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FINANCIAL ASPECT OF USING THE ASPHALT GRANULATE IN MIXTURES DESIGNED FOR ROAD SUBSTRUCTURES

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ABSTRACT: Asphalt granulate is a valuable building material suitable for the production of asphalt mixtures. Its use in modern road building is profitable not only for environmental reasons but also because of the economic aspect of saving natural aggregates and asphalt and saving road pavement construction costs. The purpose of the cost analyses was to determine the financial benefits resulting from using the asphalt granulate in asphalt mixtures. The cost calculations concerned the basic components of asphalt mixtures and the costs of constructing the pavement structure layer for which the mixtures had been intended. The analyses covered asphalt mixtures of asphalt concrete type AC 22P with different content of asphalt granulate purchased at different prices, intended for road pavement substructure layers loaded with traffic of KR3 and KR4 categories.

KEYWORDS: asphalt granulate, cost analysis, recycling, road substructure, sustainable development

Introduction

The recycling of asphalt pavements is highly desirable due to their ecological and economic aspects. The reuse of asphalt waste as an additive to asphalt mixtures began in the United States as early as 1915. However, it was only in the 1970s that there was a renewed interest in waste produced from milling the old pavements as a result of the oil crisis, which had resulted in a significant increase of prices of various materials, including bitumen (Application..., 2014, Epps, 1994, West, 2010). Not only the United States of America began the large-scale use of the asphalt granulate to produce the asphalt mixtures, but also Western European countries. However, its content in the mixtures did not exceed 20% back then. Currently, the countries leading in the road construction sector are striving for maximum use of asphalt granulate to produce new mineral and asphalt mineral mixtures (Olard et al., 2008, Valdés et al., 2011, Aurangzeb et al., 2014). Its amount depends on the granulate dosing method during the production of mixtures. In Poland, according to the Appendix to Decree no. 54 of General Director of National Roads and Motorways from 8.11.2014 „Asphalt pavements on national roads” (WT-2 2014), the addition of up to 20% (addition of asphalt granulate to the paving plant mixer without preheating – „cold method”) or 30% („hot method”, meaning the addition of asphalt granulate to the paving plant mixer with preheating) is permitted. However, the condition of use is the homogeneity of the granulate corresponding to the requirements and the presence of aggregate in the granulate, which size D must not be greater than size D for the mineral mixture included in the mineral and asphalt mixture. Taking into consideration the intended use of the mixtures, it should be noted that in most countries, using the additive is permitted in the substructure layers and in the binding layer, whereas in the surface layer using the granulate is not permitted or its use depends on the traffic load (Alenowicz, 2019, Bressi et al., 2015, Copeland, 2011, Olard & Pouget, 2014). Despite the actions taken, Poland is a country where the use of asphalt waste to construct new or strengthening existing pavements is small and far from the standards of the leading countries in this respect (Bańkowski et al., 2016). This is confirmed by the annual EAPA (European Asphalt Pavement Association) report (EAPA, 2012, EAPA, 2017), in which the last time it was found in 2012 with 4% use of granulate. The country of very significant material management is Finland. In 2017, out of 1,200,000 tonnes of asphalt waste obtained, 100% was reused (EAPA, 2017). Likewise, in Japan, 99% of all RAP (Reclaimed Asphalt Pavement) is reused in new pavement construction (West & Coupland 2015). Also, in countries such as the USA (EAPA, 2017, Willis & West, 2014), Slovakia, Hungary, and Belgium (EAPA, 2017), the problem of management of recycled

