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ALTERNATIVE USES FOR CRUSHED STONE PRODUCTS GENERATED TO MEET THE RAW MATERIAL NEEDS OF ASPHALT PRODUCTION IN HUNGARY

In Hungary, quarries that produce stone products for wearing courses of asphalt pavements also produce a significant amount of 0/4, 0/8 and 4/8 mm fractions. Because of Hungary's pavement design and asphalt production practices, these fractions do not have a suitable market and can thus be sold on alternative markets.

Purpose. To demonstrate the feasibility of using crushed fractions of 0/4 and 0/8 mm in the protection and base layers of asphalt pavements instead of sandy gravel with 0/22 mm fraction.

Methodology. The CBR method was applied to evaluate the comparability of characteristics such as particle size distribution and load-bearing capacity. The combination of the Proctor and CBR tests allowed someone to compare the expected technological characteristics of the dominant and alternative aggregate types, such as their sensitivity to water and load-bearing capacity.

Findings. The results demonstrated that the performance characteristics of conventionally used sandy gravel with a size of 0/22 mm can be achieved and exceeded by crushed material with much smaller maximum grain sizes – i.e., 0/4 and 0/8 mm.

Originality. The paper presents an original study that contradicts the industry's actual decline of crushed stone (0/4 and 0/8 mm fractions) for asphalt pavement protection layers. The potential effectiveness and functionality of the proposed coating are demonstrated through convincing tests, and thus new data and insights are introduced into the Hungarian construction industry's practice.

Practical value. The test results greatly helped in achieving the high demands of the private industrial project by proposing an alternative variant of crushed stone of 0/8 mm fraction rather than the originally planned dominant sand and gravel material. The asphalt paving experience on this site clearly demonstrated the viability of the alternative aggregate option for Hungarian roads.

Keywords: *asphalt pavement, sand and gravel products, crushed stone, alternative raw materials, load-bearing capacity, Proctor tests, CBR*

Introduction. This article examines some aspects of sustainable mineral resource management, mainly from the perspective of the field of transport infrastructure within civil engineering. This field is scarce when analyzed in isolation, and usually transport(ation) sciences [1–3]; logistics [4–6]; mining, geology, rock physics [7–9]; architecture and civil engineering [10–12], mechanical and vehicle engineering [13, 14], materials science and technology [15], electrical engineering [16], etc. can be essential subfields. The keyword and concept of sustainability can mainly explain the relationship, but of course, this does not limit the links to other related areas. The authors mention Hungary several times, but naturally, their statements are general for any country in the world, taking into account the mineral wealth there.

Hungary can be considered a country rich in construction minerals [17, 18], with different raw materials such as sandy gravel, limestone and dolomite, andesite and basalt all found in the area. Over the decades, the civil engineering profession has, therefore, been able to identify the primary uses of each type of raw material, taking into account the advantages and disadvantages of each type of use in a targeted manner and from an economic and technical point of view [7]. In this article, the reasons for the stockpiling of raw materials in the supplying quarries and one possible alternative use are presented as a consequence of the needs and habits of asphalt producers; the market and regulatory environment of the entire Hungarian raw material stockpile is described to the extent necessary for an understanding of this.

Asphalt producer practice shows [19] that different fractions of crushed aggregates vary significantly from one processing technology to another – especially for wearing courses. The use of some products is significant, while others have low amounts. The primary source of the problem is the predominance of asphalt mixes with a grain size of 11 mm in wearing courses and the established asphalt production practice that the sand fraction (below 4 mm) of wearing course mixes is typically sedimentary (dolomite or limestone), while the coarse fraction (above 4 mm) is exclusively composed of volcanic rock. Thus, in the case of asphalt mixtures with a maximal grain size of

11 mm, the grains below 4 mm are the products of sedimentary quarries, while above 4 mm, they are the products of another volcanic quarry. In the case of volcanic quarries, this means 4/8 and 8/11 mm fractions, of which 8/11 mm is the dominant demand, i.e., production/sales capacities have to be optimized accordingly. As a result, Fig. 1 shows the situation of a production/sales imbalance in the processing of a volcanic rock material positioned for the wear layer of asphalt pavements.

