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BARTŁOMIEJ GRZESIK[1]

Hornfels from Łażany and its impact on the functional properties of granodiorite aggregate

Introduction

Granodiorite is among the igneous rocks of the largest volume of the recognised resources in Poland, followed by granite, porphyry, gabro, melaphyre and basalt. Out of the 9 documented deposits, only the Łażany II deposit has been extracted, with the output volume of 387.000 Mg/year in 2016, 500.000 Mg/year in 2017, 365.000 Mg/year in 2018 and 268.000 Mg/year in 2019 (Szuflicki et al. eds. 2017, 2018, 2019, 2020). Medium-crystalline, porphyry granodiorite (along with fine-crystalline tonalite) constitutes 76% of the deposit's resources (Walendowski 2013). The granodiorites exhibit embedded xenoliths of shell rocks of various sizes, represented by hornfels, amphibolites, and crystalline carbonate rocks (Majerowicz 1966; Majerowicz and Mierzejewski 1995), as well as marble (Łobos et al. 2019). Hornfels are represented by several varieties with a different mineral composition (Majerowicz 1966). In the course of current petrographic research of Łażany aggregate components (Grzesik 2017), two basic types with a fine-grained structure were identified – light gray with a greenish tinge and dark gray. The mineral composition of hornfels consists

Corresponding Author: Bartłomiej Grzesik; e-mail: bartlomiej.grzesik@polsl.pl
[1] Silesian University of Technology, Gliwice, Poland; ORCID iD: 0000-0003-2586-887X; mail: bartlomiej.grzesik@polsl.pl

of such components as quartz, sillimanite, amphibole, biotite and less frequently feldspar represented by plagioclases. The mineral composition is complemented by opaque minerals present mainly in dark gray hornfelases, represented by ilmenite less frequently by pyrrhotine with chalcopyrite. The dark gray variety is dominated by dark components (amphibole, biotite and opaque minerals), while the light gray variety with a greenish tinge is dominated by light minerals (quartz, sillimanite and feldspar) (Grzesik 2017).

Due to its low level of extraction (Szuflicki et al. eds. 2017, 2018, 2019, 2020; Glapa ed. 2020), granodiorite does not play a key role in the domestic resource economy in the context of the production of building materials, including road aggregates. For this reason, the subject of the functional properties of granodiorite has not received much attention so far. The high quality of the raw material is confirmed by a few mentions (Dziedzic et al. eds. 1979; Kozłowski 1986). Few studies provide more detailed information on selected physical and mechanical properties of granodiorites (Koźma et al. 2013), including the granodiorite from Łażany (Glapa and Sroga 2005; Walendowski 2013). The favorable technical parameters cause that granodiorite is valuable raw material for the production of high-quality grits that are used in the most demanding road technologies, including the production of bituminous mixtures. Low water absorption by weight, high resistance to freezing, resistance to fragmentation and resistance to polishing particularly predispose granodiorite grits to be used in bituminous mixtures suitable for heavy traffic wearing courses exposed to weather conditions and direct impact of vehicle wheels. Granodiorite aggregate is bright, which is a feature that has gained importance in recent years in the light of the requirements for aggregates for wearing courses in national roads. The lightening of the wearing course is a trend aimed at increasing safety and reducing the temperature of the asphalt pavement in summer (lower absorption of sunlight) (Tran and Powell 2009; Emery et al. 2014; Filipczyk and Kukielska 2016). In addition to the physical and mechanical properties, chemical properties are also important in the technology of bituminous mixtures – in particular the content of silica, which is the criterion for the chemical classification of igneous rocks. High acidity reduces the ability of asphalt to adhere to the aggregate, i.e., it weakens the adhesion, the main force on which the durability of bituminous composites is based (Błażejowski and Styk 2004). In this view, the Łażan granodiorite, with the SiO_2 content not exceeding 65% (by weight) (Majerowicz 1972) can be still classified as an unreactive rock, which makes it more suitable for bituminous mixtures than the granites from the Strzegom-Sobótka massif containing at least 70% of SiO_2 (Majerowicz 1972).

Horfels is not extracted on an industrial scale in Poland. The reserves of this metamorphic rock in two deposits, Graniczna and Stanisław, are estimated at 2,922,000 Mg (Szuflicki et al. eds. 2020). It is not surprising that the information on the technical properties of domestic hornfels in the literature is rarely found. Its low water absorption (in the range of 0.28–1.6%), complete resistance to freezing, high compressive strength (average value 174 MPa) and good affinity with bitumen are mentioned only by Kozłowski (Kozłowski 1986) and Dziedzic et al. eds. (Dziedzic et al. eds. 1979). However, these data refer to the raw material from the Widok and Ujazd deposits, which are no longer included in The balance of mineral resources in Poland. That was time, when the Łażany II deposit (Figure 1) has not been exploited yet.

