Investigation of Diopside Rocks from Deposits of the «Aldanslyuda» Mining and Processing Plant as a Raw Material for Concrete Production

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Abstract. The paper presents the results of studies of diopside rocks collected from the “Aldanslyuda” mining and processing plant dumps as aggregates for the production of heavy-weight and sand concretes. The presented data shows that the average chemical composition of these diopside rocks is on: SiO2 - 46.38%, CaO2 - 16.53% and MgO2 - 15.30%. The low content of magnesium and calcium dioxides indicates that even when the specific surface area is increased to 5000 cm²/g and above, the diopside will only work as a filler. The mineralogical composition of rocks is represented by diopside, actinolite and paragasite. It was found that it is more efficient to use diopside rocks as an aggregate to produce concrete. By testing the crushed stone of a mixture of a fraction from 5 to 20 mm and sand from sifting of crushing solid stone, it was shown that these diopside rocks are suitable as aggregates to produce heavy-weight and sand concretes of strength class up to 60 MPa. To consider the possibility of using them to obtain high-strength concretes, it is necessary to conduct more experimental research.

1. Introduction
The problem of recycling industry waste is always relevant and aimed to solve environmental issues. On the other hand, the development of the production of building materials based on local raw materials solves several economic problems in the harsh climatic conditions of the North and especially in Yakutia, where the distances between the bases of the construction industry are significant. During the exploitation of several large deposits of phlogopites in the south of Yakutia, from the beginning of the 1940s to the beginning of the 1990s (“Aldanslyuda” mining and processing plant), a large amount of waste from the host rocks in dumps was accumulated. The use of those rocks has not been resolved yet. Currently, “Diobeton”, LLC, on the selected site of Far Eastern hectares with an area of 9.8 hectares, solves the issue of waste disposal of the previously operating concentration plant through their use in the production of building materials. According to geological surveys, the main composition of rocks in Aldan deposits of phlogopite is: diopside rocks - 75%, phlogopite - no more than 3%, scapolite (shale and skarn) - no more than 25%, granite no more than 10%. As can be seen, diopside rocks are host rocks of phlogopite mica. Diopside is a mineral belonging to ultrabasic rocks. Its chemical formula is CaMgSi₂O₆. Aldan diopside rocks are
representatives of iron diopside. The size of large fractions of the waste varies from 80 to 400 mm and more. The size of small fractions varies from 0 to 80 mm. The waste at the site formed and accumulated taking according to the parameters of technological lines of the previously operating processing plant.

As part of the preparation of the “Aldanslyda” mining and processing plant for diversification, diopside rocks were extensively studied in the 1990s. [1-4]. The possibility for using of diopside rocks (with appropriate preparation and enrichment) to produce mineral wool, ceramic products, decorative facing materials, for stone casting, welding electrodes coating, abrasive tools adhesive were discovered. However, the implementation of research results in the practice or commercialization of scientific research and technological development did not take place either then or in subsequent periods. It should be noted that it is difficult for a small enterprise to establish a production with high-temperature melting or firing. In this regard, according to the recent advances in concrete technology, it was decided to study the possibility of using diopside rocks as a raw material to produce concrete as a large and fine aggregate and filler, as well as a mineral additive to cement.

The study of the published literature on the research topic shows that researchers pay more attention to the study of diopside as a component of the magnesia composite binder [5-8] and mineral additives to portland cement [9-10]. It was found that natural diopside rocks exhibit the ability to hydrate and show greater or lesser activity. However, the opinion of scientists about the mechanism of action of diopside rock on the hardening of the material is ambiguous. For example, the authors [11] find that the activation of magnesian cement contributes to the presence of trace elements in diopside-containing initial rocks. Others [12-15] believe that the increase of strength happens because diopside, with higher hardness, than cement stone, contributes to the redistribution of mechanical stresses, i.e. acts as a reinforcement in the cement stone.

The aim of this work is the study the possibility of using diopside rocks from the dumps of the previously operating “Aldanslyda” mining and processing plant for production. At this stage of the study, the chemical and mineralogical compositions and physical and mechanical properties of crushed stone and sand have been studied.

