. Austria, Switzerland, Scotland, Ireland and Australia – do not allow usage of RA in SMA mixtures [2-3], [5-7].

In other countries, including Poland, use of RA in SMA is subject to individual acceptance [9], on condition that specific requirements are met. Similarly, use of RA in SMA mixtures in Great Britain may be allowed if the supervising body accepts a so-called "departure from specification". Analogous situation may be observed in Germany – regulations [20] do not provide for the possibility of adding RA to SMA, unless such addition (within given limits) is permitted in tender documents related to a specific project. Local regulations – for example, those in power in Hamburg [10] – enable wider usage of RA in SMA; however, the permissible content (30% by mass) is lower than in the case of AC wearing courses (50% by mass).

Owing to the fact that usage of RA in SMA may be accepted in individual cases, certain pavement sections with wearing courses of SMA with addition of RA have already been constructed [18, 21]. Construction of such sections is connected with broadened laboratory tests aimed at optimization of RA content and evaluation of key performance parameters of SMA. Polish [21-24] and British [25] experiences may serve as an example.

1.2. THE AIM AND SCOPE OF RA RESEARCH UNDER RID II RSMA2 PROJECT

The task that the Gdańsk University of Technology was involved in under the Road Innovation Development project RID-II (RID2/0009/2022) was entitled "Development of guidelines for reuse of reclaimed SMA asphalt material in new wearing courses constructed using the same technology" and referred to as rSMA2 in short. The aim of the task was to optimize the scope of testing required for RA evaluation and develop guidelines on the recommended binder replacement (BR) ratio depending on the quality and processing of RA. The works also encompassed innovative approach, which consisted in testing fine asphalt mixture (FAM) recovered from RA – in order to potentially limit the need for tests performed on bitumens recovered by means of traditional extraction, which may affect their properties. The entire rSMA2 project was realized by a research consortium comprising the Road and Bridge Research Institute (leading body), the Gdańsk University of Technology and the Warsaw University of Technology.

Works performed at the Gdańsk University of Technology included selection of SMA mixtures and SMA-based RA materials of varying age, technical condition and composition. Core samples and milled RA materials extracted from SMA wearing courses were subjected to comprehensive laboratory examination, which scope is presented in details in further chapters.

The obtained test results served as the basis for formulation of recommendations pertaining to test procedures – including simplification of the analyses by using recovered fine asphalt mixtures instead of bitumens extracted with solvents. The developed test procedures assume practicability in well-equipped road laboratories and are based on verified, advanced test methods. Due to the wide scope of the performed research, only chosen laboratory results are presented herein. Results presented in the study and conclusions from the whole RID programme can be used by other agencies as a base for introduction of RA in wearing courses. Performed advanced tests also shows promising test protocols on FAM, which can be introduced in design of asphalt mixtures with RA to avoid extensive and long test performed on asphalt mixtures.

2. MATERIALS

Laboratory tests were performed using RA materials obtained from milling of SMA wearing courses. Moreover, core samples were also extracted at the locations where the wearing course was to be milled. The selected mixtures differed in pavement age, aggregate type and bitumen type. The materials originated from SMA wearing courses from 6 pavement sections located at the following roads, which differed in technical class and maintenance standards:

- S7 (Czosnów – Modlin section), SMA 11 PmB 45/80-55, lack of precise age information,
- A1 (GTC concession section), SMA 11 PmB 45/80-55, age: 14 years,
- DK6 (Lębork), SMA 11 50/70 bitumen, age: 15 years,
- Chodecka Street in Warsaw, SMA 8 PmB 45/80-65, age: 13 years,
- DK25 (section from km 5 + 730 to 8 + 630), SMA 11 PmB 45/80-55, age: 17 years.

The following specimen types were tested: RA material obtained directly from milling (without granulation), cores extracted at the same locations, bitumens extracted from RA and FAMs separated mechanically from RA. Specimens and their codes are listed in Table 1.

