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Testing the parameters of hot-mix asphalt incorporating asphalt granulate

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Abstract: In recent years, the scale of use of recycled asphalt pavements for the production of hot mix asphalt (HMA) in Poland has been much smaller than in most other developed countries. Recently issued legal regulations and technical guidelines give hope for significant progress in this field. The article aims to investigate the parameters of HMA containing asphalt granulate (AG) in the context of using locally available materials and increasing the percentage of AG above the maximum amount recommended by current guidelines. It was found that the content of up to 40% AG used as an aggregate replacement does not significantly worsen the key parameters of HMA intended for the construction of an asphalt concrete subbase. The use of asphalt granulate may also result in a significant (up to approximately 50%) reduction in the consumption of road bitumen for the production of HMA.

Keywords: waste management, hot-mix asphalt, reclaimed asphalt pavement, asphalt granulate

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Introduction

Taking into account the current state of the Earth's natural resources, the management of post-demolition materials and post-production waste has become a necessity. Activities related to the recovery and recycling of materials do not always bring direct economic benefits, but from the point of view of reducing the environmental impact, they are justified (Tomov & Velkoska, 2022). In road construction, recycled materials can be used primarily in aggregate subbases, concrete pavements and asphalt pavements.

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Crushed concrete or artificial aggregate from blast furnace slag are increasingly used in road subbases as a natural aggregate replacement (Harwat & Respondek, 2023; Lis & Nowacki, 2022).

With regard to concrete, several directions of research can be distinguished, primarily: replacing cement with another binding material (Dębska et al., 2021), using waste as dispersed reinforcement (Helbrych, 2021) and using various waste materials as an aggregate replacement (Jura & Ulewicz, 2021; Pietrzak & Ulewicz, 2023).

In the case of asphalt mixtures, some waste materials, primarily rubber granules, can beneficially modify the technical parameters of this material (Ansari et al., 2023; Yu et al., 2023). Research is also being carried out on the use of processed reclaimed asphalt shingles (RAS) in the composition of the mixture. Such studies have been described, among others, in (Buss et al. 2014; Zieliński, 2022). However, the main aspect, in terms of ecology, is the management of reclaimed asphalt pavement (RAP) obtained primarily by milling used road pavements. RAP can be used as a component of asphalt mixture as well of cement concrete. Asphalt mixture using RAP was first produced in the USA in 1915. The shortage of road materials after World War II resulted in the development of recycling asphalt pavements especially in Western Europe, Asia and North America (*Remixing*, 2023). For example, currently in Germany 70-80% of recycled waste is reused (Ruttmar & Koźlarek, 2018). Intensive research in this field has been carried out for many years. Recently published, among others are: Abdel-Jaber et al. (2022); Andrew et al. (2022); Karthikeyan et al. (2023); Ołdakowska & Ołdakowski (2021); Xiao et al. (2023).

The development of asphalt surface recycling in Poland has not kept pace with global trends. On a larger scale, a surface containing 25% recyclate was used for the first time for the renovation of the Warsaw-Katowice road and the construction of the A-4 motorway (Kukiełka, 2013). For many years, unprocessed RAP was mainly used, without proper research, to pave secondary roads, parking lots or even private properties.

A significant barrier to the wider use of processed RAP in recent years was the lack of appropriate equipment in asphalt plants (granulation crushers, suitably adapted mixing devices). There were also administrative barriers. According to legal regulations (Act, 2012), unprocessed RAP is considered waste (its storage, transport, etc. requires appropriate administrative decisions), while processed RAP, after meeting the appropriate technical requirements, can be used in road construction and is called asphalt granulate (AG). The specific implementing regulations (Regulation, 2021) and instructions (*RID*, 2019) related to this were issued only a few years ago.

The issuance of these regulations creates an opportunity to increase interest in the recycling of asphalt surfaces in Poland and, therefore, to increase the scale of production of asphalt mixtures incorporating AG.