Fig. 1. The eastern part of the Łażany II deposit with the hornfels zone occurrence (between yellow lines)

Rys. 1. Wschodnia część złoża Łażany II ze strefą wystąpienia hornfelsów (między żółtymi liniami)

The first petrographic analyzes of the aggregate from Łażany, extracted at the time from the asphalt concrete sample of the wearing course, took place in 2015. The petrographic analysis of samples taken from 8/11 grit obtained in subsequent years from various bituminous mixture plants (WMB) excluded accidental contamination of grit with hornfels, simultaneously confirming that hornfels is a natural component of the aggregate (Grzesik 2017). Further, in-depth research that aimed at identifying the technical properties of two varieties of hornfels, isolated from the granodiorite aggregate, was conducted in 2017–2020 at the Chair of Geotechnics and Roads at the Faculty of Civil Engineering of the Silesian University of Technology. The results of these works are presented in this paper.

1. Research material

The subject of the research was crushed-stone aggregate with a grain size of 8 to 11 mm (8/11). Currently, the upper limit of the aggregate grain size used in all types of bituminous mixtures for wearing courses, both in Europe and in Poland, is 11 mm (GDDKiA 2014b).

The 8/11 fraction is at the same time the smallest one that requires determination of resistance to freezing (PN-EN 1367-1:2007) as per the national requirements (GDDKiA 2014a). It is also the only fraction for which the PSV polishing resistance is determined (PN-EN 1097-8:2020-09) as well as affinity with bitumen (PN-EN 12697-11:2012). The strict requirements in terms of physical and mechanical properties as well as resistance to weather conditions, especially concerning the aggregate with a grain size of 8/11 mm, are dictated by the special role they play as component of bituminous mixtures in the wearing courses. During the exploitation of the wearing course, partially devoid of the bitumen shell as a result of the direct impact of friction caused by contact with the wheels of moving vehicles, coarse aggregate grains determine the basic operational parameters of the road pavement. These include the parameters directly related to the safety of users: surface condition, roughness, reflectivity. In addition to mechanical factors, coarse aggregate grains on the surface of the wearing course are directly exposed to exterior factors, including those influenced by winter maintenance measures (e.g., brine). The selection of this fraction is also important due to the possibility of macroscopic identification of the petrographic type of rocks of which aggregates is composed and their manual separation. In 2016, 2017, and 2018, total laboratory sample of aggregate of the weight between 150 and 650 kg from the current production were obtained (Table 1). The preparation of laboratory samples was preceded by the following steps: washing, drying, and sorting in terms of size, consisting in the rejection of subgrain (grains smaller than 8 mm) and oversize grain (grains larger than 11.2 mm). The material prepared in this way was manually sorted according to the visually identificated petrographic type. The separated groups of: granodiorite, dark gray hornfels, and light gray hornfels with a greenish tinge (Figure 2) constituted the material for the preparation of laboratory samples.

In the period of 2016–2018, the share of individual petrographic types (in percentage by weight) in the obtained 8/11 grit total samples was also determined by the method described above (Table 1). The proportions of individual components, presented in Table 1, fluctuated significantly over the years.

Table 1. Share (by weight) of grains of particular petrographic types in the total samples of aggregate

Tabela 1. Udział ziaren poszczególnych typów petrograficznych w próbkach ogólnych kruszywa

Year of sampling	Mass of the total sample (kg)	Share of individual petrographic types % (weight) in the 8/11 aggregate		
		Granodiorite	dark gray hornfels	light gray hornfels with a greenish tinge
2016	150	91.9	5.5	2.6
2017	650	56.8	25.0	18.2
2018	150	78.5	16.0	5.5

Fig. 2. The groups of samples of selected rock types separated from aggregate with grain size 8/11 populations separated from the general 8/11 aggregate samples, from the left: granodiorite, dark gray hornfels, light gray hornfels with a greenish tinge

Rys. 2. Wyodrębnione z próbek ogólnych kruszywa 8/11 próbki wybranych typów skał, od lewej: granodioryt, hornfels o barwie ciemnoszarej, hornfels o barwie jasnoszarej z odcieniem zielonkawym

2. Standard

The nature of the research was comparative. Determinations of the most important properties in the context of the use of aggregate in bituminous mixtures, especially for wearing courses, were carried out for the petrographic types of rocks isolated from the aggregate.

The current requirements for aggregates used in road construction relate primarily to physical and mechanical properties (PN-EN 1097 standard series: Tests for mechanical and physical properties of aggregates). In the case of aggregates used in road construction, weathering properties (PN-EN 1367 standard series: Tests for thermal and weathering properties of aggregates) and affinity between aggregate and bitumen (PN-EN 12697 standard: Bituminous mixtures – test methods for hot mix asphalt) should also be considered as important. Chemical properties complete the characteristics of the aggregate, while for natural aggregates only the determination of lightweight contaminators like lignite or coal (according to PN-EN 1744-1+A1:2013-05 standard) is required along with the simplified petrographic characteristics according to PN-EN 932-3. The method of preparing the research material excluded the possible presence of light impurities in laboratory samples, therefore this aspect was beyond the scope of the research program. A simplified petrographic description is most often identified with the determination of the chemical composition of the aggregate, which allows for not only qualitative, but also quantitative identification of chemical components, such as silica (SiO_2), which content is crucial for the possible use of aggregate in bituminous mixtures.