Thus, on average, 1.5–1.7 tonnes of raw material are needed to produce 1 ton of asphalt mixture. Consequently, the production surplus is not used in the asphalt industry but accumulates in the quarries, in this case resulting in a significant surplus of 0/4 and 4/8 mm fractions. With a possible harmonization and optimization of asphalt production practices, this ratio could be reduced to 1.2–1.4 tonnes, thus facilitating the highest possible use of the finite, best-quality mineral raw material [19].

However, mining companies facing this problem have a daily challenge to dispose of such unmarketable products within the quarry and are looking for alternative markets for their products that are not useful in asphalt production. The search for these alternative markets should take into account the options available, which are summarized in Table 1.

It can be seen from the above that although crushed stone can be used in all major applications, using dead stocks in alternative applications is rather complicated due to established user habits.

From a mineral resource management point of view, it would be desirable that the use of the highest quality raw material stock should be utilized to the highest level; i.e., if the quality of the raw material allows for application in the asphalt industry, then the highest quality stock of suitable raw material should be used in this specific area. In practice in Hungary, especially for motorways' wearing courses, SMA11 (stone mastic asphalt, $D_{\max} = 11$ mm) mixtures with a maximum grain size of 11 mm have become dominant. In these mixtures, sedimentary stone products are the most popular in terms of sand fraction (i.e., below 4 mm), with coarse fractions of 4/8 and 8/11 mm originating from igneous quarries. On average, the 8/11 mm fraction is used in quantities twice that of the 4/8 mm fraction. Fig. 1 shows that the use of 100,000 tonnes of 8/11 mm would result in a surplus of 60,000 tonnes of 4/8 mm and around 130,000 tonnes of 0/4 mm,

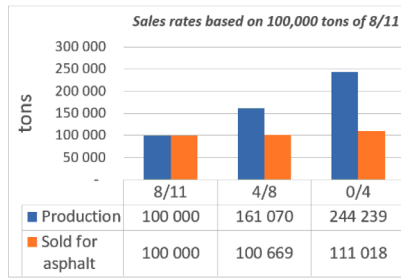


Fig. 1. Sales rates based on 100 kilotons of 8/11 production

Table 1

Classification of raw materials by the different market areas based on Hungarian habits and standards

Market areas	Total market (estimated)		
	Gravel pit ~ 70 %		Crushed stone is 30 %, from which ~70 % is sedimentary rock
	Type of quarries		
	Gravel pits	Limestone and dolomite quarries	Volcanic quarries
Earthworks	Most popular	Depends on price	Depends on price
Capping layer	Most popular	Depends on price	Depends on price
HBM (hydraulically bond materials)	Most popular	Depends on price	Depends on price
Base layer (Non hydraulic)	Partly allowed	Most popular	Most popular
Asphalt base layer	Not allowed	Most popular	Depends on price
Asphalt binding layer	Not allowed	Most popular	Depends on price
Asphalt wearing course	Not allowed	Only sand (0/2, 0/4)	Most popular
Ready mix concrete	Most popular	Not popular	Not popular
Concrete for pavement	Partly allowed	Not allowed	Most popular
Precast concrete	Most popular	Not popular	Not popular

which would be reflected in the accumulation of dead stock in the quarries if the current practice of using dead stocks is followed.

These products are made from the best quality raw materials from the quarries, so asphalt and concrete would be beneficial for these mineral resources. In the case of asphalt pavement construction and maintenance, this significant surplus of 0/4 and 4/8 mm products could be used to a significant extent in the construction and maintenance of wearing courses, for example, through the application of surface coatings, which are popular in many countries for maintenance activities, and the equally popular 8 mm grain size wearing courses.