Table 1. Specimen sources, types and codes used in result presentation

No.	Road location	RA	Bitumen extracted from RA	FAM recovered from RA
1	S7 Czosnów – Modlin	RA_11_S7	B_11_S7	FAM_11_S7
2	A1 km 41 + 000 (right roadway, emergency lane)	RA_11_A1_bx	B_11_A1_bx	FAM_11_A1_bx
3	A1 km 2 + 300 – 9 + 370 (right roadway) or km 20 + 450 – 25 + 496 (left roadway)	RA_11_A1_ibdim	B_11_A1_ibdim	FAM_11_A1_ibdim
4	DK6, Lębork	RA_11_DK6	B_11_DK6	FAM_11_DK6
5	Chodecka Street, Warsaw	RA_8_Ch	B_8_Ch	FAM_8_Ch
6	DK25, km 5 + 730 – 6 + 530; km 7 + 830 – 8 + 630	RA_11_DK25	B_11_DK25	FAM_11_DK25

3. LABORATORY TESTS AND RESULT ANALYSIS

3.1. SCOPE OF LABORATORY TESTS

Selection of appropriate laboratory tests depended on the type of material analyzed. Cored samples of SMA (extracted from in-service sections before milling of the SMA wearing course) were tested first. After the chosen sections had been milled, samples of the obtained RA were set aside for testing. Further tests were performed on RA itself, bitumens extracted from RA and FAMs separated from RA. While the tests encompassed 6 RAs in total (from 6 different sections), core samples were obtained on 5 sections.

3.2. TESTING OF RA MATERIALS

Basic testing of RA obtained from each road section encompassed: a) determination of bitumen content by extraction, both using milled RA samples and core specimens; b) determination of particle size distribution of milled RA ("black grading curve") by means of sieve analysis; c) etermination of particle size distribution after bitumen extraction ("white grading curve") – performed both on milled RA samples (9 specimen for each) and cored specimens (3 specimen per section) by means of sieve analysis.

Based on the performed testing of bitumen content, it must be stated that currently the results of bitumen content in cored samples should not be treated as representative of bitumen content in milled RA. Bitumen content analyses should be based on testing of milled RA itself. Results obtained from the cores overestimated the bitumen content from 0.4 up to 1.0 percent point.

When particle size distribution is analyzed for RA before bitumen extraction ("black grading curve"), the material is characterized by considerable variability in grading between individual samples. Among 9 measurements, the greatest differences ranged from 16% to 27%, with the mean value of 20.9%. Most frequently, the greatest differences in grading were observed for the middle sieves, from 2 mm to 11.2 mm; however, there were also exceptions (RA_11_S7). In general, RA after milling does not contain fine fractions. Comparison of the "black grading curves" for materials that displayed the greatest and the lowest variabilities in particle size distribution is shown in Fig. 1.