materials is addressed rationally. The barriers for promoting the recycling of materials already identified by PIARC Technical Committee (Review..., 2007) are legislation, economics, lack of knowledge of road managers (investors). Therefore, the expected increase in using the granulate is a result of administrative activities, stable and long-term policy, the development of research and educational activities (Alenowicz, 2019). In recent years in Poland, there have been no clear provisions in the regulations governing the use of asphalt granulate and some provisions in the technical specifications for road investments, sometimes even limiting using the asphalt granulate in asphalt mixtures (Wasilewska et al., 2015). However, an increasing number of newly built and renovated roads has contributed to the adjustment of regulations allowing for reuse of „waste material”, which, as indicated by studies conducted in many research centres (Bańkowski et al., 2018, Edil, 2018, Ma et al., 2011, Mangiafico et al., 2013, Nokkaew, 2018, Plati & Cliatt, 2019, Reza Pouranian & Shishehbor, 2019, Sangiorgi et al., 2017, Tabaković et al., 2010, Xiao et al., 2018), may be a very valuable material for reuse.

Such reuse has many financial and environmental benefits (Horvath, 2003, Lee et al., 2010, Jamshidi & White 2020):

- reduction of dumps in landfills, and thus reduction of storage costs (for storage of asphalt waste in Poland an environmental fee is charged (Obwieszczenie ..., 2020), which in 2021 is to 20.82 PLN/Mg; 1 PLN = 0.26 USD),
- reduction of road pavement construction costs due to lower demand for new material,
- reduction of transport costs if the material is reused on-site,
- reduction in environmental costs (Zarei et al., 2020) connected with recovery and preparation of primary material and production of asphalt mixtures in the world (production absorbs large amount of non-renewable natural resources and is responsible for tens of millions of tons of CO₂, which record concentration in the atmosphere, on the weekend of 12-13 May 2019, recorded and confirmed by the scientists from the Observatory Mauna Loa in Hawaii, amounted to 415.26 ppm (TVNMETEO).

The use of asphalt granules in asphalt mixtures incorporated into the structure of new pavements is a direct saving of natural aggregates and bitumen (materials from non-renewable sources). It also means direct savings on the costs of road pavement construction, which depend on the prices and availability of the materials used. Furthermore, asphalt granulate in asphalt mixtures built into the structure of new pavements is also a response to the reduction of environmental pollution. The paper aims to determine the level of savings resulting from using the „valuable waste material” (which is an asphalt granulate) in the asphalt mixtures.

Subject and method of calculation

Subject of analysis

In order to determine the financial benefits resulting from using the asphalt granulate in asphalt mixtures, the cost analyses have been carried out, including the calculation of costs of basic components of asphalt mixtures and the valuation of costs of constructing the pavement layer for which the mixtures were intended. To assess the costs, the asphalt mixtures of asphalt concrete of type AC 22 P were used, intended for substructure layers of road pavement loaded with traffic of categories KR3 and KR4. The asphalt mixtures have been designed in accordance with (WT-2 2014). They were made from the mixture of aggregates (limestone dust, crushed and washed sand 0/2, broken sand 0/2, grit 2/8; grit 8/16; grit 11/16, grit 16/22) of constant granulometric composition and asphalt granulate in the amount of 0% (reference mixture), 10%, 15%, and 20%, meeting the requirements (WT-2 2014, PN-EN 13108-8:2016). Road bitumen 35/50 was used for the asphalt mixtures. The list of compositions, averaged over several designed asphalt mixtures, is presented in table 1.

Table 1. List of compositions (share in %) of asphalt mixtures AC 22 P 35/50 KR 3-4 containing various amounts of asphalt granulate

Type of material	Composition (share in %) of asphalt mixtures AC 22 P 35/50 KR 3-4 with use of granulate in the amount of			
	0%	10%	15%	20%
Bitumen	4.20	3.60	3.30	3.00
Aggregate	95.80	86.70	82.20	77.60
Granulate	-	9.70	14.50	19.40
Total	100.00	100.00	100.00	100.00

Source: author's work.

Calculation method

The assessment of costs of manufacturing the asphalt mixtures AC 22 P 35/50 KR 3-4 of different granulate content and the assessment of costs of manufacturing 1 m² of substructure layer were carried out based on a detailed calculation method (according to the commonly accepted cost calculation principles) and with use of prices and cost factors included in the monthly information (Informacja miesięczna..., 2021) and quarterly information (Informacja o stawkach..., 2021 and Informacja o cenach..., 2021) of "Seko-

cenbud” publishing house. The granulate price was determined based on sales offers (unit prices ranged from PLN 45 to 75 per Mg).

