STANISŁAW MAJER[1)]
BARTOSZ BUDZIŃSKI[2)]

USE OF RECLAIMED ASPHALT PAVEMENT (RAP) AS AGGREGATE FOR PRODUCTION OF CEMENT-BOUND GRANULAR MIXTURES

WYKORZYSTANIE DESTRUKTU ASFALTOWEGO JAKO KRUSZYWO DO MIESZANEK STABILIZOWANYCH SPOIWEM CEMENTOWYM

STRESZCZENIE. Destrukt asfaltowy może stanowić półprodukt w nowych mieszankach mineralno-asfaltowych jak i być wykorzystywany do mieszanek w technologii recyklingu na zimno. Pierwsza technologia jest właściwa w sytuacji kiedy destruktu jest jednorodny i pochodzi z nawierzchni o znanych lub możliwych do ustalenia parametrach. Druga technologia może być wykorzystana do przetwarzania starych nawierzchni asfaltowych, o zmiennych parametrach (różne warstwy z różnym lepiszczem), które nadal dominują na drogach lokalnych. Technologie na zimno z różnych względów nie zawsze mogą być zastosowane, np. w sytuacji, której przewidywany zakres prac jest niewielki. Alternatywą może być wykorzystania destruktu asfaltowego jako kruszywo do wykonania mieszanek stabilizowanych spoiwem. Autorzy przeprowadzili program badawczy, który miał na celu określenie parametrów mieszanek stabilizowanych spoiwem cementowym z wykorzystaniem destruktu. W badaniach określono takie cechy jak: gęstość, wytrzymałość na ściskanie w różnych temperaturach, wytrzymałość na rozciąganie przy rozłupywaniu, badanie stabilności wg Marshalla. Na podstawie przeprowadzonych badań, ustalono, że destrukt asfaltowy może zostać z powodzeniem wykorzystany jako kruszywo do produkcji mieszanki związanej spoiwem cementowym.

SŁOWA KLUCZOWE: destrukt asfaltowy, mieszanka związana spoiwem cementowym, wytrzymałość na ściskanie, stabilność, recykling.

ABSTRACT. Asphalt concrete from old pavements may be reused as a semi-product in production of new bituminous mixtures or recycled in place using the cold-in-place recycling method. The first of the two above-mentioned recycling methods is appropriate when dealing with uniform materials, coming from bituminous pavements whose parameters are either known or can be reliably determined. The second method comes into play when dealing with old pavements in which the mixes used for the respective layers included different bituminous binders, typical of local roads in Poland. Smaller size jobs are an example of works for which cold-in-place recycling methods are not practicable. Fortunately, there is an option of using the old asphalt or reclaimed asphalt pavement (RAP) as aggregate in production of cement-bound mixtures. This paper describes the study on determination of their properties. These properties included density, compressive strength at different temperatures, split tensile strength and Marshall stability. The results of the relevant tests, which were carried out as part of this study, showed suitability of RAP as aggregate used for production of cement stabilised base mixtures.

KEYWORDS: reclaimed asphalt pavement (RAP), cement bound granular mixture, compressive strength, Marshall stability, recycling.

DOI :10.7409/rabdim.023.033

1) West Pomeranian University of Technology, Szczecin, Poland; majer@zut.edu.pl ✉
2) West Pomeranian University of Technology, Szczecin, Poland, bartosz.budzinski@zut.edu.pl;

*) An extended version of the article from the Conference "Modern Road Pavements – MRP'2023" – Recycling in road pavement structures co-edited by Martins Zaumanis and Marcin Gajewski, published in frame of the Ministry of Education and Science project No. RCN/SP/0569/2021/1