The aim of the article is an instrumental testing of the parameters of hot mix asphalt (HMA) containing asphalt granulate in the context of using locally available materials (aggregate, RAP) and increasing the percentage of AG above the maximum recommended by the current guidelines. According to the current instructions regarding the parameters of asphalt mixtures (*WT-2*, 2014), the maximum content of AG in HMA is 30%.

1. Materials and methods

Three series of HMA samples were tested: a reference series (without AG), a series with 20% AG content (as an aggregate replacement) and a series with 40% AG content.

The base material for the production of the AG used in the research was RAP obtained from the renovated roads DK94 and DW790. This material was processed at the asphalt plant BITUM S.A. in Lipie Śląskie (Fig. 1). The origin of the remaining materials is shown in Table 1. Aggregate from local mines was used.

a) b)

Fig. 1. Asphalt granulate: a) RAP processing in the asphalt plant in Lipie Śląskie, b) asphalt granulate 0/16 used for tests (Source: *own photos*)

The main tests were preceded by control tests of the HMA component materials, including AG, in terms of meeting the requirements of the relevant subject standards.

Then, the composition of laboratory recipes for all three series was determined by extracting trial mixtures, as described in Section 2.

The main research program included:
– maximum density according to PN-EN 12697-5;
– bulk density according to PN-EN 12697-6;
– the air voids content and the voids content in the mineral aggregate filed with binder in a layer according to PN-EN 12697-8;
– permanent deformations resistance (method B, small apparatus – in the air) according to PN-EN 12697-22;
– water sensitivity according to PN-EN 12697-12 and (*WT-2*, 2014).

Most of the tests were performed in the laboratory at the asphalt plant BITUM S.A. in Lipie Śląskie. Due to the lack of appropriate equipment, tests for resistance to permanent deformation and water resistance were commissioned to an accredited external laboratory.

To determine the resistance to permanent deformation, two flat samples with dimensions of 305×305 mm and a thickness of 50 mm were made for each series. For the remaining tests, cylindrical samples 100 mm, 63 mm high were used. Three samples were made for each series.

2. Determining the composition of the tested mixes

The final HMA composition (laboratory recipe) for each series was determined by the extraction of the trial mixtures and appropriate composition adjustments. The tests were performed using an automatic ultrasonic extractor InfraTest. The composition of the mixture ingredients was selected so that all series were characterized by a similar content of soluble bitumen (3.7-3.8%) and all graphs of the aggregate mixture (AM) grading curves met the requirements (*WT-2*, 2014) for an asphalt concrete subbase layer. An example grain size curve is shown in Figure 2, the final composition of the mixtures is listed in Table 1.

Table 1. HMA recipes for individual test series (Source: *research report*)

Material	Origin	Test series					
		0% AG		20% AG		40% AG	
		Content [wt. %]					
		AM	HMA	AM	HMA	AM	HMA
Fine aggregate 0/2 (gabbro)	Braszowice	10	9.6	–	–	–	–
Continuous gradient aggregate 0/4 (dolomite)	Siewierz	19	18.3	12	11.7	12	11.8
Coarse aggregate 4/8 (dolomite)	Siewierz	23	22.1	15	14.6	12	11.8
Coarse aggregate 8/16 (dolomite)	Siewierz	19	18.3	23	22.4	12	11.8
Coarse aggregate 16/22 (dolomite)	Siewierz	25	24	27	26.2	23	22.6
Asphalt granulate 0/16	–	–	–	20	19.5	40	39.1
Limestone filler	Raciszyn	4	3.8	3	2.9	1	1
Road bitumen 35/50	–	–	3.9		2.7	–	1.9
Adhesive measure	–	–	0.3		0.3	–	0.3
	Sum	100	100	100	100	100	100