Analysed data

In order to determine the costs of manufacturing the asphalt mixtures of different granulate content, three formulations of mixtures in 4 price variants (differing in the unit price of granulate) have been considered: variant I – PLN 45 per Mg, variant II – PLN 55 per Mg, variant III – PLN 65 per Mg, variant IV – PLN 75 per Mg). Prices of 1 ton of waste material do not include the purchase costs and the external transport costs, which should be calculated individually according to the actual distance of deliveries and construction site organisation. The unit prices of other components of mixtures AC 22 P 35/50 KR 3-4 are listed in table 2.

Table 2. List of unit prices (PLN/t) of materials used for the production of asphalt mixtures AC 22 P 35/50 KR 3-4 containing various amounts of asphalt granulate

Material	Price [PLN/t]
Limestone dust	94.04
Crushed and washed sand 0/2	30.60
Broken sand 0/2	54.51
Grit 2/8	104.81
Grit 8/16	87.80
Grit 11/16	87.80
Grit 16/22	89.72
Bitumen 35/50	1 750.00

Source: author's work.

Table 3. List of unit prices of labour and work of construction equipment used for the realisation of substructure made from asphalt mixtures AC 22 P 35/50 KR 3-4 containing various amounts of asphalt granulate

Specification	Price
Labour	21.10 [PLN/man-hour]
Self-propelled static roller 10 t	87.73 [PLN/machine-hour]
Self-propelled static roller 15 t	97.13 [PLN/machine-hour]
Bituminous mass spreader	204.23 [PLN/machine-hour]

Source: author's work.

In order to determine the costs to be incurred for the realisation of 1 m² of substructure layer made from mixtures with various granulate contents, the price assumptions for labour and work of construction equipment were

made in accordance with (Informacja o stawkach..., 2021 and Informacja o cenach..., 2021) and shown in table 3.

The cost estimate price for realisation of the substructure layers was determined using formula (1) (Kowalczyk and Zabielski, 2011):

$$C_k = \sum (L \times n \times c) + K_p + Z + P_v, \quad (1)$$

where:

C_k – cost estimate value,

L – number of take-off units,

n – unit expenditures,

c – unit prices of production factors,

K_p – indirect costs for the whole range of works,

Z – calculation profit for the whole works,

P_v – value-added tax.

The unit expenditures were determined according to the Outlays In-kind Catalogue 2-31 (Katalog... KNR 2-31, 1997). The overhead indices for engineering works, which include construction works: road works (including access roads, parking lots, and garbage yards included in the construction equipment), track works, bridge works, works in the range of power networks and connections, telecommunication, water, sewage, gas, and heating networks, sewage treatment plant and water treatment plants works, as well as greenery, hydrotechnical, water and melioration, and well works, etc., have been based upon (Informacja miesięczna..., 2021).

Results and discussion

The costs of basic components needed to realise asphalt mixtures of different granulate content are presented in tables 4, 5, 6, and 7. Table 4 (variant I) contains cost data estimated upon the basis of calculations, assuming that the granulate costs PLN 45 per Mg. The results of price calculations included in tables 5, 6, and 7 (variants II, III, and IV, respectively) are the values determined on the assumption that PLN 55, PLN 65, and PLN 75 will have to be paid for 1 ton of granulate.

The total amount, including the values of all components of the mineral and asphalt mixture AC 22 P 35/50 KR 3-4 without the addition of asphalt granulate, is PLN 149.88. The most expensive component in the analysed mixture is bitumen, for which, at its current prices, one must pay PLN 73.50, which accounts for 49.04% of the total cost. The cost of aggregate is the value of PLN 76.38, i.e. 50.96% of total outlays.