1. INTRODUCTION

1.1. USE OF RECLAIMED ASPHALT PAVEMENT IN CEMENT BOUND GRANULAR MIXTURES

In cement-bound mixtures RAP was used primarily in Portland cement (PC) bound concretes [1–5], including structural concretes. The studies carried out so far show that RAP addition decreases the compressive strength of cement concretes [2–6], compared to mixtures containing solely natural aggregate. This may be due to poor bond to the bitumen that covers the RAP aggregate grains, i.e. within the aggregate/ cement matrix interfacial zone [4]. However, 25% addition of RAP decreased the compressive strength by only 9%, which is not to be considered a large drop [5]. The specimens containing RAP had different failure mode than the control. The inclination of the force-displacement curve indicates a lower E-modulus value, and thus a greater deformation capacity [7]. According to Iwański et al., RAP may be successfully used in PC pavement courses [8]. However, Vaitkus et al. pointed out to the risk of cracking of roadbases made of mixtures in which RAP is bound solely by Portland cement. This cracking is bound to propagate to the overlying bituminous layers [9]. CBR tests showed a decrease of the CBR value as the amount of RAP added to the mixture increased [10]. Still, the CBR values remained within the acceptable range. Taha et al. made a point of the economic potential of the use of RAP in mixtures designed for cement stabilised sub-base courses [11].

1.2. RATIONALE FOR THIS RESEARCH

So far, the research projects in this area focused primarily on mixtures containing bitumen emulsion or foamed bitumens [12–16]. The relevant technologies allowed reusing of both pure bituminous and tar-containing asphalts. The objective of the research proposed in this paper was to determine the suitability of RAP as an ingredient of mixtures designed for lower pavement courses. Based on this determination, this material could then be used in hydraulically-bound mixtures. To this end, the selected mixtures containing RAP, Portland cement, natural aggregate and fly ash were tested to determine the relevant strength parameters.

2. MATERIALS AND METHODS

2.1. THE TESTED BITUMINOUS MIXTURES

Nine mixtures containing different amounts of RAP, Portland cement, fly ash and medium sand as natural aggregate were initially used (Table 1). They were designed to maximise the amount of RAP contained in the mixture. The relevant aggregate grading curves of these mixtures are displayed in Fig. 1. Figure 2, in turn, shows the grading curves of three groups of the tested mixtures, containing RAP only, RAP + fly ash and RAP + medium sand. Besides RAP, the tested mixtures contained fly ash and CEM II/B-M(S-LL) 32.5R composite Portland cement.

Table 1. The tested bituminous mixtures

No. Mixture	Component content			
	RAP	Cement	Ash	Sand
-	[%]	[%]	[%]	[%]
1	95	5	-	-
2	94	6		
3	93	7		
4	90	5	5	-
5	89	6		
6	88	7		
7	85	5	-	10
8	84	6		
9	83	7		

2.2. TESTING OF HYDRAULICALLY STABILISED MIXTURES

Compressive strength

Compressive strength was tested as per EN 13286-41. Cylindrical specimens were used in the test, prepared in forms the size of 150 mm in diameter by 120 mm high. Proctor compaction with standard compaction effort was used to consolidate the specimens. The determinations were done on four specimens. The load increase rate used in the test was intended to cause failure of the specimens within 60 sec. from the beginning of load application. In the first series specimens representing nine different mixes were tested after 7, 28 and 56 days of curing. The test temperature was 20°C. Based on the compressive test results, three mixtures were chosen for the further full-

