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Results of the Study of Mining and Processing Plant Waste for the Construction of Motor Roads and Railway Tracks

Abstract. The pavement of technological motor roads consists of rock formations extracted from the quarry. With the current increase in the tonnage of quarry transport, the road pavement structure is also changing. On the other hand, the construction of the railway subgrade on dumps and stripping horizons of the quarry leads to increased operating costs for track repair and maintenance works. The relevant task is to investigate the physical and mechanical properties of rock materials from PJSC "Inhulets Mining and Processing Plant" (InGZK), to develop optimization measures and recommendations for the efficient use of these rocks for technological road pavements and the construction of railway embankments within the quarry and waste dumps of PJSC "InGZK". The aim of this paper is to study the physical and mechanical properties of the rock formations of PJSC "InGZK" and to determine the grain-size composition of crushed stone produced from dense hard rocks. To determine the physical and mechanical properties of the rock materials of PJSC "InGZK," the following were sampled: iron ore rock (migmatite) and associated dense rock types such as amphibolites, schists, granites, substandard quartzites, oxidized quartzites, oxidized jaspilites, and arkosic metasandstones. Experimental studies provided the physical and mechanical parameters and data on the grain-size composition of crushed stone from these rocks. Examination of the structure of amphibolites and schists from PJSC "InGZK" showed that these rocks have a dense texture, which provides high strength (1000 and 1200), and their mineral inclusions do not require additional beneficiation. The grains of crushed stone obtained from amphibolites and schists of PJSC "InGZK" have a cubical shape and high void content. This opens up the possibility of their use in the construction of roads and railway tracks, as well as in concrete and reinforced-concrete structures.

Keywords: physical and mechanical properties; rock; motor roads; technological quarry roads; railway tracks.

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Introduction.

Dense rocks, including iron ore rocks and associated dense rocks produced during iron ore extraction, are used for the construction of technological transport roads and railway tracks within quarries and waste dumps at every mining and processing plant [6,8]. For urban, civil, industrial, and highway construction, dense waste rocks are currently almost never used and are instead accumulated as waste material. Therefore, a more detailed study of the rock formations of the Inhulets Mining and Processing Plant is of current relevance. Determining their physical and mechanical properties and the possibilities of their use in construction materials production creates prospects for the construction of motor roads and railway lines and contributes to solving environmental problems.

Analysis of Recent Research and Publications.

The work [4] notes that the use of mining and processing plant waste in road construction significantly increases production efficiency and reduces the cost of modern construction materials.

Studies, industrial trials, and the experience of several industrial enterprises show that extraction and beneficiation waste serve as excellent raw material for the production of crushed stone and other construction materials. In [5], the issues of recycling mining and processing waste are addressed; these wastes can serve as raw materials for producing building materials, including those for road construction.

It is determined that the use of various waste materials during the construction of motor roads is a viable option that requires further study [6].

In the Kryvyi Rih Iron Ore Basin, five mining and processing plants operate, employing ball and autogenous grinding technologies, as discussed in [8].

However, these sources do not contain information regarding the determination of the physical and mechanical properties of hard rock materials, which could reveal their potential for use in construction.

An additional problem is that most of the dense rock materials are used for technological quarry roads and are stockpiled in dumps, while their use in railway track construction is limited due to uncertainty regarding their properties. This emphasizes the need to study the physical and mechanical properties of dense rocks, both for mining and processing plants and for the construction of intercity motor roads and railway tracks in general.

Purpose and Research Methods.

The objective of the study is to investigate the physical and mechanical properties of hard rock formations and to determine the characteristics of crushed stone obtained from dense hard rocks for use in construction. The research was conducted in the following sequence. Point samples of dense hard rocks were taken from the quarry of PJSC "InGZK." After sampling, the point samples were combined into laboratory samples, which, depending on the rock type, were selected from the stockpile and transported to the laboratory.

Figure 1 – Sampling of dense rock specimens from the storage site (Source: Author's photo)

For the testing, laboratory samples prepared by the quartering method were used with particle sizes of 0–70 mm and 0–40 mm. Laboratory tests were carried out according to the methodology of physical and mechanical tests in compliance with [2].

Main Material and Results

Order of research performed: determination of grain composition, content of flaky (lamellar) and needle-shaped grains, bulk density, determination of crushability of crushed rock from dense rock formations of PJSC "Ingulets GOK".