Table 4. List of costs [in PLN] of the basic components of asphalt mixtures AC 22 P 35/50 KR 3-4 containing various amounts of asphalt granulate, assuming that the granulate costs PLN 45/ton

Type of material	Costs [in PLN] of the basic components of asphalt mixtures AC 22 P 35/50 KR 3-4 with use of granulate in the amount of			
	0%	10%	15%	20%
Bitumen	73.50	63.00	57.75	52.50
Aggregate	76.38	70.49	67.53	64.49
Granulate	-	4.37	6.53	8.73
Total	149.88	137.86	131.81	125.72

Source: author's work.

Table 4, apart from the costs of components of the reference mixture AC 22 P 35/50 KR 3-4, also presents the costs of components of the mixtures with 10%, 15% and 20% of asphalt granulate content, which costs PLN 45 per ton. Expenditures on materials in case of a mineral and asphalt mixture with 10% addition of asphalt granulate equal to PLN 137.86, and at the same time, the value is lower by PLN 12.03 (8.02%) than the price of the reference mixture. The expenditures to be spent on materials necessary to make a mixture with 15% of granulate are PLN 131.81, which is the value lower by PLN 18.08 in relation to the standard mixture. In case of a mineral and asphalt mixture with 20% share of granulate, the price decreased by PLN 24.16 and amounted to PLN 125.72.

In order to determine the impact of the addition of asphalt granulate purchased at the price of PLN 55 per ton (table 5) on the costs of asphalt mixtures for the substructure layer, an analogous analysis was performed as in the case of a variant I, using the formulas of mixtures presented in table 1.

Table 5. List of costs [in PLN] of the basic components of asphalt mixtures AC 22 P 35/50 KR 3-4 containing various amounts of asphalt granulate, assuming that the granulate costs PLN 55/ton

Type of material	Costs [in PLN] of the basic components of asphalt mixtures AC 22 P 35/50 KR 3-4 containing various amounts of asphalt granulate of			
	0%	10%	15%	20%
Bitumen	73.50	63.00	57.75	52.50
Aggregate	76.38	70.49	67.53	64.49
Granulate	-	5.34	7.98	10.67
Total	149.88	138.83	133.26	127.66

Source: author's work.

The costs of components needed to make 1 ton of mineral and asphalt mixture AC 22 P with the addition of asphalt granulate (costing PLN 55 per Mg) in the amount of 10% are PLN 138.83. It is less by PLN 11.06 than the mixture without the addition of asphalt granulate. The higher amount of waste material in the composition of mixtures means lower total prices of those mixtures – respectively PLN 133.26 in case of 15% content of valuable waste material and PLN 127.66 in relation to 20% of its amount.

Table 6 presents a list of costs of analysed mixtures assuming that the granulate will be purchased at the price of PLN 65 per Mg. Each of the mixtures is characterised by a different price due to the different granulate content, which also affects the correction of the binder and aggregate quantity.

Table 6. List of costs [in PLN] of the basic components of asphalt mixtures AC 22 P 35/50 KR 3-4 containing various amounts of asphalt granulate, assuming that the granulate costs PLN 65/ton

Type of material	Costs [in PLN] of the basic components of asphalt mixtures AC 22 P 35/50 KR 3-4 with use of granulate in the amount of			
	0%	10%	15%	20%
Bitumen	73.50	63.00	57.75	52.50
Aggregate	76.38	70.49	67.53	64.49
Granulate	-	6.31	9.43	12.61
Total	149.88	139.80	134.71	129.60

Source: author's work.

A list of costs (table 6) of the basic components of asphalt mixtures with different contents of asphalt waste shows its clear impact on the total price of the mixture. One may notice that the more material created after milling old pavements in the mixture, the lower the price of the mixture and the smaller the amount of aggregate and asphalt. Thus, the addition of 10% of granulate made the total cost of all components lower by PLN 10.09 compared to the cost of a mixture containing no asphalt granulate. The presence of 15% of the waste material caused the costs reduction to PLN 134.71, while the addition of 20% caused the price reduction to PLN 129.60.