The study also included methods currently not applicable, such as determination of bitumen adhesion (according to PN-B-06714-22:1984 standard withdrawn in 2016) and determination of crushing strength (according to PN-B-06714-40 standard withdrawn in 2005). It was considered that these parameters would complete the image of the examined aggregates in terms of determination of the affinity between aggregate and bitumen (according to PN-EN 12697-11 standard) and determination of resistance to fragmentation (according to PN-EN 1097-2 standard), as defined using a different methodology.

The following properties of the aggregates were determined in the course of comparative tests:

- determination of resistance to fragmentation according to PN-EN 1097-2:2010 standard,
- determination of particle density according to PN-EN 1097-6:2013-11 standard,
- determination of water absorption according to PN-EN 1097-6:2013-11 standard,
- determination of resistance to freezing and thawing according to PN-EN 1367-1:2007 standard,
- determination of resistance to freezing and thawing in the presence of salt (NaCl) according to PN-EN 1367-6:2008 standard,
- determination of the affinity between aggregate and bitumen according to PN-EN 12697-11:2012 standard,
- determination of bitumen adhesion according to PN-B-06714-22:1984 standard,
- determination of crushing strength according to PN-B-06714-40 standard,
- simplified petrographic description according to PN-EN 932-3:1999 as the oxide composition analysis made with ZSX PRIMUS RIGAKU X-ray fluorescence spectrometer,
- examination for the presence of reactive iron sulphide particles according to chapter 14 of the PN-EN 1744-1+A1:2013-05 standard.

3. Results

The averaged results of resistance to fragmentation with standard deviation for five test series (error bars) are displayed in Figure 3.

The averaged results of determination of crushing strength with standard deviation for five test series (error bars) are displayed in Figure 4.

Density and water absorption were determined by means of pycnometry. The density result was presented as an arithmetic mean of two determinations on samples weighing 1,000 g (Figure 5). The water absorption result was presented as an arithmetic mean of three determinations on 1,000 g samples (Figure 6). Error bars show the standard deviation in each series.

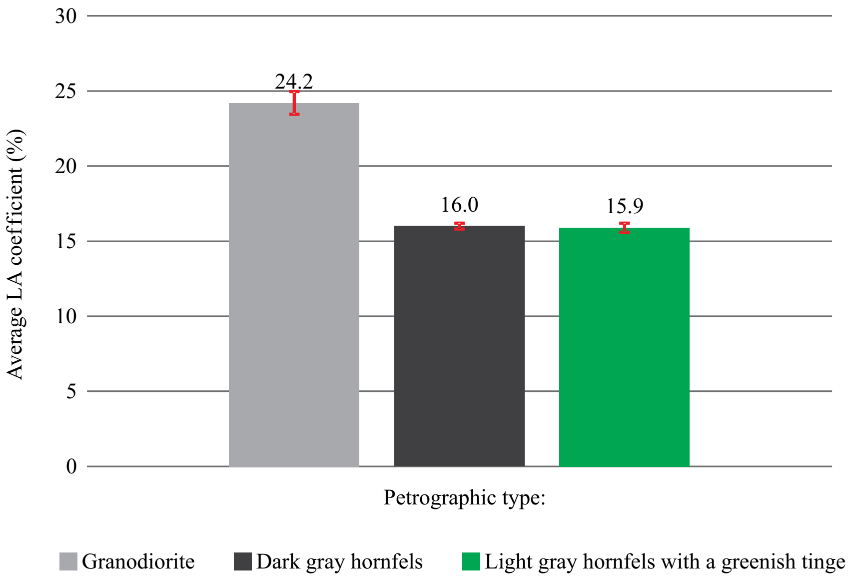

Fig. 3. Determination of resistance to fragmentation of investigated aggregate in relation to selected petrographic rock types

Rys. 3. Określenie odporności na rozdrabnianie kruszywa w zależności od typu petrograficznego skały

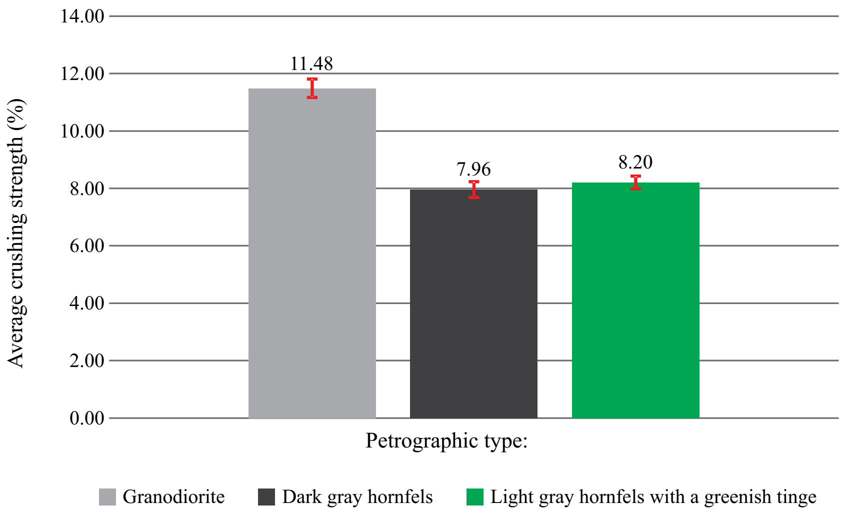

Fig. 4. Average crushing strength of investigated aggregate in relation to selected petrographic rock types