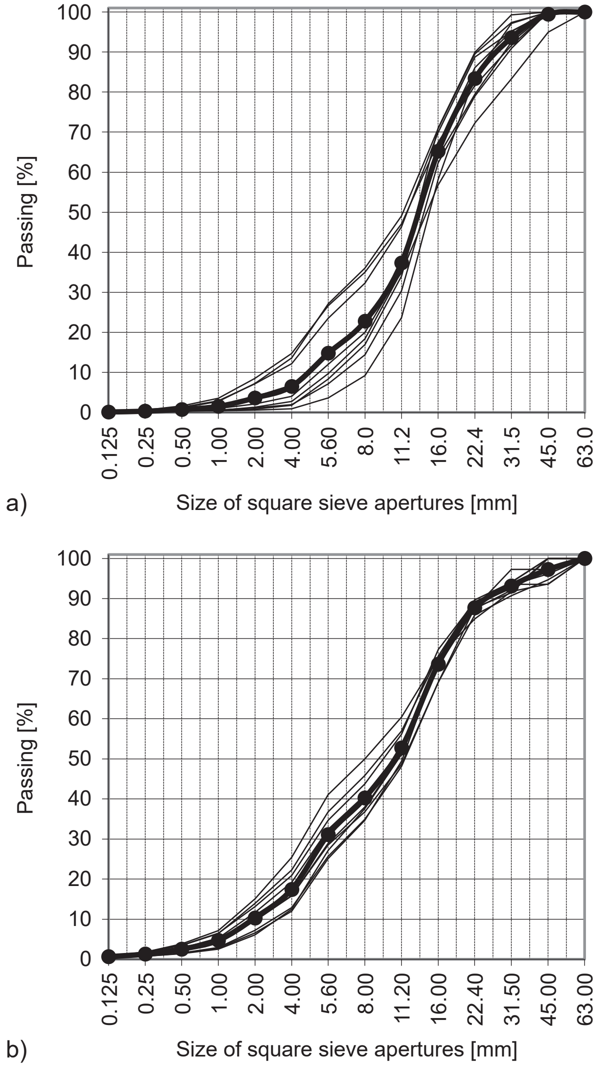


Fig. 1. Grading of RA before bitumen extraction ("black grading curve") for materials displaying grading variability: a) the greatest (RA_11_DK6), b) the lowest (RA_11_A1 (2)

In the case of particle size distribution analyses performed after bitumen extraction ("white grading curve"), the material also displayed considerable variability in grading between samples. Over 9 measurements, the greatest differences ranged from 7% to 23%, with the mean value of 13.4%. Most frequently, the greatest differences in grading were observed for the middle sieves, from 2 mm to 5.6 mm. High variability in RA grading will limit the effective quantity of reusable RA, due to the permissible deviations in grading of the newly produced asphalt mixtures. Comparison of the "white grading curves" for materials that displayed the greatest and the lowest variabilities in particle size distribution is shown in Fig. 2.

Comparisons of particle size distribution between milled RA samples and cored specimens (in terms of their "white curves") proved interesting. Grading of aggregate from RA and from its corresponding cored specimen was similar in two cases; however, it proved different in three cases, with differences reaching as much as 27%. The greatest differences were observed for the finest mixture, SMA 8.

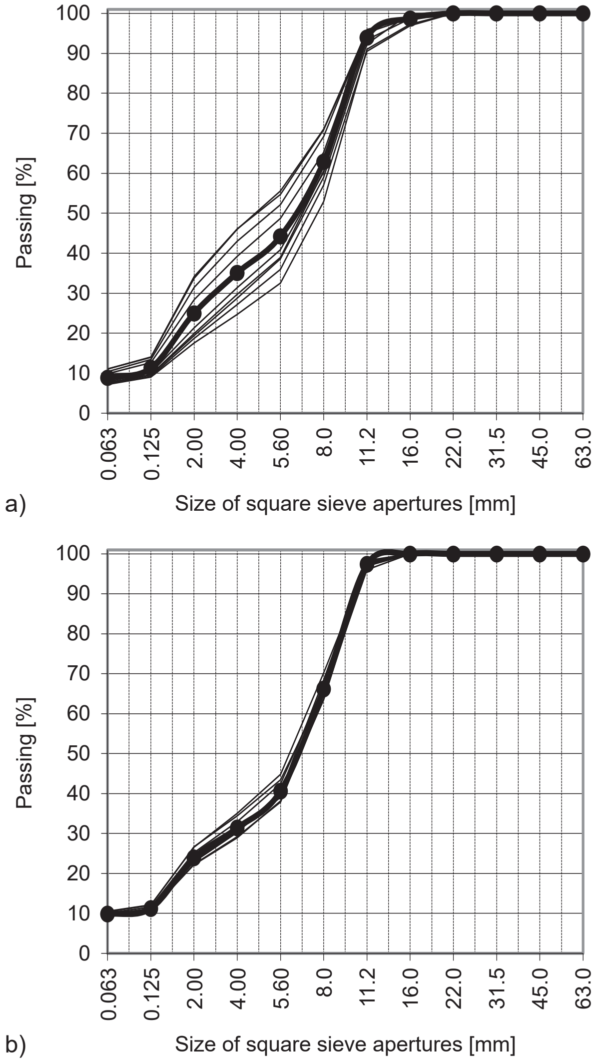


Fig. 2. Grading of RA after bitumen extraction ("white grading curve") for materials displaying grading variability: a) the greatest (RA_11_DK6), b) the lowest (RA_11_S7)

In summary, the performed tests indicated that the design of new hot-mix SMA mixtures incorporating RA should be based on grading of RA after bitumen extraction (its so-called "white grading curve"). In this case, design of new SMA based on grading results of core specimens extracted from the old pavement is incorrect. In Figs. 1 and 2 thick line represents the mean value, while thin lines represent the single test result.