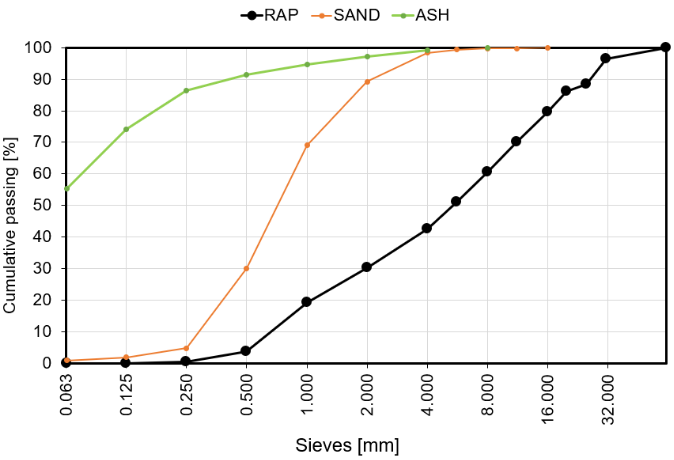

Fig. 1. Mixture components grading curves

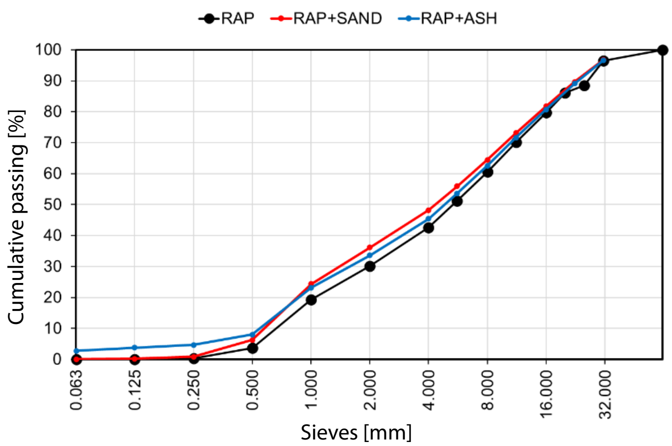

Fig. 2 Mixes grading curves

scope testing. These three mixtures were subsequently tested after 28 days of curing at four different test temperatures: 0°C, 10°C, 30°C, 40°C.

Split tensile strength

In the split tensile strength test 15×15×15 cm cubes were used, prepared by compacting in three lifts by Proctor rammer at standard compaction effort. The determinations were done on four specimens. Only the mixes that had been pre-selected based on the compressive strength results were tested at this step. The specimens were cured for 7 and 28 days respectively, and then a continuous load was applied axially to the surface via two steel separators. The test temperature was 20°C.

Marshall stability and deformation

The specimens were compacted in the Marshall compactor by 50 blows applied on each side, as per EN 12697-30. The specimens were 63.5 mm high and 101.6 mm in diameter, a typical size of Marshall test specimens. They were cured for 7 and 28 days respectively, and then tested at 60°C test temperature.

3. TEST RESULTS AND DISCUSSION

Compressive strength

The compressive strengths obtained on specimens cured for 28 days at 20°C ranged from 3.1 MPa (mixture No. 1) to 7.6 MPa (mixture No. 6). This indicates over two-fold difference. The recycled mixtures did not show any significant increase in strength between the 28th and 56th day of curing. The only exception to that was mixture No. 1. Based on the obtained results, the following three mixtures with similar compressive strength values were selected for further testing: No. 3 – including RAP only, No. 5 – including RAP and fly ash and No. 9 – including RAP and medium sand. The underlying idea was to have one representative mixture from each group.

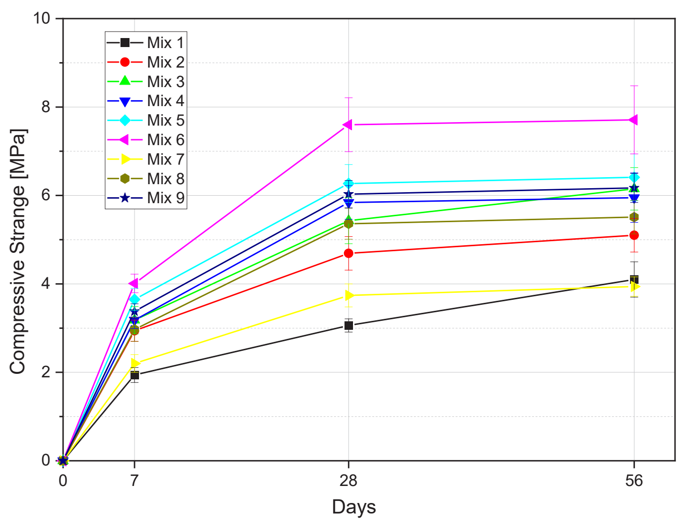

Fig. 3. Compressive strength of all the tested recycled mixtures

Now the selected mixtures were tested at different temperatures (Fig. 4). A strong linear relationship of R^2=0.96-0.99 was obtained for the effect of temperature for the mixtures including sand and fly ash. The mixtures including only RAP and 7% Portland cement obtained lower compressive strength values at 0°C and 10°C. Also a different failure behaviour i.e. abrupt brittle failure was observed in this case. This failure mode indicates a beneficial effect of natural aggregate or fly ash on the pavement durability over the whole operating temperature range. Taking into account the risk of cracking, especially at low temperatures,