Rys. 4. Średnia wytrzymałość na miażdżenie kruszywa w zależności od typu petrograficznego skały

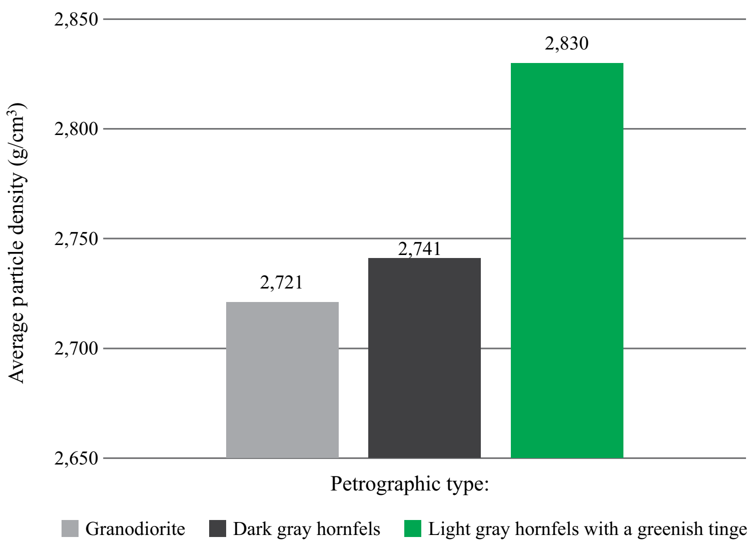

Fig. 5. Average particle density of investigated aggregate in relation to selected petrographic rock types

Rys. 5. Średnia gęstość ziaren kruszywa w zależności od typu petrograficznego skały

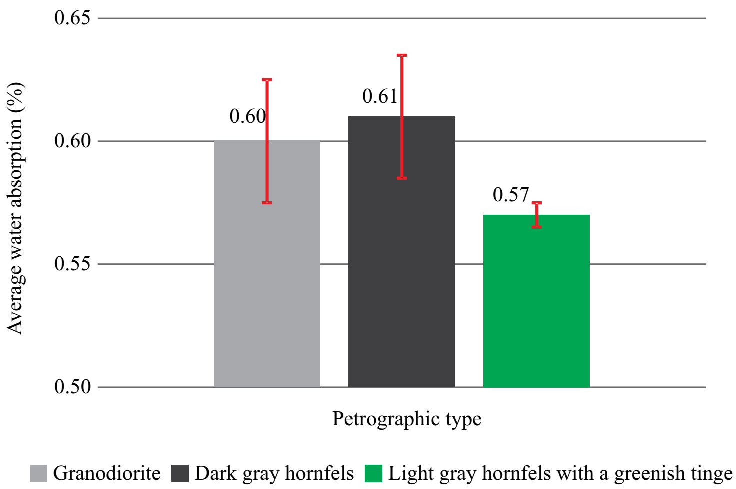

Fig. 6. Average water absorption of investigated aggregate in relation to selected petrographic rock types

Rys. 6. Średnia nasiąkliwość kruszywa w zależności od typu petrograficznego skały

Resistance to freezing is closely related to water absorption. Aggregates with water absorption below 0.5% (weight) can be considered frost-resistant. In the case of greater water absorption, resistance to freezing should be determined. In accordance with the requirements for aggregates used for wearing courses, the resistance to freezing in 1% NaCl solution is additionally determined, simulating aggressive conditions occurring during winter maintenance of the pavement. The measure of resistance to freezing is the loss of mass of a sample expressed as the mass which, after a specified number of freeze-thaw cycles, passes through a sieve of size d/2. In the case of 8/11 aggregate, the weight loss consists of grains smaller than 4 mm. All determinations of resistance to freezing were carried out on a series of three samples weighing 2,000 g each. The results are summarised in Figure 7.