2. Experimental procedure

The laboratory sample was prepared by quartering the technological sample. To determine the chemical and mineralogical composition by quartering, two samples were taken (samples 1 and 2 from specimen No. 1, samples 3 and 4 from specimen No. 2) and transparent sections for petrographic analysis were made. The chemical composition of the samples was determined using X-ray chemical analysis on a BrukerSRS-3400 spectrometer. The petrographic composition of rocks was studied on an AxioScopeA2m / 2m microscope in transmitted light in transparent thin sections. To determine the mineral composition, an X-ray analysis was used using a D8-DISCOVER X-ray diffractometer (Bruker, Germany Thermal analysis (TG / DSC / DTA) was performed using a NETZSCHSTD Q600 V20.9 thermal analyzer for simultaneous thermal analysis. The study was conducted to a temperature of 1000 ° C in air.

A mixture of crushed stone fraction was used as a coarse aggregate: fractions from 5 to 10 mm – 40%, fractions over 10-20 mm - 60%. The necessary crushed stone fractions were obtained by crushing the coarse fraction of diopside rock (40-70) mm in a rotary crusher. The assessment of the suitability of diopside crushed stone was carried out by comparing the physical and technical indicators with the requirements of GOST 26633-2015 «Heavy-weight and sand concretes. Specifications» for heavy-weight concrete. The crushed stone tests were made according to the GOST 8269.0-97 “Mountainous rock road-metal and gravel, industrial waste products for construction works methods of physical and mechanical tests”.

The sand from the crushing screenings was obtained by sieving the sample through a sieve with 5 mm holes. The sand was washed with a stream of water over a sieve with openings of 0.16 mm to reduce the content of mica, the presence of which was detected visually. Technical requirements for fine aggregate of concrete is set by GOST 26633-2015, while for the manufacture of heavy and fine-
grained concrete, it is possible to use sand from the crushing screenings of dense rocks according to GOST 31424-2010 «Non-metallic construction materials from sifting of crushing solid stone in aggregate manufacturing. Specifications». The tests of the sand were carried out in accordance with GOST 8735-88 «Sand for construction work. Testing methods».

3. Results and discussion

3.1. Chemical and mineralogical composition of diopside rocks

The chemical compositions of the investigated rock specimens are shown in table 1.

**Table 1.** Chemical composition of the diopside rocks from “Aldanslyuda” mining and processing plant waste dumps (“Bezymyannyj” deposit).

| Specimen No. | Sample name | SiO$_2$ | TiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | MgO | CaO | Na$_2$O | K$_2$O | ppp | Sum |
|--------------|-------------|---------|---------|-------------|-------------|-----|-----|--------|-------|-----|------|
| 1            | Sample 1    | 46.2    | 0.42    | 10.6        | 6.48        | 15.6| 16.7| 1.6    | 0.92  | 1.3 | 100  |
|              | Sample 2    | 45.9    | 0.38    | 10.4        | 6.32        | 15.2| 16.6| 1.4    | 0.89  | 1.1 | 100  |
| 2            | Sample 3    | 46.4    | 0.41    | 10.8        | 6.19        | 15.4| 16.3| 1.5    | 0.93  | 1.2 | 99.9 |
|              | Sample 4    | 46.8    | 0.40    | 11.0        | 6.11        | 15.0| 16.5| 1.7    | 0.94  | 1.5 | 99.9 |
|              | Average     | 46.3    | 0.40    | 10.7        | 6.28        | 15.3| 16.6| 1.6    | 0.93  | 1.3 | 99.87|

From the table 1 the SiO$_2$ content in the studied rocks varied from 45.9 to 46.8% and the values almost does not differ from the average 46.45% considering the previously obtained data from the deposit. The content of the two basic oxides MgO and CaO in the studied samples of the diopside rocks averaged 15.3 and 16.5%, respectively. The content of Al$_2$O$_3$ ranged from 10.4 to 11.2%, the content of Fe$_2$O$_3$ varied from 6.11 to 6.48%, and the alkali content of Na$_2$O + K$_2$O was 2.47% on average.

The mineralogical compositions (digital photographs) of the objects are presented in figures 1-2.

**Figure 1.** Diopside plagioclases 1 - plagioclase; 2 - monoclinic pyroxene; 3 - biotite; 4 - olivine; 5 - hornblende; 6 - sphen.