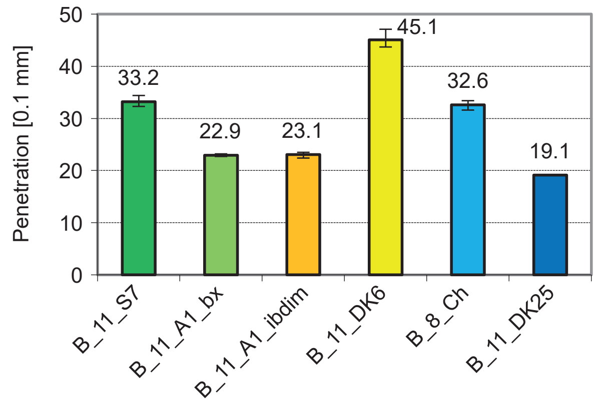
3.3. TESTING OF BITUMENS RECOVERED FROM RA

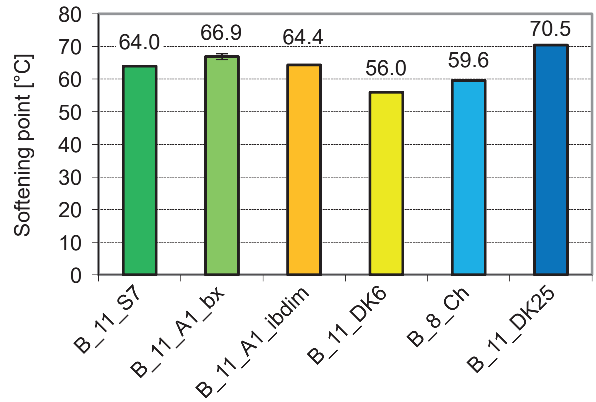
Testing of bitumens recovered from RA encompassed both the basic classification tests according to PN-EN standards and advanced rheological and fatigue tests according to PN-EN and international standards. Additionally, non-standard tests were performed, including relaxation tests [26] and trials with the BTSV (ger. *Bitumen-Typisierungs-Schnell-Verfahren*) assessment methodology based on different parameters from the DSR device [27-28]. Only selected test results are presented herein.

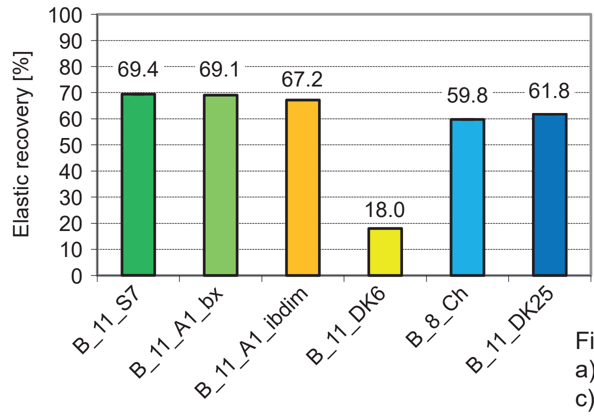
Results of the basic classification tests according to PN-EN, such as penetration, softening point, elastic recovery and breaking point, are shown in Fig. 3. Advanced test results are shown in Fig. 4 (Black diagrams) and Fig. 5 (BTSV classification).