In terms of concrete mixes, sandy gravel products are the most common, with the exception of paving concretes, which are built to a small extent. The main reason for this is that Hungary is basically rich in these resources and, except in a few cases, the transport distances do not result in a situation where crushed stone is more competitive. Consequently, although there is favorable experience with the use of these 0/4 and 4/8 mm crushed products in the concrete industry, their use in the concrete industry is somewhat limited from a technical and economic point of view. The situation is further complicated because profession-

als in Hungary, who are used to using concrete mixes made from sandy gravel, are opposed to crushed aggregates in fresh concrete mixes and are averse to them, assuming that they entail additional risks. As a result, concrete mix producers are approaching the usage of crushed aggregates in the concrete industry with excessive caution so that their low competitiveness does not result in substituting the usual sandy gravel products.

It can be seen from the above that, in the use of asphalt mixtures, the combined use of 8 and 11 mm maximum aggregate size mixes and the development of surface coatings would eliminate the production of total waste in these quarries, resulting in the highest possible utilization of the best quality, finite mineral resources. Achieving this in the short term is not a realistic objective in the current industry environment, but it would be preferable from both a mining and a mineral resource management perspective.

However, companies facing this problem will have to find a short-term solution to sell the dead stocks accumulating in their quarries because they have limited possibilities to dispose of them in the quarry and deposit them in landfills. This led to the idea that market acquisition in the field of non-binding applications, also dominated by sandy gravel, offers an opportunity to use some of the stocks already accumulated, which was the basis for the studies presented in this article.

For applications without binders (unbound), the 0/22 mm fraction of sandy gravels predominates, other (typically smaller) grain sizes are accepted by the industry with caution and skepticism, and the 0/4 and 4/8 mm crushed fractions, which form the dead stock of volcanic quarries, are not preferred for application in these areas.

However, unbound applications can sometimes require a significant amount of aggregate product, depending on the project size, which is often available in a short time for production and delivery; therefore, the availability of large quantities of dead stock is a particular advantage in this area, so that if technically suitable, there are no constraints on the production of the product during sale. In addition, the advantage of the application of these materials is that they do not require expensive and time-consuming testing methods to verify their conformity, which can be quickly and clearly verified by the traditional methods of test compaction and checking for compactness (density) and/or load-bearing capacity.

From an economic point of view, the current inflationary environment and volatile energy costs do not allow manufacturers to maintain the price of their products in the longer term, for example, for multi-year projects, so the risk of price changes carries additional risks for both manufacturers and contractors; however, the large quantities of stock already produced, stored and accumulated in the quarry are free of these risks, making pricing more predictable for both manufacturers and contractors.

Literature review. A review of the relevant literature shows that the topic is of interest from the technical, mineral resource management, environmental, and economic perspectives. For example, the SNAP-SEE project [17] has comprehensively analyzed information on the South-East European region's mineral management, consumption, and supply. It was found that demand could rise from the current 6 tons/person/year to as much as 12 tons/person/year soon, in line with economic development, making it essential to strive for the most efficient use of resources in the production of raw materials for the construction industry, which is a finite resource industry.

In Hungary, a comprehensive professional work entitled Sustainable Roads [19] was launched in 2013 with the significant involvement of the state, where, with the participation of road construction experts (engineers, lawyers, economists, etc.), the general practices used in the development and operation of the Hungarian road network and the related international methods were identified and analyzed with sustainability aspects taken into account. The comprehensive technical material provides the technical background for developing industry policy. Its environmental chapters address the issue of the

accumulation of tailings in mining operations, outlining the causes and consequences for the industry and highlighting the need for more effective mineral resource management. The current article offers a possible technical solution in response.

As the requirements for unbonded pavement materials vary worldwide, depending on the raw materials' quality, many researchers and experts are investigating alternative sources and materials available in specific regions. One of the reasons for this is the wide range of options available for the design and pavement requirements of unbound pavement layers, which are, at the same time, significant raw material requirements. Fladvad and Ulvik, in their paper [20], have reviewed and collected the requirements to materials used in unbonded pavements worldwide, as well as their pavement design implications. Their work mentioned the efficient use of best-quality finite resources and the track structure aspects of using alternative resources.