Determination of grain composition

The migmatites of PJSC "InGZK" are lamellar quartz-ferruginous metamorphic rocks of volcanogenic-sedimentary origin with a high iron content, classified as dense hard rocks. They are used as iron ore in current production at PJSC "InGZK" and as crushed stone for technological roads and railway tracks on ore horizons of the quarry. The grain-size composition of the 5–70 mm fraction of migmatite is presented in Table 1.

Table 1 – Grain-size composition of 5–70 mm class from migmatite, PJSC "InGZK", m = 10,906 g

Sieve, mm	40	20	10	5
mi, g	1486	6400	2450	570
ai, %	13,2	56,9	21,8	5,1

Substandard quartzites are quartz-ferruginous metamorphic rocks of volcanogenic-sedimentary origin with low iron content and belong to the category of hard rocks [1,3].

They are used for technological quarry roads, railway tracks, and are stockpiled in waste dumps of PJSC "InGZK." The grain-size composition of 5–70 mm classes of substandard and oxidized quartzites is presented in Tables 2 and 3.

Table 2 – Grain-size composition of 5–70 mm class from substandard quartzites, PJSC "InGZK", m = 13,320 g

Sieve, mm	40	20	10	5
mi, g	540	7060	3900	1820
ai, %	3,9	51,4	28,4	13,3

Table 3 – Grain-size composition of 5–70 mm class from oxidized quartzites, PJSC "InGZK", m = 8,914 g

Name of the residue	Residues, %, by weight on sieves, mm			
	40	20	10	5
mi, g	540	7060	3900	1820
ai, %	3,9	51,4	28,4	13,3

Oxidized jaspilites are metamorphic rocks with silicate interlayers, laminated, of reddish tint, and folded texture. The iron content is insignificant. These are stockpiled in dumps of PJSC "InGZK." The grain-size composition of oxidized jaspilites is shown in Table 4.

Figure 2 presents their sieving on a standard set of sieves using electronic digital bench scales.

Table 4 – Grain-size composition of 5–70 mm class from oxidized jaspilites, PJSC "InGZK", m = 12,808 g

Sieve, mm	40	20	10	5
mi, g	412	6363	1898	4135
ai, %	4,4	68,2	20	44

Figure 2 – Sieving of 5–70 mm fraction from oxidized jaspilites, PJSC "InGZK" (Source: Author's photo)

Schists of PJSC "InGZK" are talc-bearing rocks composed of talc flakes with admixtures of quartz, chlorite, mica, and occasionally magnesite. Color: grey, with a silky luster. The iron content is almost absent. They are used for technological quarry roads and stockpiled in waste dumps of PJSC "InGZK." The grain-size composition of schists is given in Table 5, and Figure 3 shows the weighing of the 20–40 mm crushed stone fraction on electronic bench scales.

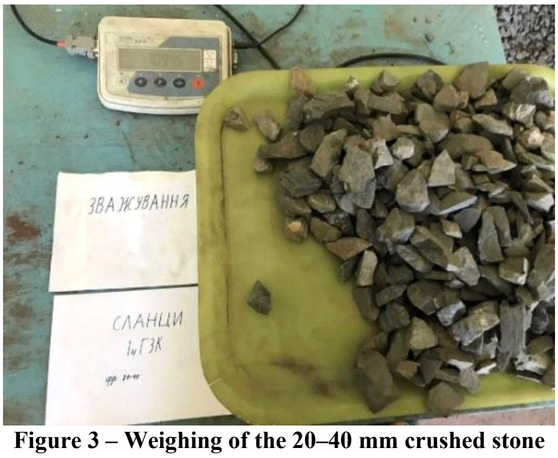

Figure 3 – Weighing of the 20–40 mm crushed stone fraction from schists on electronic bench scales " (Source: Author's photo)

Table 5 – Grain-size composition of 5–70 mm class from oxidized quartzites, PJSC "InGZK", m = 8,914 g

Name of the residue	Residues, %, by weight on sieves, mm			
	40	20	10	5
mi, g	820	7100	3632	1381
ai, %	6	53	27	10

Amphibolite is a metamorphic hard rock. It contains no iron. It is formed from deep metamorphic basalts, gabbros, marly clays, limestones, and peridotites. It is used for the construction of technological quarry roads at PJSC "InGZK."

The grain-size composition of the 0–70 mm class from amphibolites of PJSC "InGZK" is presented in Table 6, and that of arkosic metasandstones is shown in Table 7**.**

Table 6 – Grain-size composition of the 0–70 mm class from amphibolite, PJSC "InGZK", m = 3807g

Sieve, mm	40	20	10	5
mi, g	600	2307	467	443
ai, %	15	59	12	11

Arkosic metasandstone is a clastic sedimentary rock composed of sand-sized grains of quartz and orthoclase. The fragments are cemented with clay minerals, silica, and iron oxides. It is stockpiled in waste dumps.