Level of penetration observed for modified bitumens extracted from RA was usually lower than that of corresponding new (freshly produced) bitumens subjected to short-term RTFOT aging. Among modified bitumens, the lowest penetration value was displayed by the bitumen obtained from the oldest layer of the DK25 section; the highest penetration was noted for the newest section of Chodecka Street. In the case of neat paving-grade bitumen (B_11_DK6), its penetration corresponded to typical values obtained in laboratory after RTFOT aging. Softening point of all the bitumens extracted from RA was on the same level as after RTFOT aging. Elastic recovery (which is required only for modified binders) of recovered bitumens proved considerably lower than in the case of new bitumen subjected to RTFOT aging. In terms of breaking point of bitumens extracted from RA, it is observable that for the neat paving-grade bitumen 50/70 this parameter remained on the level still meeting the requirements for new paving-grade bitumen (≤−8°C). However, breaking point values of modified bitumens in most cases (4 out of 5) proved higher than the acceptable limit for new modified bitumens (≤−15°C), with one exception, in which breaking point equaled −15°C.

Results from DSR device shown in the form of Black diagrams show trends typical for modified bitumens – the slope of the plot is lower in the range corresponding to lower complex modulus values. This feature indicates that the polymer network is activated in stress transfer when temperatures are high or frequencies are low – confirming polymer modification. Values plotted for bitumen B_11_DK6 differ from other plots, because this particular bitumen is a paving-grade (unmodified) bitumen. The most elastic response is displayed by sample B_11_25, as shown by the lowest values of phase angle. Among the modified bitumens, the highest phase angle and the greatest viscous component is displayed by bitumen B_8_Ch. It should be noted, however, that these differences are not substantial.







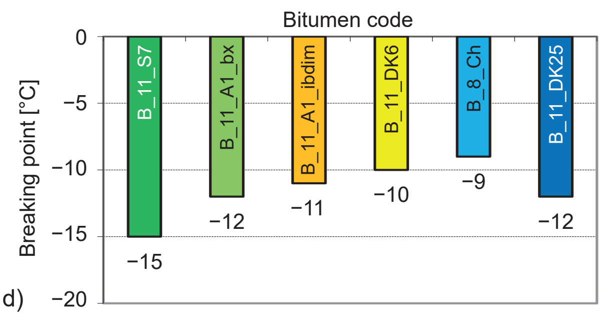


Fig. 3. Classification test results for bitumens recovered from RA: a) penetration (acc. to PN-EN 1426), b) softening point (acc. to PN-EN 1427), c) elastic recovery (acc. to PN-EN 13398), d) Fraass breaking point (acc. to PN-EN 12593)

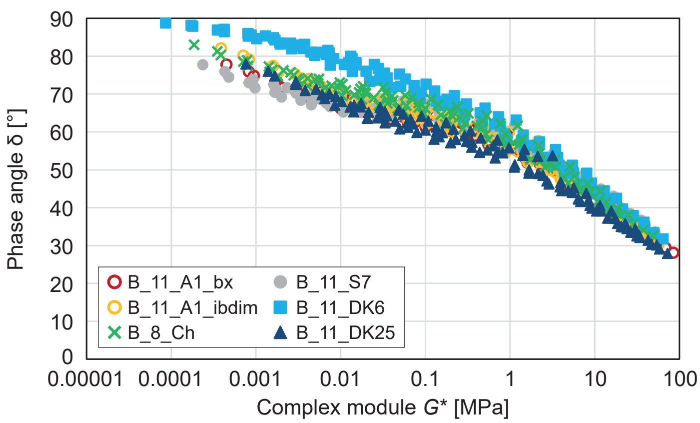


Fig. 4. Results of complex modulus G^* and phase angle δ (shown as the so-called "Black diagrams") for bitumens recovered from RA