The methodological framework for the series of tests that formed the basis for writing the current paper was based on the authors' previous research work [21], a similar methodology to that used in Budiarto's paper [22], in which he analyses the load-bearing capacity enhancing effect of crushed aggregates added to natural aggregates. Satyanarayana, et al. [23] analyze the behavior of unbound fractions as a function of their fine-fraction content.

Previously unresolved aspects of the overall problem. Using aggregates in unbonded structures, it is not difficult to understand that the behavior of the built-up layers is determined by the internal friction angle typical of granular soils. In the construction of road structures, the professionals involved in the realization of projects concentrate on the compliance of the technical requirements for the structures in question, i.e., the values of compactness (density) and bearing capacity [24]. Practical experience in the mining industry has shown that crushed 0/4 mm and crushed 0/8 mm products, considered dead stock from the quarries concerned, can achieve excellent bearing capacity with low water sensitivity. Although the literature suggests that, despite the lower maximum particle size due to the crushed grains, these products can reach or even exceed the performance of 0/22 mm sandy gravels, the industry has been reluctant to apply these products for this purpose. It has not been able to construct test sections to demonstrate excellent performance at low maximum particle size. To prove this, a comprehensive series of studies has been launched to refute the prejudice of the profession by providing objective measurement results.

Purpose. The aim is to initiate a comprehensive series of tests using 0/22 mm sandy gravel, crushed 0/4 and 0/8 mm to provide data that will allow comparison of the behavior and load-bearing capacity of the 0/22 mm sandy gravel, which is the dominant material in unbound applications, and the crushed 0/4 and 0/8 mm fractions, which are proposed as alternatives. Limited resources were available for the tests, so simple and low-cost measurement methods were preferred where possible. Overall, it was found that combinations of particle size distribution, Proctor, and CBR tests can model the structural behavior of granular materials [21–23] with sufficient accuracy. Because of their widespread application, they can be considered as a very economical test method. In addition, the results can be simply and generally interpreted by the industry. It was hoped that this would stimulate the interest of some contractors and that experience could be gained on real projects with the alternatives proposed, thus refuting existing professional prejudices against 0/4 and/or 0/8 mm products for use without binders.

Methods. Classification of granular materials can be easily done based on the particle size distribution and Proctor tests, which can be used to determine the compactability, voids, permeability, and general suitability for earthworks. These tests were supplemented by a Proctor test [25] with a CBR test [26] so that not only the compressibility–water content but also the water content–load-bearing capacity relationships could be described and compared, as shown in Fig. 2. By analyzing the resulting Proctor curves, the water content-dependent compressibility of the materials and the potential risk becomes

comparable. At the same time, the associated load-bearing capacity values allow the extent and risks of the expected loss of bearing capacity at the same level of compressibility to be analyzed. The bearing capacity values were compared using the theoretical E_2 values determined by the formula $E_2 = 10 \times CBR^{2/3}$ based on the CBR values [26] (where E_2 is the value of load-bearing capacity in MPa unit based on static plate tests, and CBR is the load-bearing capacity value based on CBR tests.)

Using both the crushed 0/8 and crushed 0/22 mm products, a trial compaction was planned under quarry conditions, within the capabilities of the operation, using both fractions, spreading the layers along the quarry roads at a width of about 5–6 m and a thickness of about 30 cm. These were compacted by overlaying the quarry traffic. A sprinkler truck, whose main task is to keep the roadways free of dust, regularly watered the layers, and the quarry truck traffic compacted the layers. The measurement and the results are illustrated in Fig. 3.