Table 7 – Grain-size composition of the 0–70 mm mixture from arkosic metasandstones, PJSC "InGZK", m = 7628 g

Sieve, mm	40	20	10	5
mi, g	600	2307	467	443
ai, %	15	59	12	11

According to [1, 2, 3], in crushed stone fractions supplied for construction, the amount of grains smaller than d should not exceed 10%, and grains larger than 1.25 × D should not exceed 0.5%.Analysis of data from Tables 1–7 on grain-size distribution shows that:

a) the mixtures of 5–70 mm crushed stone fractions of substandard quartzites, oxidized jaspilites, amphibolites, and schists are comparable;

b) mixtures of 10–70 mm crushed stone fractions correspond to migmatite and oxidized quartzite;c) mixtures of 20–70 mm fractions correspond to arkosic metasandstone.

Determination of the Content of Flaky (Lamellar) and Needle-Shaped Grains in Crushed Stone

The content of flaky (lamellar) and needle-shaped grains in the crushed stone was evaluated based on the number of grains whose thickness is less than one-third of their length [2].

The testing procedure was as follows: after measuring the analytical sample with a caliper and separating grains of lamellar and needle shape, the weighed portions of crushed stone were determined on electronic bench scales for the fractions 5–10 mm, 10–20 mm, and 20–40 mm, including the separated lamellar and needle-shaped grains.For all rock types, the following steps were performed: sampling of the laboratory specimen from the stockpile, weighing the laboratory specimen, taking and weighing the analytical sample for each fraction, and selecting and weighing the lamellar and needle-shaped grains in the crushed stone.

The content of lamellar and needle-shape grains (20-40 mm fraction) was determined: in oxidized quartzites and migmatites 17–18%; in shales, amphibolites, non-standard quartzites, oxidized jaspilites, arkose metapískovíky 8.1–13%.

Determination of Bulk Density of Crushed Stone from Dense Rocks

To determine the bulk density of sand and crushed stone from dense rocks of PJSC "InGZK," the following were used: iron ore rock and associated dense hard rocks of iron ore production — migmatites, amphibolites, schists, substandard quartzites, oxidized quartzites, oxidized jaspilites, granites, and arkosic metasandstones.

The bulk density of the crushed stone was determined by weighing a dried analytical sample of a given fraction to a constant mass.For the test, the crushed stone was dried to constant mass, poured into a pre-weighed cylinder from a height of 10 cm until the formation of a cone, which was leveled with a steel ruler flush with the edges (without compaction), and then the cylinder with the crushed stone was weighed.

The established bulk densities of the hard rocks of PJSC "InGZK" are as follows:

- schists, amphibolites, substandard quartzites, oxidized jaspilites, oxidized quartzites — 1500 kg/m³;
- migmatites, granite — 1300 kg/m³;
- arkosic metasandstones — 1260 kg/m³.

Determination of Crushed Stone Strength (Crushability) from Dense Rocks of PJSC "InGZK"

The crushability of the crushed stone was determined by the degree of grain destruction under compression (crushing) in a steel cylinder. Two analytical samples of at least 4 kg each were taken for testing in a cylinder with a diameter of 150 mm. The arithmetic mean value of parallel tests was accepted. The results of the crushability determination for the 20–40 mm fraction of migmatite are shown in Table 8, and the filling of the cylinder with migmatite crushed stone before testing is shown in Figure 4.

Table 8 – Crushability of crushed stone from migmatite

Fraction, mm	20-40
m1, g	2188
m, g	2486

Figure 4 – Filling the cylinder with migmatite crushed stone before testing (Source: Author's photo)

The results of determining the crushability of the 20–40 mm fraction from substandard quartzites are shown in Table 9. The crushed stone sample from substandard quartzites in the cylinder under the plunger before loading is shown in Figure 5, and the loading of the oxidized quartzite crushed stone sample — in Figure 6. The results of the crushability test for oxidized jaspilites are presented in Table 10.