Based on the data presented in Fig. 5, it is observable that the results obtained for modified bitumens recovered from RA may be grouped in three distinct clusters. The greater the distance of a given data point from the typical area corresponding to its bitumen type, the greater the aging indicated by this data point. The greatest aging was noted for recovered bitumen B_11_DK25. Slightly lower aging values were observed for recovered bitumens B_11_A1(1) and B_11_A1(2). The lowest degree of aging (the lowest observed values) was obtained for recovered bitumens B_11_S7 and B _11_S51. For now, however, there is no comparison base available to precisely evaluate the level of aging. Therefore, recovered bitumens may only be compared in qualitative terms (i.e. more aged, less aged). Similarly to the basic tests, BTSV testing also indicated that bitumen B_11_DK25 (extracted from the oldest section) displayed the greatest aging. According to BTSV, bitumen B_11_S7 has aged the least among modified bitumens; unfortunately, information about the exact age of pavement from which it was extracted is unavailable. Surprisingly, neat paving-grade bitumen B_11_DK6 recovered from RA still exhibits values within the range typical of new unaged bitumens, despite having been subjected to long-term aging on the road section. The observed differences between the materials investigated may result not only from variations in the long term aging rate but also from differences in the initial unaged or short-aged properties of the binder at the various sites.

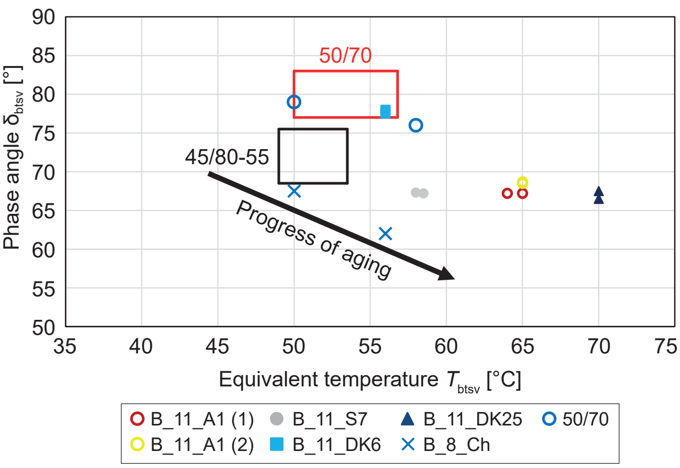


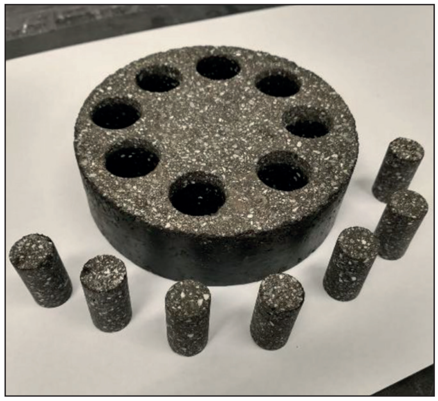
Fig. 5. BTSV test results for bitumens recovered from RA

Trial application of the BTSV methodology provided promising results. However, there is no result database available at the moment that would enable determination of specific and binding criteria.

3.4. TESTING OF FINE ASPHALT MIXTURES (FAM) RECOVERED MECHANICALLY FROM RA

The idea of FAM recovery consisted in its mechanical separation from RA (as opposed to chemical separation, i.e. use of solvents). Fine asphalt mixture (sometimes referred to as "bituminous mortar") includes bitumen with various additives, filler (including stabilizing fibers, where applied) and fine aggregate fractions below 2 mm. Research works encompassed development of FAM recovery procedure comprising several steps, which have been described in detail in the manual and research reports. The process consists in cooling loose mixture to the temperature of <−20°C, granulation of the cooled mixture in a laboratory granulator and sieving the material. Research included trials with various manners of granulation and sample formation, based on similar tests described in the literature [29]. Results of tests performed on cylinders cored from larger cylindrical plates (Fig. 6a) are shown herein as an example. Before testing, the specimens were fitted with special steel plates, which enabled their mounting in the device (Fig. 6b).

a)



b)

Fig. 6. Example cylindrical FAM specimens of 12 mm in diameter and 25 mm in height: a) after being cored from a larger plate; b) mounted in the DSR device

Research works included adjustment of the following DSR procedures from bitumen testing to FAM testing: determination of complex modulus and phase angle, fatigue resistance in linear amplitude sweep (LAS) and stress relaxation at low temperatures. Test procedures have been described in detail in the research report [30]. This article only includes selected results of the complex modulus tests.