The values of materials used to prepare asphalt mixtures AC 22 P 35/50 KR 3-4 with 10%, 15%, and 20% of the quantity of asphalt granulate purchased at the price of PLN 75 per ton are presented in table 7.

The last analysed variant is a variant in which the use of granulate purchased at the price of PLN 75 per ton was considered, which means that it will be cheaper only by 28% than the most expensive component of the aggregate mixture, and at the same time, it will be more expensive by more

than 60% compared to the price assumed in variant I (“the cheapest”). Similarly to the considered variants, No. I, II, and III, the asphalt granulate in the amount of 0% (standard mixture), 10%, 15%, and 20% were used.

Table 7. List of costs [in PLN] of the basic components of asphalt mixtures AC 22 P 35/50 KR 3-4 containing various amounts of asphalt granulate, assuming that the granulate costs PLN 75/ton

Type of material	Costs [in PLN] of the basic components of asphalt mixtures AC 22 P 35/50 KR 3-4 with use of granulate in the amount of			
	0%	10%	15%	20%
Bitumen	73.50	63.00	57.75	52.50
Aggregate	76.38	70.49	67.53	64.49
Granulate	-	7.28	10.88	14.55
Total	149.88	140.77	136.16	131.54

Source: author's work.

As a result of the analysis of costs of the components needed for production of asphalt mixtures without and with asphalt granulate it has been found that the cost of the mixture decreased with the increase in the quantity of asphalt granulate in the mineral and asphalt mixture and irrespective of its purchase price (in the range considered). The percentage differences in relation to the prices of the reference mixture are shown in table 8.

Table 8. List of percentage differences of costs of the basic components of asphalt mixtures AC 22 P 35/50 KR 3-4 containing various amounts of asphalt granulate in relation to the reference mixture

Mixture with granulate in amount of	Granulate price			
	PLN 45	PLN 55	PLN 65	PLN 75
10%	12.03%	11.06%	10.09%	9.12%
15%	18.08%	16.63%	15.18%	13.73%
20%	24.16%	22.22%	20.28%	18.34%

Source: author's work.

The values presented in table 8 indicate that regardless of the amount of asphalt granulate additive and its purchase price (in the range considered), the use of the waste allows for significant savings. First of all, those are savings of natural aggregates and asphalt (granulate is a component “rich” in full value asphalt binder; it also reduces the amount of added aggregate), and

secondly, those are savings in the cost of the mixtures themselves. The presence of 10% of the waste material is the cost of materials lower by over 9÷12% (in relation to the amounts set for the reference mixture), 15% of the content of milled old pavement is lower by 13÷18%, while using the waste material in the amount of 20% is the cost reduced by 18÷24%.

In order to compare the level of costs to be incurred for the realisation of 1 m² of the typical substructure an analysis has been performed based upon the presented formulas of asphalt mixtures with different content of asphalt granulate. The differences in financial outlay for the construction of a typical 10 cm layer of the substructure result only from differences in unit prices of materials, as in each analysed case, the costs of labour and equipment, indirect costs, profit, and VAT are the same. The summary of costs of construction of 1 m² of the substructure layer is presented in table 9. In contrast, table 10 shows the percentage differences in relation to the construction costs of the substructure layer using the reference mixture.

Table 9. List of costs of the basic components of asphalt mixtures AC 22 P 35/50 KR 3-4 containing various amounts of asphalt granulate purchased at different prices

Mixture with granulate in amount of	Granulate price			
	PLN 45	PLN 55	PLN 65	PLN 75
0%	58.52	58.52	58.52	58.52
10%	55.06	55.34	55.62	55.90
15%	53.32	53.74	54.16	54.57
20%	51.57	52.13	52.69	53.25

Source: author's work.