Table 9 – Crushability of crushed stone from substandard quartzites

Fraction, mm	20-40
m1, g	2630
m, g	2100

Figure 5 – Crushed stone sample from substandard quartzites in the cylinder under the plunger before loading (Source: Author's photo)

Figure 6 – Application of 200 kN (20,000 kgf) load to the crushed stone sample from oxidized quartzites (Source: Author's photo)

Table 10 – Crushability of crushed stone, 20–40 mm fraction, from oxidized jaspilites

Fraction, mm	20-40
m1, g	2454
m, g	2888

Crushability results for the 20–40 mm fraction of crushed stone from arkosic metasandstones of PJSC "InGZK" are given in Table 11.

Table 11 – Crushability of crushed stone from arkosic metasandstones

Fraction, mm	20-40
m1, g	1840
m, g	2390

The results of crushability testing of the 20–40 mm fraction from amphibolites of PJSC “InGZK” are presented in Table 12, and from schists — in Table 13. Figure 7 shows the weighing of crushed stone from schists after loading.

Table 12 – Crushability of crushed stone from amphibolite

Fraction, mm	20-40
m1, g	2304
m, g	2618

Table 13 – Crushability of crushed stone from schists

Fraction, mm	20-40
m1, g	2366
m, g	2632

Figure 6 – Weighing of crushed stone sample from schists after loading (Source: Author’s photo)

The crushing process determines the grade of rock formations at Ingulets GOK, which is as follows: granite – 1400; shale – 1200; amphibolites, migmatites, substandard quartzites – 1000; oxidized jaspilites – 800; oxidized quartzites – 600; arkose metapískoviki – 400

Conclusions

1. According to grain-size composition, amphibolites, schists, substandard quartzites, and oxidized jaspilites are the most suitable for use as crushed stone in construction.

2. It is established that schists, amphibolites, substandard quartzites, oxidized jaspilites, and arkosic metasandstones have a cubical grain shape.

3. Schists, amphibolites, substandard quartzites, oxidized jaspilites, and oxidized quartzites (1500 kg/m³); migmatites and granites (1300 kg/m³); and arkosic metasandstones (1260 kg/m³) are dense hard rocks of PJSC “InGZK,” exhibiting crushing strength grades from 400 to 1400.

4. Based on physical and mechanical properties, the hard rocks of PJSC “InGZK” meet the requirements for crushed stone used in the construction of technological roads and railway tracks within quarries and dumps. Amphibolites, schists, and substandard quartzites are recommended for intercity road and railway construction, monolithic buildings and structures, and may be used in reinforced-concrete products and constructions.

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Результати дослідження відходів гірничо-збагачувального комбінату для будівництва автомобільних доріг і залізничних колій

Аннотація. Покриття технологічних автомобільних доріг формується з гірських порід, видобутих у кар'єрі. За умов сучасного зростання тоннажності кар'єрного транспорту відбувається зміна конструкції дорожнього одягу. Водночас улаштування залізничного земляного полотна на відвалах і розкривних горизонтах кар'єру призводить до підвищення експлуатаційних витрат на ремонт і утримання колії. Актуальним є дослідження фізико-механічних властивостей гірських матеріалів ПрАТ «Інгулецький гірничо-збагачувальний комбінат» (ІнГЗК), розроблення заходів оптимізації та рекомендацій щодо ефективного використання цих порід для влаштування покриттів технологічних автомобільних доріг і спорудження залізничних насипів у межах кар'єру та відвалів ПрАТ «ІнГЗК». Метою роботи є дослідження фізико-механічних властивостей гірських порід ПрАТ «ІнГЗК» та визначення гранулометричного складу щебеню, отриманого з щільних міцних порід. Для визначення фізико-механічних властивостей гірських матеріалів ПрАТ «ІнГЗК» було відібрано зразки залізорудної породи (мігматиту) та супутніх щільних порід, зокрема амфіболітів, сланців, гранітів, некондиційних кварцитів, окиснених кварцитів, окиснених яспілітів і аркозових метапісковиків. У результаті експериментальних досліджень отримано фізико-механічні показники та дані щодо гранулометричного складу щебеню з цих порід. Аналіз структури амфіболітів і сланців ПрАТ «ІнГЗК» показав, що зазначені породи мають щільну текстуру, яка забезпечує високу міцність (1000 і 1200), а їх мінеральні включення не потребують додаткового збагачення. Зерна щебеню, отриманого з амфіболітів і сланців ПрАТ «ІнГЗК», характеризуються кубовидною формою та високою порожнистістю. Це відкриває можливості їх використання у будівництві автомобільних доріг і залізничних колій, а також у бетонних і залізобетонних конструкціях.

Ключові слова: фізико-механічні властивості; гірські породи; автомобільні дороги; технологічні кар'єрні дороги; залізничні колії.

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