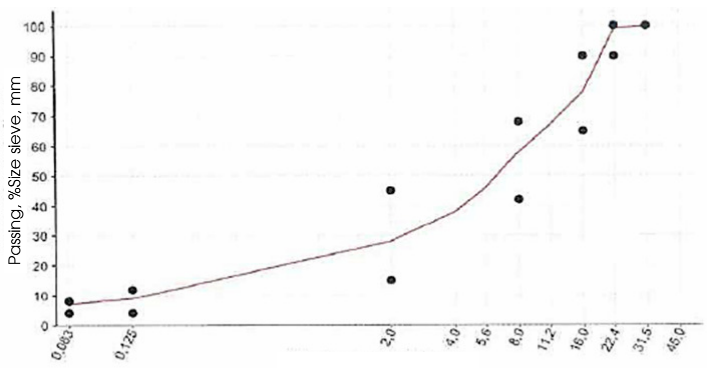

Fig. 2. Example grading curve of the aggregate mixture after extraction (40% AG content). The black points show the limit values according to the requirement (*WT-2*, 2014) (Source: *research report*, *printout*)

3. Results

Figure 3 shows the results of the HMA maximum density and bulk density tests. The values in the graph show the average values from three samples and the error bars represent the standard deviation (in Figures 4 and 6 – similarly). There was no significant effect of AG content on the tested values. Average values for samples with AG differ by no more than 1.1% from the reference series.

a) b)

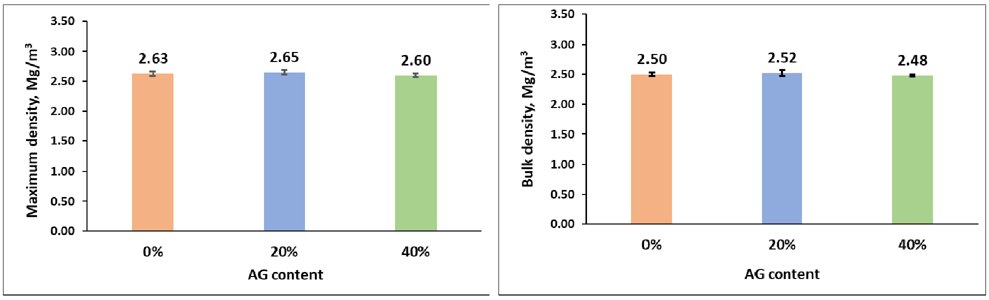

Fig. 3. Influence of AG content on: a) HMA maximum density, b) HMA bulk density (Source: *own research*)

A small impact of the AG content on the test results was also observed for the voids content in HMA (Fig. 4a). This showed a difference of up to 2.5% and for filling the voids with asphalt (Fig. 4b), a difference of up to 0.6%. The dashed line in Figure 4a and the following graphs indicates the limit values recommended by (*WT-2*, 2014) for the asphalt concrete subbase layer if any were specified.

a) b)

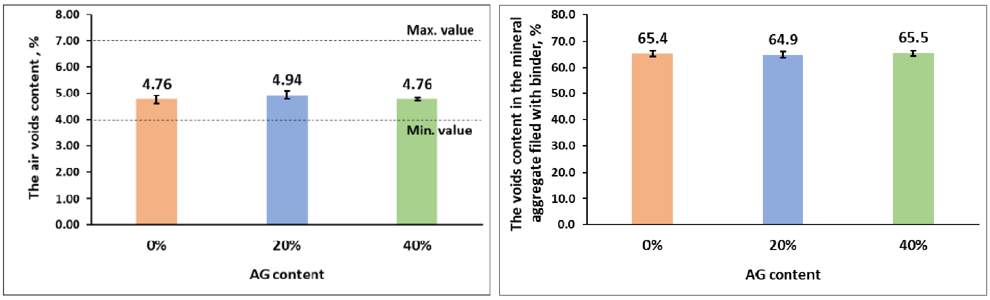

Fig. 4. Influence of AG content on: a) the air voids content, b) the voids content in the mineral aggregate filed with binder (Source: *own research*)