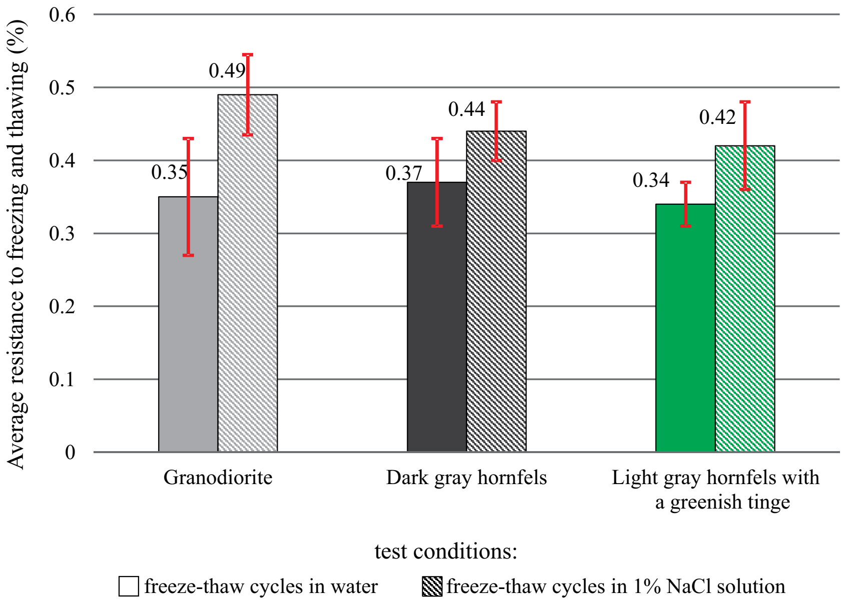

Fig. 7. Average resistance to freezing and thawing results of samples submerged in water (left side) and in 1% NaCl solution (right side)

Rys. 7. Średnia mrozoodporność próbek zanurzonych w wodzie (po lewej) oraz w 1% roztworze NaCl (po prawej)

In the case of both methods of determining bitumen adhesion to aggregate, its measure is the degree of asphalt coverage of the grains expressed in (%); however, the test process differs significantly. Testing of bitumen adhesion to aggregate according to the PN-B-06714-22:1984 standard consists in acting on the aggregate sample surrounded by bitumen with boiling water. After the samples have been prepared and placed in the beakers, they are brought to the boiling state in 10±1 min. After this time, the samples should be kept in this state for 3 minutes. After finishing the boiling and drying, the samples are visually assessed to determine the percentage of asphalt remaining on the aggregate surface. Due to the assumptions of the standard, the weight of the laboratory sample of 8/11 aggregate and the necessary amount of 50/70 road bitumen to cover the surface of all its grains were interpolated.

Finally, the weight of the aggregate sample was assumed at 75 g, and the amount of bitumen at 2.2 g. The test result is the arithmetic mean of two determinations.

In the case of affinity determination according to the PN-EN 12697-11 standard, the test consists of placing aggregate samples surrounded by bitumen in a roller agitator and

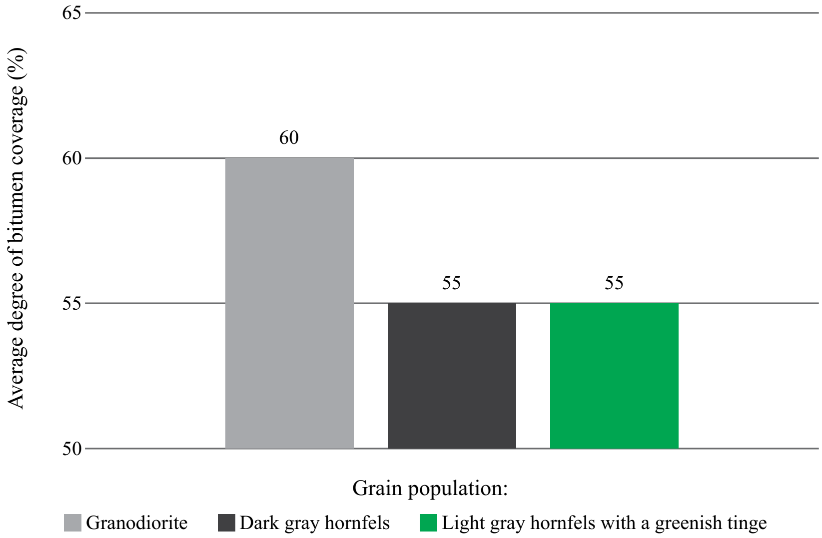

Fig. 8. Average degree of bitumen coverage according to the PN-B-06714-22:1984 standard

Rys. 8. Średni stopień pokrycia bitumem według normy PN-B-06714:22:1984

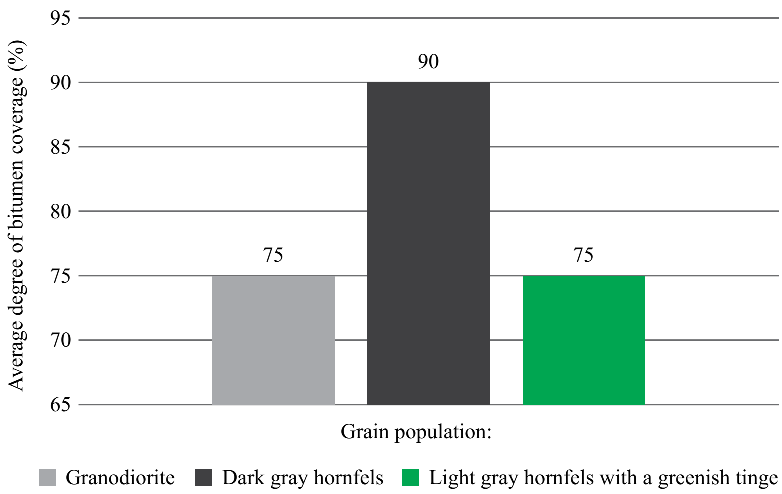

Fig. 9. Average degree of bitumen coverage after 6 hours of rolling according to the PN-EN 12697-11:2012 standard