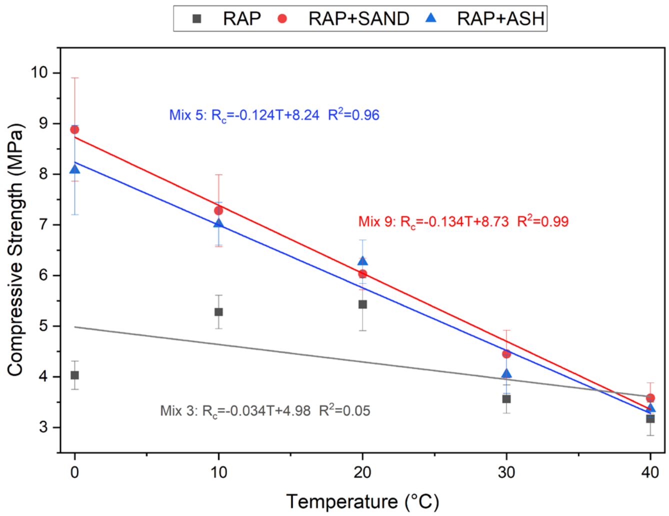

Fig. 4. Compressive strength of the selected mixtures at five different test temperatures

we recommend to use RAP or natural aggregate/ fly ash and cement mixtures for the sub-base course placed under the crushed aggregate roadbase layers. The role of this sub-base layer would be to mitigate reflective cracking.

Split tensile strength

The obtained split tensile strength values are given in Fig. 5 below. The highest values were obtained for the mixture including RAP, fly ash and cement and the lowest for the mixture that included solely RAP and Portland cement.

Marshall stability and deformation

The Marshall stability values obtained on the specimens cured for 7 days (Fig. 6) and 28 days indicate deformation capacity of the analysed mixtures. The load/ displacement curve of the 7-day specimens had a smaller inclination than the curve obtained after 28 days (Fig. 7).