The comparative performance analysis was based on the main applications of crushed 0/22 and uncrushed 0/22 mm sandy gravel products and the properties expected in this field. It is well known that one of the main applications of these products is the construction of unbound layers, where the following criteria are crucial for the choice of the product:

- the layer is expected to have a medium-high load-bearing capacity (70–90 MPa);
- the surface of the layer must be sufficiently closed and uniform, so products with a larger grain size are not an option;
- the thickness of the construction layer is relatively low, so maximum grain size is of particular importance from a construction technology point of view;
- the product is used for surface leveling and leveling, where a continuous particle size distribution and a low D_{max} (i.e., the maximal grain size) are important, primarily because of the surface sealing;
- additional construction tasks are planned on the layer, such as piling, for which the primary considerations are to ensure walkability and ease of drilling;
- where a layer with a better bearing capacity than sandy gravel is required in areas where sandy gravel is commonly used, crushed 0/22 mm is the most typical crushed alternative;
- other considerations may include favourable logistical conditions and user needs related to the availability (capacity) of the material, as well as technical and economic considerations not listed here.

In these application areas, 0/D products should be evaluated and compared on the basis of soil mechanics.

The following tests were conducted:

- determination of particle size distribution according to standard EN 933-1 [27];
- determination of the direct load-bearing index (CBR) according to EN 13286-47 [26];
- Proctor-compacting according to EN 13286-2 [25];

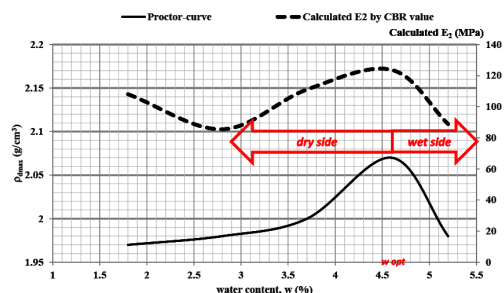


Fig. 2. Proctor-curve (bottom and continuous line) combined with load-bearing capacity measurements (upper and dashed line). The Proctor-curve is the so-called compressibility–water content function [25]. The load-bearing capacity was considered as CBR test [26]

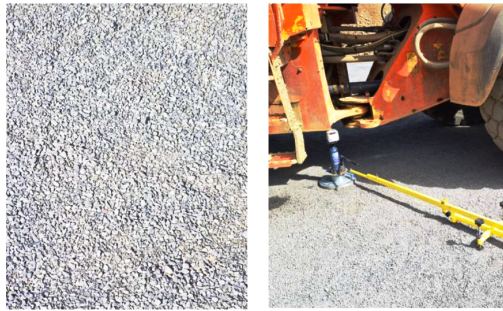


Fig. 3. Surface appearance of a layer of crushed 0/8 mm product and the process of load-bearing capacity measurement

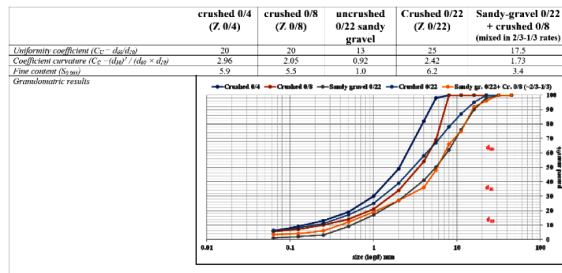


Fig. 4. Particle size distribution curves

- measurement of the load-bearing capacity with static load plate tests on built-up layers according to MSZ 2509-3:1989 [24].

Results. The particle distribution results (Fig. 4) show that all the particle distribution curves are continuous, and the shape of the particle distribution curve is plain (i. e., elongated or in other words, not steep). In all cases, a low fine-grain content can be observed. All the variants can be considered excellent for adequate soil materials.

Based on the particle size distribution results and soil classification, it can be concluded that there is no significant difference between the grading classes of all the investigated aggregates in the construction area (Table 2). The 0/22 mm sandy gravel and the sandy gravel-crushed material mixture are classified as excellent earthwork materials due to their more advantageous ($S_{0.063} < 5\%$) fine-grain content. In contrast, the other products are classified as suitable earthwork materials one category lower due to their fine grain content above 5%. The water conductivity also slightly differs due to the lower fine-grain content.