Complex modulus and phase angle results are shown in the form of Black diagrams in Fig. 7. The shape of the plots is similar across all the analyzed materials (assuming the form resembling a downward-opening parabola); however, it visibly differs from the Black diagrams plotted for bitumens (Fig. 4). FAMs are significantly stiffer than bitumens, as indicated by higher values of G^*; they are also more elastic, as shown by lower phase angle values. The downward bend in the plot around the range of lower G^* values (a decrease in δ) reflects greater contribution of mineral aggregate to load transfer at low temperatures, which is not observed in the results for extracted bitumen itself.

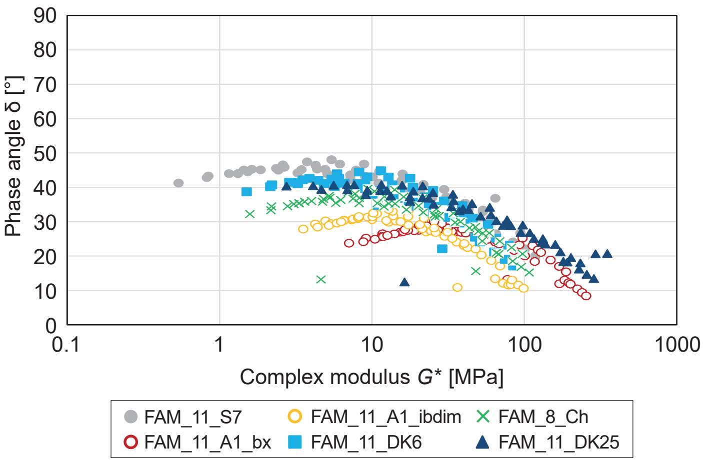


Fig. 7. Results of complex modulus G^* and phase angle δ (shown as the so-called "Black diagrams") for fine asphalt mixtures (FAM)

A shift of the plot towards the bottom right part of the chart reflects stiffening of FAM and may indicate more advanced long-term aging. It indicates that RAs obtained from DK25 and A1 display the greatest degree of aging, while RA obtained from S7 has aged the least. This observation is in agreement with the BTSV test assessment of bitumens (Fig. 5).

4. CONCLUSIONS

Based on the literature review, laboratory investigations, and analysis of the results obtained, the following conclusions were drawn:

1. Use of RA originating from recycling of SMA wearing courses is considerably limited in many countries due to the high risk of failure and its potential consequences. This is related to strict material requirements and technological difficulties connected with SMA properties.
2. In some countries production of SMA for wearing courses using the hot recycling technology is prohibited; in others (e.g. Great Britain, Germany) it may be accepted in individual cases based on detailed testing.
3. Research performed on Polish SMA mixtures reclaimed from wearing courses on national roads (13-20 years of service) confirmed their potential for reuse in production of new SMA mixtures based on the hot recycling technology in mixing plants. The materials were characterized by good aggregate skeleton and dominant share of polymer modified bitumens.
4. Analysis of not processed RAs obtained from wearing courses indicated considerable variability in particle size distribution and binder content, which may limit their reuse in greater quantities without the risk of exceeding grading tolerances and deviating from target properties of new mixtures. It was noted that homogenization of milled RA and its direct use in composition testing was necessary; testing on cored specimens alone was insufficient. When designing SMA in hot recycling technology, it is advisable to use data from particle size distribution tests performed on RA after bitumen extraction (so-called "white grading curve").
5. Bitumens extracted from reclaimed SMA displayed signs of aging, including: lower penetration, decreased elastic recovery, increased stiffness and deteriorated resistance to low-temperature cracking. Despite the small number of samples (6 road sections), several tests confirmed that aging processes did progress with service time.
6. While the increased stiffness and low phase angle may be favorable in terms of resistance to rutting, the same parameters may adversely affect resistance to fatigue and low-temperature cracking. These observations imply the need for composition adjustments or additional modification of bitumen in new SMA mixture produced using hot recycling technology.
7. Analysis of BTSV equivalent temperature proved useful for aging evaluation, indicating a need for creation of national database of bitumens typically used in Poland. This need was pointed out in the final recommendations from the conducted research project.
8. Important aspects of the research works included development of innovative procedures for separation of fine asphalt mixture (FAM) from reclaimed asphalt,

granulated reclaimed asphalt (RA/GRA) and asphalt mixtures. The recovered material was used for preparation of FAM specimens for dynamic shear rheometer (DSR) tests.