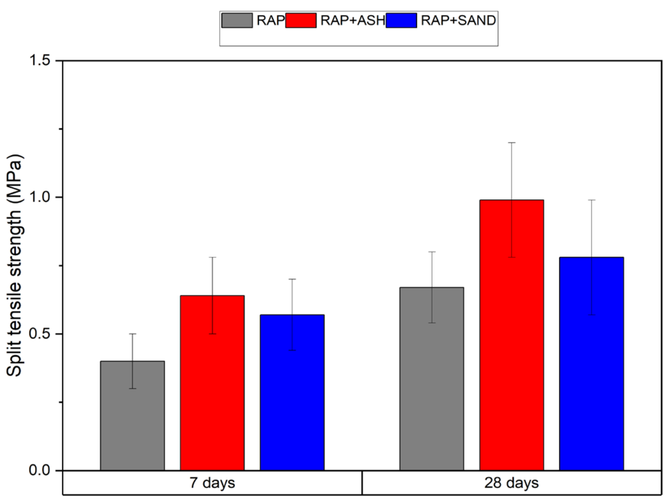

Fig. 5. Split tensile strength

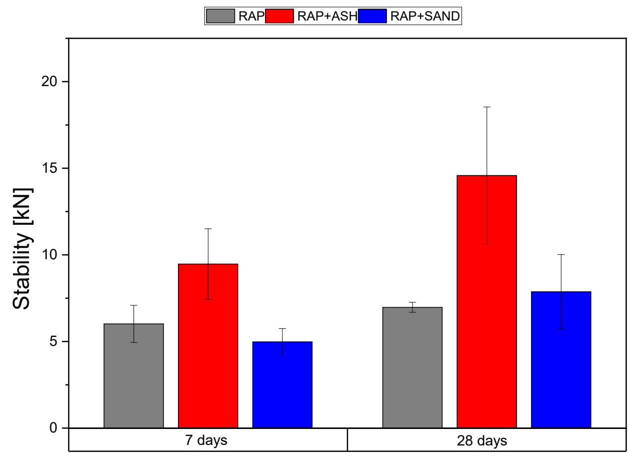

Fig. 6. Marshall stability after 7 and 28 days

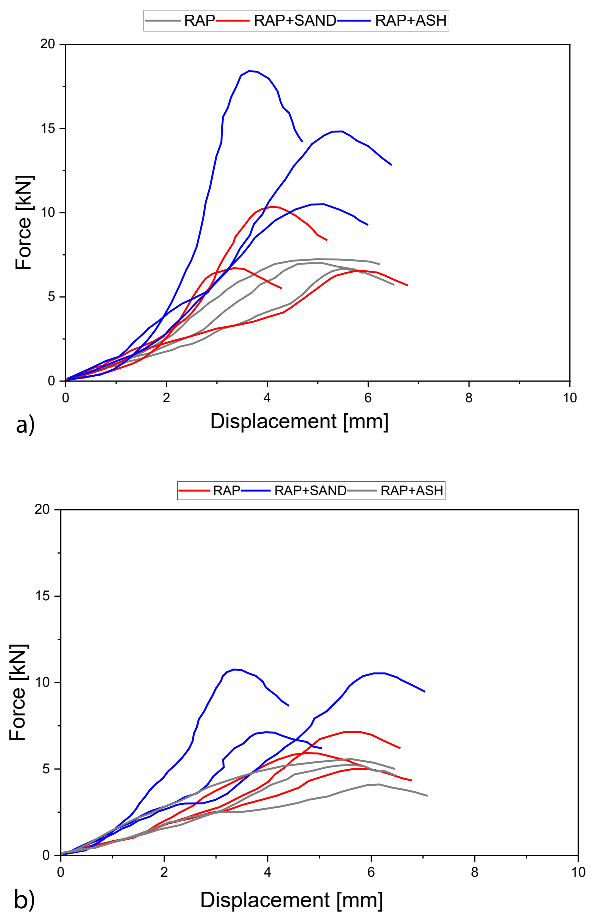

Fig. 7. Marshall stability after 7 and 28 days represented by load-displacement curves

4. FINAL CONCLUSIONS

This study tested cement-aggregate mixtures including reused, i.e. RAP aggregate. The results allowed us to conclude that:

- cement-bound aggregate mixtures including RAP characterized by below 10 MPa i.e. low compressive strength may be a good choice as a material for construction of roadbase and sub-base layers of road pavements,
- In these mixtures RAP should preferably be accompanied by fine aggregate (such as medium sand or fly ash) in order to reduce stiffness at low temperatures,
- the layer placed on top of cement-bound RAP mixtures, possibly including natural aggregate/ fly ash, should preferably be unbound i.e. mechanically compacted roadbase layer.

The promising results of this study call for further research on the mixtures containing RAP, natural aggregates, fly ash and cement. Experimental determination of parameters used in mechanic-empirical design methods, i.e. stiffness modulus and fatigue resistance should be part of these future studies.

REFERENCES

[1] *Abraham S.M., Ransinchung G.D.R.N.*: Influence of RAP Aggregates on Strength, Durability and Porosity of Cement Mortar. Construction and Building Materials, **189**, 2018, 1105–1112, DOI :10.1016/j.conbuildmat.2018.09.069

[2] *Andrew B., Buyondo K.A., Kasedde H., Kirabira J.B., Olupot P.W., Yusuf A.A.*: Investigation on the Use of Reclaimed Asphalt Pavement along with Steel Fibers in Concrete. Case Studies in Construction Materials, **17**, e01356, 2022, DOI: 10.1016/j. cscm.2022.e01356

[3] *Debbarma S., Singh S., Ransinchung R.N.G.D.*: Laboratory Investigation on the Fresh, Mechanical, and Durability Properties of Roller Compacted Concrete Pavement Containing Reclaimed Asphalt Pavement Aggregates. Transportation Research Record: Journal of the Transportation Research Board, **2673**, 10, 2019, 652–662, DOI: 10.1177/0361198119849585