A comparison of the maximum dry bulk densities available (ρ_{dmax}) shows that the crushed 0/4 mm product has the lowest value, which is achieved at higher void contents (Table 3). Higher void contents are indeed associated with increased permeability. The highest dry bulk density was obtained for the crushed 0/22 mm product.

The optimal water content values were found to be lowest for the 0/22 mm sandy gravel and highest for the crushed 0/22 mm product (Fig. 5). Based on the water content ranges for the 95% compaction requirement, it can be seen that for the crushed material and the mixture, it exceeds 8%, which is only 4% for the sandy gravel. In practice, this means that the variants with crushed grains are much less sensitive to water content during processing, i. e., the desired compactness (density) and, thus, the desired load-bearing capacity can be achieved within a broader range.

The CBR results, combined with the Proctor test (Fig. 5), clearly show that the theoretical E_2 value for sandy gravel is the lowest in the range of water contents required for processing at the correct compactness, followed by the values of the crushed 0/4 mm product, then the sandy gravel-crushed mix, then the crushed 0/8 mm, and finally the crushed 0/22 mm product.

During the trial construction, the load-bearing capacity of the pavements was checked using a static load plate test after two days of compaction by traffic. The results showed that the crushed 0/8 mm product layer had a uniform bearing capacity of around 120 MPa with a compaction factor between 1.6 and 1.9, which meets the strictest Hungarian requirements for crushed stone foundations in terms of load-bearing capacity and compactness (density). The load-bearing capacity of the crushed 0/22 mm layer was lower than that of the crushed 0/8 mm product (70–80 MPa), but the compaction factor exceeded 2.0, i. e., in this case, the degree of compactness can be increased, which leads to an increase in the load-bearing capacity. Based on the results of the static load plate tests in the field, it is clear that the crushed 0/8 mm product has excellent bearing capacity and compactability.

Conclusions. In summary, the analysis of the results shows that all the samples tested are suitable for earthworks. Considering the classification and the results of the water content and load-bearing capacity, the products tested can be ranked as follows, the first being the most favorable and the last the least favorable:

- 1) crushed 0/22 mm product;
- 2) crushed 0/8 mm product;
- 3) mixture of 0/22 mm sandy gravel and crushed 0/8 mm product;
- 4) crushed 0/4 mm product;
- 5) 0/22 mm sandy gravel.

It is also concluded that:

- the 0/4 and 0/8 mm crushed products are an advantageous substitute for 0/22 mm sandy gravel, with better construction properties (compactability, water content in the mixture during construction, etc.) and better performance (theoretical E_2 load-bearing capacity);

- the results obtained with the 0/8 mm crushed product are close to the theoretical load-bearing capacity values obtained with the 0/22 mm crushed product, and they also have very similar behavior so that they are interchangeable despite their differences in maximum particle size;

Table 2

Applicability for earthworks by e-ÚT 06.02.11 (ÚT 2-1.222) [28]

Applicability for earthworks by e-ÚT 06.02.11 (ÚT 2-1.222)					
	Crushed 0/4 (Z 0/4)	Crushed 0/8 (Z 0/8)	Uncrushed 0/22 sandy gravel	Crushed 0/22 (Z 0/22)	Sandy-gravel 0/22 + crushed 0/8 (Mixed in 2/3-1/3 rates)
Qualifying of drainage (by granulometric)	The border of V-2-good drainage and V-3-medium level of drainage	The border of V-2-good drainage and V-3-medium level of drainage	V-2- good drainage	The border of V-2-good drainage and V-3-medium level of drainage	V-2- good drainage
Qualifying sensitivity for erosion	E-2 – not sensitive to erosion	E-2 – not sensitive to erosion	E-2 – not sensitive to erosion	E-2 – not sensitive to erosion	E-2 – not sensitive to erosion
Qualifying sensitivity for freezing	X-1 – not sensitive against freezing	X-1 – not sensitive against freezing	X-1 – not sensitive against freezing	X-1 – not sensitive against freezing	X-1 – not sensitive against freezing