Rys. 9. Średni stopień pokrycia bitumem po 6 godzinach mieszania zgodnie z normą PN-EN 12697-11:2012

Table 2. Chemical composition (in percentage by weight) of the investigated petrographic varieties of aggregate

Tabela 2. Skład chemiczny (w procentach wag.) badanych odmian petrograficznych kruszywa

Chemical component	Granodiorite	Dark gray hornfels	Light gray hornfels with a greenish tinge
SiO_2	60.77	67.99	58.33
TiO_2	1.11	0.59	0.42
Al_2O_3	16.26	11.81	14.91
Fe_2O_3	4.44	4.90	4.42
MnO	0.07	0.12	0.15
MgO	1.30	1.88	1.56
CaO	5.43	2.73	11.45
Na_2O	3.81	2.30	4.41
K_2O	3.26	2.80	0.90
P_2O_5	0.53	0.21	0.25
VO_2	0.00	0.02	0.01
Cr_2O_3	0.00	0.01	0.01
CoO	0.00	0.00	0.00
NiO	0.00	0.01	0.00
CuO	0.00	0.00	0.00
ZnO	0.01	0.01	0.01
SrO	0.05	0.02	0.08
ZrO_2	0.01	0.01	0.02
Nb_2O_5	0.00	0.00	0.00
Ga_2O_3	0.00	0.00	0.00
Rb_2O	0.01	0.01	0.00
Y_2O_3	0.00	0.00	0.00
BaO	0.06	0.07	0.03
PbO	0.00	0.00	0.00
SO_3	0.03	1.20	0.02
C	2.03	1.95	2.13
F	0.02	0.00	0.00
Cl	0.02	0.02	0.01
LOI	0.76	1.32	0.88
Total	100.00	100.00	100.00

mixing with an appropriate rotational speed, depending on the type of bitumen used. Mixing takes place at room temperature for 6 hours ± 15 minutes. After this time, the water is drained from the bottle and the aggregate is placed in the test bowl and completely covered by pouring fresh water. Then, the degree of aggregate coverage with asphalt rounded up to 5% is estimated based on visual assessment. Optionally, the aggregate test can be continued by further assessing the degree of asphalt coverage after the next 18 hours, 48 hours, and 72 hours of washing. The weight of a single laboratory sample was 150 g, including 4.7 g of bitumen. This amount of bitumen had to be corrected in accordance with the assumptions of the standard for the density of the aggregate (Figure 5). The test result is the arithmetic mean of three determinations.

Due to the significantly different method of washing the aggregate, the obtained results of both methods presented in Figure 8 and 9 should not be correlated – they should be interpreted independently.

The chemical (oxide) composition is presented in Table 2.

Due to the significantly higher content of SO_3 identified in dark gray hornfels, an additional examination for the presence of reactive iron sulphide particles according to chapter 14 of the PN-EN 1744-1+A1:2013-05 standard has been conducted. The test consists in a 30-minute immersion of the aggregate in saturated limewater. The alkaline environment is to provoke the decomposition of reactive iron sulphide. FeS pyrrhotite is considered as the reactive iron sulphide and oxidises 20 to 100 times faster than FeS_2 pyrite (Shaw et al. 1998). The appearance of a blue-green gelatinous precipitate of iron (II) hydroxide (incorrectly referred to as ferrous sulphate in the standard) within 5 minutes confirms the presence of pyrrhotite (FeS). Next, the precipitate changes rapidly to brown iron (III) hydroxide on exposure to air and light. The chemical reactions are as follows:

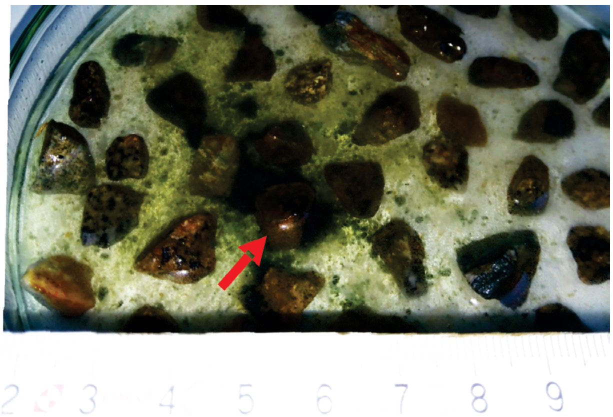

Fig. 10. Precipitate of short-lived iron (II) hydroxide formed around the dark gray hornfels grain (marked) containing pyrrhotite

Rys. 10. Nietrwały osad wodorotlenku żelaza (II) powstały wokół ziarna hornfelsu o barwie ciemnoszarej (strzałka) zawierającego pirotyn

$$FeS + 2O_2 \rightarrow FeSO_4$$

$$FeSO_4 + Ca(OH)_2 \rightarrow Fe(OH)_2 + CaSO_4$$

$$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$$

The observed iron (II) hydroxide in the tested dark gray hornfels sample is presented in Figure 10.