9. New test procedures were developed for testing of FAM in the DSR device, mostly based on corresponding procedures for bitumens. New test procedures for rheological parameters of FAM significantly broaden the quality assessment of recovered material; most importantly, they enable comprehensive evaluation of material composition without the use of solvents. The main advantage of this approach over testing of bitumens recovered by extraction is the possibility of evaluating blending and compatibility of the old and new binder in the newly designed SMA mixture.
10. One of the primary recommendations from the rSMA2 project pertains to collection of a result database using the new test procedures, which will broaden the knowledge of component compatibility (including recycling agents) and enable determination of requirements in future.
11. Laboratory test results confirmed the need for precise design of mixtures incorporating RA and good control over the quality of reclaimed material to ensure the required long-term performance of the pavement.
12. Moreover, the research project has provided new tools that will enable usage of greater quantities of RA in SMA mixtures without increasing the risk of premature pavement degradation.

ACKNOWLEDGEMENT

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Ocena jakości destruktu asfaltowego pochodzącego z mieszanek SMA z asfaltem drogowym i modyfikowanym polimerem

Streszczenie: Recykling na gorąco mieszanek mineralno-asfaltowych w otaczarkach jest jedną z metod pozwalającą w sposób zrównoważony produkować nowe mieszanki mineralno-asfaltowe, wykorzystując destrukt asfaltowy pochodzący z rozbiórek już eksploatowanych nawierzchni. O ile wykorzystanie recyklingu na gorąco w warstwie wiążącej lub w warstwie podbudowy zaczyna być typowym rozwiązaniem, o tyle wykorzystanie tej technologii do warstw ścieralnych jest zagadnieniem nie w pełni rozpoznanym. W chwili obecnej zbliża się okres wymiany warstw ścieralnych na polskich drogach ruchu szybkiego, budowanych w latach 2010-2013, na których powszechnie stosowano mieszanki SMA z asfaltami modyfikowanymi polimerem. Jednym z głównych problemów związanych z recyklingiem na gorąco jest ocena jakości materiału, pochodzącego z rozbiórek tych warstw i ocena czy nadaje się on do wykorzystania w technologii recyklingu na gorąco przy produkcji nowych warstw ścieralnych z SMA. Dotyczy to zarówno oceny składu destruktu jak i jakości samego lepiszcza w destrukcie, poddanego procesom starzenia. W artykule przedstawiono rezultaty prac w ramach projektu badawczego RID II rSMA2, którego celem była między innymi ocena jakości 6 destruktów asfaltowych, pochodzących z rozbiórek warstw ścieralnych z mieszanki SMA8 i SMA11. W pięciu destruktach asfaltowych zastosowany został asfalt modyfikowany polimerem, w jednym zaś przypadku zastosowano asfalt drogowy (niemodyfikowany). W ramach oceny jakości destruktu asfaltowego wykonano badania składu destruktu, uziarnienia odzyskanego materiału mineralnego, oceniono cechy asfaltów odzyskanych destruktu oraz zapraw asfaltowych (mieszaniny asfaltu oraz frakcji pyłowej i piasku). Dokonano też analizy uzyskanych wyników badań. Do oceny asfaltów odzyskanych wykonano badania w oparciu o procedury europejskie oraz amerykańskie, w przypadku materiału mineralnego oceniano tak zwane białe oraz czarne krzywe uziarnienia, a także po raz pierwszy w Polsce dokonano oceny zapraw asfaltowych przygotowanych z pozyskanych granulatów.

Słowa kluczowe: granulat asfaltowy, recykling na gorąco, relaksacja, SMA, zaprawa asfaltowa.