Proctor and CBR test results

Considered physical parameters	Crushed 0/4 (Z 0/4)	Crushed 0/8 (Z 0/8)	Uncrushed 0/22 sandy gravel	Crushed 0/22 (Z 0/22)	Sandy-gravel 0/22 + Crushed 0/8 (Mixed in 2/3-1/3 rates)
ρ_{dmax} (g/cm ³)	1.88	1.91	2.07	2.09	2.00
Optimal water content w_{opt} (%)	6.5	5.0	4.5	7.7	7.5
Water content range required for application to achieve 95 % degree of compactness (%)	2.0–10.0 % (8 + %)	2.0–10.0 % (8 + %)	2.0–6.0 (4 %)	4.0–11.0 (7 %)	2.0–10.0 % (8 + %)
The theoretical load capacity value range is the workable water content (MPa)	120–165	170–195	85–120	250–306	110–180

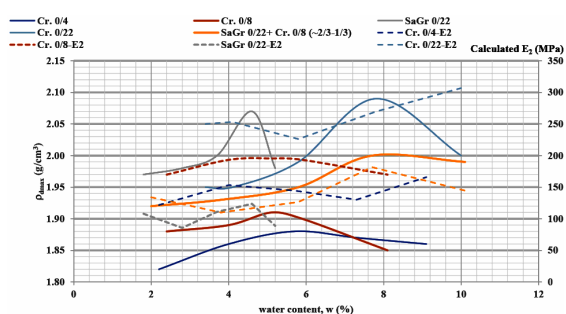


Fig. 5. Graphs of Proctor tests combined with CBR tests (Cr. means crushed, SaGr. means sandy gravel)

- by mixing the crushed 0/8 product with 0/22 mm sandy gravel, a stockpile with a significantly more favorable behavior could be obtained compared to the construction characteristics and theoretical load-bearing capacity values of pure sandy gravel;

- the experience of the trial compaction clearly shows that the crushed stone layer produced from the crushed 0/8 mm product has an excellent bearing-bearing capacity and good compaction tendency, as confirmed by E_2 values of around 120 MPa and compaction coefficient values between 1.6 and 1.9.

The results reported in this paper have led to the successful construction of a protective layer of an industrial facility originally designed with 0/22 mm sandy gravel using the crushed 0/8 mm fraction; in this project, approximately 200,000 tonnes of 0/8 mm material was installed as a protective layer, and construction experience shows favorable compactness (density) and load-bearing capacity and confirms the laboratory results. Due to the favorable behavior of the crushed 0/8 mm fraction observed in this project, it is expected that in the future, it will be easier to replace the 0/22 mm sandy gravel, which is dominant in the Hungarian environment, with alternative crushed materials that represent dead stocks of aggregates due to the asphalt production characteristics described for the Hungarian quarries operating in the market environment presented.

It has to be mentioned that the road and railway network (primarily the high axle-load public rail network) is an integral part of the country's economy, and the quality of the infrastructure is a crucial factor in its efficiency. A significant proportion of asphalt pavements (> 90 %) are made up of mineral raw materials (aggregates) extracted from domestic quarries, and the same is true for crushed stone ballast materials for railway tracks; their quality has a corresponding impact on the lifetime characteristics of the roads and railway permanent ways. For the wearing course of the motorway network and the ballast bed of railway tracks, the best quality resources of the domestic mineral wealth are needed, which is a fraction of the total stock, and its absolute value is therefore determined by the applicability criteria assigned to the best quality. On this basis, both the asphalt wearing course of motorways and the railway lines designed for speeds above 120 km/h use the best quality part of the mineral wealth. The steadily decreasing amount of this limited reserve may become critical in the