The other two grain populations did not indicate the presence of pyrrhotite.

4. Discussion of test results

The analysis of the resistance to fragmentation test results leads to surprising conclusions. Taking into account the current requirements for aggregates used in bituminous mixtures for wearing courses, the separated granodiorite qualifies according to the PN-EN 13043 standard to the LA_{25} category, which enable use it in mixtures for the heaviest traffic of the KR5-7 category. In turn, both types of hornfels are characterised by resistance to fragmentation classified in a higher category, i.e. LA_{20}. The high mechanical resistance of hornfels aggregate is confirmed by the crushing strength tests, according to which both varieties are characterised by resistance higher by 30% than granodiorite.

In the case of the physical parameter of key importance for the durability of the aggregate, i.e., the water absorption, granodiorite and both types of hornfels exhibit the level of approx. 0.6% of weight. In the light of the PN-EN 13043 standard, all the identified varieties of rocks have been qualify in terms of water absorption into the $WA_{24}1$ category (water absorption lower than 1.0% of weight). Although currently the requirements (GDDKiA 2014a) do not specify the maximum level of water absorption, and the manufacturer only has to declare it, the value as low as 0.6% by weight should be considered very desirable in the context of bituminous mixtures, especially for wearing courses. A similarly balanced level is presented by the freezing resistance test results obtained for granodiorite and two types of hornfels (loss of 0.3–0.4% by weight). It is worth noting that the determination carried out in an aggressive environment of 1% NaCl causes only a slightly greater loss of sample mass in relation to the loss demonstrated during the test in water (by approx. 0.1%). Currently, the resistance to freezing required from aggregates for bituminous mixtures for: (1) the base, (2) binding, and (3) wearing courses for the heaviest traffic (GDDKiA 2014a), is respectively: F_4 category (up to 4% by weight), F_2 category (up to 2% by weight), and $F_{NaCl}7$ category (up to 7% by weight). This means that the studied granodiorite and hornfels grains meet these requirements with a very large reserve.

The determination of the affinity with bitumen performed by means of the aforementioned two methods yielded divergent results. In the case of the current method, where the bitumen covering the aggregate grains is mechanically separated during the rotation of the bottles with samples, the dark gray hornfels was characterised by coverage at the level of 90% (after 6 h). Samples of granodiorite and light gray hornfels with a greenish tinge showed coverage at the level of 75%. Comparing the results to the applicable requirements (GDDKiA 2014b) for this feature, i.e., at least 80% of bitumen coverage of the grains after 6 hours, the presence of dark gray hornfels in the aggregate should be considered highly desirable. In assessing the correctness of the results obtained using this method, it is useful to analyse the chemical composition of the examined aggregates. Dark gray hornfels contains noticeably more SiO_2 (approx. 68% by weight) than light gray hornfels and granodiorite. Meanwhile, bitumen is an electronegative colloid, therefore it exhibits better adhesion to basic (electropositive) aggregates than to acidic (electronegative) aggregates (Pawłowska et al. 2018). Therefore, it was expected that the dark gray hornfels would show the lowest degree of asphalt coverage. The above results lead to the conclusion that the relatively even level of coverage of the grains of all investigated petrographic types after washing in boiling water is in this case more reliable than the one obtained according to the applicable methodology. Coverage of 60% is typical for aggregates with silica content at this level and indicates the need for adhesives in the production of Warm Mix Asphalt.

The chemical composition tests confirm that in the light of the generally accepted division of rocks into acidic, nonreactive, and alkaline depending on the silica content, granodiorite from Łażany is classified as nonreactive (60.77% SiO_2). Light gray hornfels with a greenish tinge (58.33% SiO_2) also belongs to this group. Meanwhile, the dark gray variety of hornfels is an acidic rock (67.99% SiO_2). In the context of the durability of the aggregate, it is worth paying attention to the content of total sulphur (here converted to SO_3). Dark gray hornfels contains noticeably more sulphur (1.2% SO_3) than granodiorite and light gray hornfels. In the case of sulphur content at this level (which is approx. 0.5% of weight, converted into elemental sulphur S), it is advisable to determine its source. Particularly undesirable sources of sulphur include sulphides present in the mineral composition of the rock, especially iron sulphide FeS (pyrrhotite). Due to its reactivity, the PN-EN 1744-1+A1:2013-05 standard provides for the examination for the presence of reactive iron sulphide particles as components affecting the concrete surface finish. The sulphur level and the possible presence of sulphides are not limited by the requirements of PN-EN 13043:2004 standard in the case of aggregates for bituminous mixtures, while in the case of aggregates for concrete, the PN-EN 12620+A1:2010 standard specifies such restrictions. According to the PN-EN 12620+A1:2010 standard, the total sulphur content in the aggregate should not exceed 1% (weight), and if the presence of pyrrhotite in the aggregate has been confirmed, only 0.1% (weight). In the reaction with saturated limewater, the presence of pyrrhotite was confirmed in some grains of the dark gray hornfels sample. The presence of this iron sulphide should be taken into account when using aggregate in concrete, e.g., in a concrete pavement.