[4] *Paluri Y., Heeralal M., Pancharathi R.*: A Study on the Use of Reclaimed Asphalt Pavement Aggregates in Pavement Quality Concrete. Cement, Wapno, Beton, **24**, 6, 2019, 421–431, DOI: 10.32047/CWB.2019.24.6.1

[5] *Panditharadhya B.J., Ramachandra S.*: Utilization of RAP Aggregates in Pavement Quality Concrete. 2015

[6] *Senesavath S., Salem A., Kashkash S., Zehra B., Orban Z.*: The Effect of Recycled Tyre Steel Fibers on the Properties of Concrete. Pollack Periodica, **17**, 1, 2022, 43–49, DOI: 10.1556/606.2021.00388

[7] *Hassan K.E., Brooks J.J., Erdman M.*: The Use of Reclaimed Asphalt Pavement (RAP) Aggregates in Concrete. in: Waste Management Series. Elsevier, **1**, 2000, 121–128

[8] *Iwański M., Linek M., Nita P., Piotrowska P., Remišová E.*: Assessment of Suitability of Reclaimed Asphalt Pavement Material for Use in Cement Concrete Pavements. Roads and Bridges – Drogi i Mosty, **22**,1, 2023, 63–80, DOI: 10.7409/rabdim.023.004

[9] *Vaitkus A., Gražulytė J., Juknevičiūtė-Žilinskienė L., Andrejevas V.*: Review of Lithuanian Experience in Asphalt Pavements Cold Recycling. in: “Environmental Engineering” 10th International Conference Vilnius Gediminas Technical University, Lithuania, 27–28 April 2017, DOI: 10.3846/enviro.2017.153

[10] *Seferoğlu A.G., Seferoğlu M.T., Akpınar M.V.*: Investigation of the Effect of Recycled Asphalt Pavement Material on Permeability and Bearing Capacity in the Base Layer. Advances in Civil Engineering, **2018**, 2018, 1–6, DOI: 10.1155/2018/2860213

[11] *Taha R., Al-Harthy A., Al-Shamsi K., Al-Zubeidi M.*: Cement Stabilization of Reclaimed Asphalt Pavement Aggregate for Road Bases and Subbases. Journal of Materials in Civil Engineering, **14**, 3, 2002, 239–245, DOI: 10.1061/ (ASCE)0899-1561(2002)14:3(239)

[12] *Dołżycki B., Jaczewski M., Szydłowski C., Bańkowski W., Gajewski M.D.*: Analysis of Selected Mechanical Properties of Mineral-Cement-Emulsion Mixtures (MCE). Roads and Bridges – Drogi i Mosty, **22**, 1, 2023, 41–61, DOI: 10.7409/rabdim.023.003

[13] *Iwański M.M., Chomicz-Kowalska A., Maciejewski K.*: Resistance to Moisture-Induced Damage of Half-Warm-Mix Asphalt Concrete with Foamed Bitumen. Materials, **13**, 3, 654, 2020, DOI: 10.3390/ma13030654

[14] *Kukiełka J., Bańkowski W.*: The Experimental Study of Mineral-Cement-Emulsion Mixtures with Rubber Powder Addition. Construction and Building Materials, **226**, 2019, 759–766, DOI: 10.1016/j.conbuildmat.2019.07.276

[15] *Chomicz-Kowalska A., Maciejewski K.*: Multivariate Optimization of Recycled Road Base Cold Mixtures with Foamed Bitumen. Procedia Engineering, **108**, 2015, 436–444, DOI: 10.1016/j.proeng.2015.06.168

[16] *Iwański M., Chomicz-Kowalska A., Maciejewski K., Iwański M.M., Ramiączek P., Stępień J.*: Evaluation of Mixture Grading and Binder Composition Effects on the Characteristics of Cold-Recycled Mixtures with Foamed Bitumen. Transportation Research Procedia, **72**, 2023, 2776–2783, DOI: 10.1016/j.trpro.2023.11.820