medium term from a supply security point of view since the domestic mining operations in the domestic mining industry, which means that sustainable management of the mining industry is not possible; only a conscious and optimal use of minerals. The more efficient use of mineral resources from existing and operating quarries when new areas are opened up (new mining operations) will have a significantly lower environmental impact, both in terms of land use for mining and the environmental impacts of mining activities, including increased road traffic in the area. For this reason, the reduction of supply risks and the increase in availability time should be achieved by optimizing the application requirements and quality standards. This is supported by literature showing that countries with similarly developed road and rail networks have widely differing requirements for the mineral raw materials to be used, essentially determining the quantity of raw material available for a given purpose. This means that roads and railways worldwide can operate at a similar level of service using different grades of aggregate.

As a result of the planned research work in the future, the authors would like to analyze the domestic and international relationship between the quality requirements of mineral raw materials critical for transport construction. At the same time, the quantity and the national distribution of the available raw materials for the construction of motorway wearing courses and railway tracks under current regulatory conditions will be estimated. Comprehensive experiments will help to explore the relationships between the measurable characteristics of the aggregates and the expected behavior of the asphalt wearing course/railway ballast bed made from them, identifying properties of particular importance for the pavement's/railway ballast bed's life under domestic conditions. A comprehensive analysis of international practice and domestic application conditions, as well as the expected depletion (consumption) rate of the available mineral resource, in the light of the results of the detailed series of studies, should provide an opportunity to optimize the domestic requirements regime, thereby increasing the quantity of aggregate available for wearing course/railway ballast bed and the time of resource supply without the need for new quarrying or the authorization of new extensions to existing quarries.

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Альтернативне застосування щебеню для виготовлення асфальтобетонних сумішей в Угорщині

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Кар'єри Угорщини, що видобувають кам'яні вироби для зносостійких асфальтобетонних покриттів, також виробляють значну кількість фракцій 0/4, 0/8 і 4/8 мм. У зв'язку з конструкцією дорожнього покриття та практикою виробництва асфальту в Угорщині, ці фракції не мають відповідного ринку збуту й тому можуть бути продані на альтернативних ринках.

Мета. Обґрунтування можливості використання альтернативної супутньої сировини – подрібнених фракцій 0/4 і 0/8 мм – у захисному й базовому шарах асфальтобетонних покриттів замість піщаного гравію фракції 0/22 мм.

Методика. Порівнянність характеристик оцінювалася шляхом випробувань на гранулометричний склад і несучу здатність за методом СБР. Поєднання тестів Проктора та СБР дало можливість порівняти очікувані технологічні особливості домінуючих і альтернативних типів заповнювачів, включаючи їх чутливість до води та значення несучої здатності, які можуть бути досягнуті.

Результати. Результати показали, що експлуатаційні характеристики піщаного гравію, який використовується традиційно, розміром 0/22 мм можуть бути досягнуті й перевищені за рахунок значно меншого максимального розміру зерен подрібненого матеріалу – 0/4 і 0/8 мм.

Наукова новизна. У роботі представлено оригінальне дослідження, в якому спростовується фактичне неприйняття промисловістю застосування щебеню (фракції 0/4 і 0/8 мм) для захисних шарів асфальтобетонних покриттів. Потенційна ефективність і функціональність запропонованого покриття доводяться за допомогою переконливих випробувань, і, таким чином, вносяться нові дані та уявлення у практику будівельної галузі Угорщини.

Практична значимість. Результати випробувань значно допомогли задовольнити високі потреби приватного промислового проекту за допомогою запропонованого альтернативного варіанту дробленого щебеню фракції 0/8 мм замість початково запланованого домінуючого піщано-гравійного матеріалу. Досвід укладання асфальтобетонного покриття на цій ділянці чітко підтвердив життєздатність альтернативного варіанту заповнювачів для доріг Угорщини.

Ключові слова: асфальтобетонне покриття, піщано-гравійні вироби, щебень, альтернативна сировина, несуча здатність, тести Проктора, СБР

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