Conclusions

Recently, a trend of using aggregates made up of different rocks with varying properties in wearing courses produced with mineral mixtures has become noticeable. Grains from different types of rocks show different susceptibility to the damaging effects of traffic, weather, or chemical factors (winter maintenance). If the right proportions are retained when composing such mineral mixtures, the wearing course can maintain the desired level of certain performance characteristics such as roughness or reflectivity for a longer period. In principle, the homogeneous granodiorite aggregate was unintentionally modified due to the hornfels grains present in it. As demonstrated in the research, the presence of hornfels with a strength 30% greater than that of granodiorite has a positive effect, mainly on the mechanical properties of the aggregate produced in Łażany. Hornfels exhibits practically the same physical properties as granodiorite and in this respect it does not lower the quality of the aggregate. In terms of chemical properties, the tested aggregate components are more diversified. Although the differences in the silica content reach 10% by weight, no significant differences in the affinity with bitumen were found for the individual populations of grains. However, among the tested populations the content of reactive iron sulphide in dark gray hornfels is higher. This feature is undesirable from the perspective of using aggregate in cement concrete. It is also worth examining when the aggregate is intended for bituminous mixtures used in wearing courses.

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HORNFELS FROM ŁAŻANY AND ITS IMPACT ON THE FUNCTIONAL PROPERTIES OF GRANODIORITE AGGREGATE

Keywords

granodiorite, hornfels, aggregate, asphalt mix, wearing course

Abstract

This paper presents the results of research on the admixture of other rock fragments in the granodiorite aggregate (two types of hornfels) produced in Łażany II quarry. It discusses the impact of these components on the selected chemical and mechanical properties important for the use of the aggregate in road construction. Analysed granodiorite grit is a high-class construction material suitable for bituminous mixtures. Its quality is verified in accordance with the PN-EN 13043 standard. The admixture of hornfels in aggregate composition is a consequence of the natural occuring this rock in the Łażany II granodiorite deposit in the Strzegom-Sobótka massif. As there is not selective exploitation of the deposit an extracted raw material is not separated during processing As a result, the aggregate, composed predominantly of granodiorite, comprises variable admixture of hornfels. Tests of properties, such as water absorption, resistance to freezing, resistance to fragmentation, crushing strength, carried out on grain populations of various petrographic types separated from the general samples, exhibit that the presence of hornfels in the aggregate has a beneficial effect, particularly on the mechanical parameters of the produced aggregate. Moreover, two varieties of hornfels differ in terms of some chemical properties (affinity with bitumen, presence of sulphides). These features may affect the durability of the aggregate in the wearing course which is directly influenced by the exterior conditions typical for road pavements.

**HORNFELS Z ŁAŻAN I JEGO WPŁYW
NA WŁAŚCIWOŚCI UŻYTKOWE KRUSZYWA GRANODIORYTOWEGO**

Słowa kluczowe

granodioryt, hornfels, kruszywo, mieszanka mineralno-asfaltowa, warstwa ścieralna

Streszczenie

W artykule przedstawiono wyniki badań obecnych w produkowanym w Łażanach kruszywie granodiorytowym domieszek innych fragmentów skał (dwóch odmian hornfelsu). Omówiono ich wpływ na kształtowanie wybranych właściwości chemicznych i mechanicznych, istotnych z uwagi na wykorzystanie wyrobu w drogownictwie. Badany grys granodiorytowy jest wysokiej klasy wyrobem budowlanym przeznaczonym do mieszanek mineralno-asfaltowych, którego jakość weryfikuje się zgodnie z normą zharmonizowaną PN-EN 13043. Domieszka ziaren kruszywa zidentyfikowanych jako hornfels jest konsekwencją naturalnej obecności tej skały w złożu granodiorytu Łażany II w masywie Strzegom-Sobótka. Podczas przeróbki surowce skalne występujące w złożu nie są separowane, a w efekcie kruszywo, którego dominującym składnikiem jest granodioryt, wykazuje także zmienną w czasie zawartość hornfelsu. Badania właściwości takich jak nasiąkliwość, mrozoodporność, odporność na rozdrabnianie, odporność na miażdżenie, przeprowadzone na populacjach ziaren różnych typów petrograficznych wyodrębnionych z próbek ogólnych dowodzą, że obecność hornfelsu w kruszywie ma korzystny wpływ zwłaszcza na poziom parametrów mechanicznych produkowanego kruszywa. Ponadto dwie odmiany hornfelsu wykazują zróżnicowanie w aspekcie niektórych cech chemicznych (powinowactwo z asfaltem, obecność siarczków). Cechy te mogą wpływać na trwałość kruszywa w warstwie ścieralnej pozostającej pod bezpośrednim wpływem zewnętrznych warunków typowych dla nawierzchni drogowych.