Table 10. List of percentage differences of costs of realisation of 1 m² of the substructure from the asphalt mixtures AC 22 P 35/50 KR 3-4 containing various amounts of asphalt granulate in relation to realisation costs with the use of the reference mixture

Mixture with granulate in amount of	Granulate price			
	PLN 45	PLN 55	PLN 65	PLN 75
10%	5.91%	5.43%	4.96%	4.48%
15%	8.89%	8.17%	7.45%	6.75%
20%	11.88%	10.92%	9.96%	9.01%

Source: author's work.

Analysing the data presented in table 10, one should say that using the granulate (costs of labour and equipment, indirect costs, and contractor's

profit do not change) causes reduction of realisation costs of 1 m² of the substructure. The realisation of the layer from the mixture AC 22 P 35/50 KR 3-4 without the addition of asphalt granulate was characterised by a cost equal to PLN 58.52. In case of using 10% of asphalt granulate, the price of 1 m² of substructure decreased to PLN 55.06, assuming that the granulate cost PLN 45 per ton, or to PLN 55.90 when PLN 75 was allocated for its purchase (1 ton). It makes a difference of 5.91% or 4.48%, respectively, compared to the realisation of 1 m² of the substructure from the reference mixture. The cost of constructing of the assumed substructure from a mixture in which the share of waste material amounted to 15%, decreased by 6.75% for the „most expensive” price variant of the waste material. In the case of a mineral and asphalt mixture with the addition of 20% of granulate, the price decreased by 11.88% (assuming that it will cost PLN 45 per Mg) and amounted to PLN 51.57.

The decrease of realisation price per 1 m² of road substructures may seem low, but considering the amounts connected with construction of many kilometres of roads, they may become very important in the total investment costs.

Conclusions

Using asphalt waste in the form of granulate in modern road construction is profitable not only for environmental reasons but also due to the economic aspect. The performed analysis clearly shows that with the increased amount of added asphalt granulate, the price of asphalt mixtures as well as the cost of their incorporation decrease. It results from lower demand for aggregate (desirable in the situation of increasingly limited access to high-quality rock raw material) and bitumen, the price of which is crucial for the production costs of mixtures. Another economic benefit associated with using the asphalt granulate for the production of new mixtures is the reduction in the number of waste dumps where the milled waste material is stored, for which fees must be paid. Using the asphalt granulate, apart from financial aspects, directly impacts environmental protection by solving the problem of granulate management and significantly reduces the use of natural non-renewable raw materials. The reuse of asphalt granulate as an additive to the asphalt mixtures gives measurable environmental and economic benefits without any negative impact on the final product, i.e. the mineral and asphalt mixture.

The cost analysis performed on the example of asphalt mixtures without asphalt granulate and with 10%, 15%, 20% of additive intended for road substructures, with presented assumptions, allowed to formulate the following conclusions:

- With the increasing content of asphalt granulate in the constitution of a mineral and asphalt mixture, the costs of its components decrease. The cost of components needed to make a mineral and asphalt mixture AC 22 P 50/70 KR3-KR4 without the addition of asphalt granulate is PLN 149.88. The addition of asphalt granulate purchased at the price of PLN 45 and in quantities of 10%, 15%, and 20% resulted in a decrease of price by PLN 12.03, PLN 18.08, and PLN 24.16, respectively, which in relation to the reference mixture constitutes respectively 8.02%, 12.06%, and 16.12%.
- The price of realisation of 1 m² of 10 cm thick substructure layer made from mineral and asphalt mixture AC 22 P 5/50 KR3-KR4 without the addition of asphalt granulate was estimated at PLN 58.52. On the other hand, a layer made from the mixture with 10% of granulate content purchased at the price of PLN 75 per ton was valued at PLN 55.90 (less by PLN 2.62); a 10 cm thick substructure layer with 15% of waste material (also purchased at the price of PLN 75 per Mg) is the cost of PLN 54.57 (less by PLN 3.95). The presence of 20% of asphalt granulate in the mixture means the price lower by PLN 5.27 in relation to the reference mixture.

The decrease of realisation price per 1 m² of road substructures may seem low. However, considering the amounts connected with construction of many kilometres of roads, they may become very important in the total investment costs.

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