Figure 5 shows the results of tests performed with a wheel tracking test machine (small apparatus). The values in the graphs show the average values for two samples tested simultaneously. The sample with 20% AG showed the best resistance to permanent deformation (rutting). The rut depth was 23% smaller than for the reference series.

a) b)

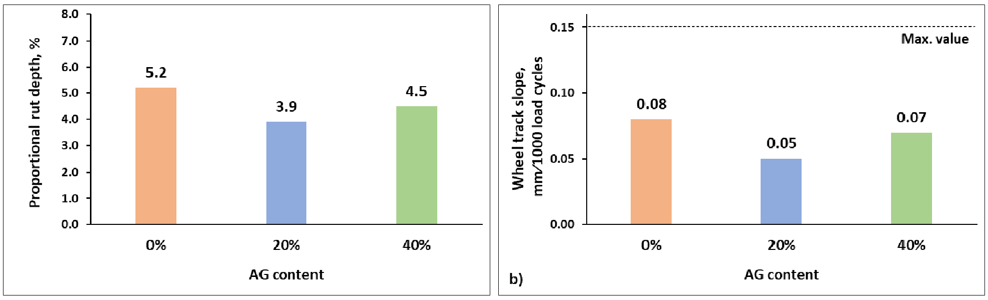

Fig. 5. Influence of AG content on: a) proportional rut depth, b) wheel track slope (Source: *own research*)

Figure 6 shows the results of water sensitivity tests. A reliable parameter here is the indirect tensile strength ratio ITSR, which shows the decrease in the strength of samples exposed to water and frost compared to "dry" samples. In this case, the AG content has a negative effect: The ITSR value is reduced by 8.2% for a content of 20% AG and by 9.7% for a content of 40% AG. Nevertheless, all three HMA series meet the requirements (*WT-2*, 2014).

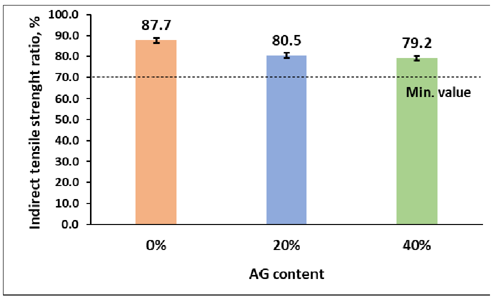

Fig. 6. Influence of AG content on indirect tensile strength ratio ITSR (Source: *own research*)

Conclusion

Reclaimed asphalt pavement (RAP) is a material that has long been used in many countries as a component of asphalt mixtures. However, in Poland, the scale of recycling of used asphalt pavements has been unsatisfactory for many years. The issuance of appropriate regulations and technical instructions regarding the processing of RAP in recent years, as well as the increase in the ecological awareness of road designers, gives hope for increased interest in using this material for pavement construction.

Based on the conducted research, it was found that the use of asphalt granulate as an aggregate replacement does not significantly worsen the parameters of the hot asphalt mix, even with the AG content of 40%, which is higher than recommended for HMA in the current guidelines (*WT-2*, 2014).

With respect to maximum density, bulk density, void content and filling of voids with asphalt in HMA, the influence of the granulate content was negligible. AG with a content of 20% improved the parameters related to rutting by 23%. However, water sensitivity deteriorated. With 40% AG content, the ITSR value was 9.7% lower than for the reference series. However, this did not result in non-compliance with current technical recommendations.

Asphalt granulate can therefore be used as a full-value component of asphalt mixtures, provided that research is carried out leading to the development of an appropriate laboratory recipe, which is also shown in the article. It is important to develop a recipe for each individual case because locally available materials (aggregate from different deposits, RAP from different structures) may differ significantly in properties.

It should be mentioned that the use of AG also gives noticeable savings in road bitumen consumption. Comparing the recipes for individual test series, it was found that for the 20% AG content, 30.8% less bitumen was used than for the reference series. For a content of 40% AG, this saving is 51.3%.

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