**Figure 2.** Diopside crystalline slate 1 - olivine, 2 - diopside, 3 - chrome diopside 4 – phlogopite.

Figure 1 shows a 500 thin section of the sample 1. The rock is a Na[AlSi$_3$O$_8$] crystalline slate consisting of plagioclase-40%, CaMg[Si$_2$O$_6$] monoclinic pyroxene - diopside-20%, KMg$_2$[AlSi$_3$O$_10$] phlogopite-10%, (Mg, Fe)$_2$[SiO$_4$] olivine-10%, (Ca, Na,K)$_2$$_3$(Mg$_2$Fe$^{2+}$,Fe$^{3+}$,Al)$_3$[Si$_3$(Al, Si)O$_11$] hornblende-10%, sphen, magnetite-5%, NaCa$_2$Mg$_2$Al(Si$_6$Al$_3$)O$_22$(OH)$_2$ pargasite and Ca(Mg,Fe,Al)(Si,Al)$_2$O$_8$ actinolite-5%. Thus, sample 1 of a grayish light green color is a metamorphic rock.
As can be seen from figure 2 (thin section 508, specimen 2), the rock consists of diopside - 40%; chrome diopside - 10%; olivine - 30%; hornblende, sphene - 5%; phlogopite - 5%; the secondary minerals of pargasite (this is a band silicate from the amphibole family) - 10%. Sample 2 was dark green macroscopically with a fine-grained structure belongs to the monomineral diopside shales.

Analysis of the results of processing the diffraction pattern and thermogram of specimen No. 1 (figures 3a, 4) shows that the main rock-forming minerals are: 00-106 plagioclase; 00-017-0318 (D)Diopside CaMg(SiO₄)₂; 00-041-1483 (I) Actinolite Ca(Mg,Fe,Al)(Si,Al)₂O₆; 00-041-1430 (I) Pargasite NaCa₂Mg₂Al(Si₆A₈₂)O₂₂(OH)₂.

The results of the study of specimen No. 2 (figures 3b, 4) showed that diopside rock consists of diopside, actinolite and pargasite, the presence of which explains small weight loss during dehydration on the thermogram: 00-041-1370 (*) Diopside Ca(Mg,Al)(Si,Al)₂O₆, 00-041-1483 (I) Actinolite Ca(Mg,Fe,Al)(Si,Al)₂O₆, 00-041-1430 (I) Pargasite NaCa₂Mg₂Al(Si₆A₈₂)O₂₂(OH)₂.

Thus, the analysis of the mineralogical and chemical composition of specimens of diopside rock showed that the chemical compositions of the studied samples, despite the different external description of the rocks, were practically the same. The MgO content in the rock was 15.35%; in terms of its content, the rock can be attributed to a medium-magnesium-silicate raw material containing 15-45% MgO (chemical activity in the ternary diagram MgO-CaO-SiO₂, class III). The rock was characterized by low CaO content (16.53%) and by two more major oxides (Al₂O₃ and Fe₂O₃, respectively, 10.70 and 6.33%).

3.2. Diopside crushed stone
The test found that diopside crushed stone except for three indicators (average density, content of weak rocks and frost resistance) meets the requirements of GOST 26633-2015 for the manufacture of concrete, including high-strength concrete.

The average density of crushed stone is 3135 kg/m³, according to GOST 26633-2015, while the average density should be from 2000 to 3000 kg/m³. The content of weak rocks is from 6.4 to 7.5%, which exceeds the permissible value of 5% to produce high-strength concrete. Water absorption of diopside crushed stone fraction from 5 to 20 mm varies from 0.27 to 0.41%, which greatly exceeds the rate of limestone, the main type of conventional aggregates of concrete. The content of lamellar and angular grains in diopside crushed stone does not exceed 35%, which makes it possible to attribute it in the shape of grains to an improved group.

Grade of frost resistance crushed stone corresponds to F50, which is no exception for conditions of the North. For example, limestone crushed stone widely used in the conditions of Yakutia for the manufacture of driven cast-in-situ pile for concrete, which must meet F1500 requirements, is also characterized by the F50 frost resistance grade. At the same time, the frost resistance of concrete is ensured by the design of the concrete composition using the plasticizing-air-entrained additive PFM-NLK, which was specially developed for this purpose by the YPNII Institute together with NIIZHB. In addition, according to 4.5.3 of GOST 26633-2015, the possibility of using materials, which parameters (in this case, the grade of frost resistance of rubble, the content of weak rocks) which do not meet the requirements of the standard, must be confirmed by substantiating studies. When designing the concrete composition for specific products which subject to high frost resistance requirements, it is necessary to apply special technological methods to ensure the frost resistance of concrete. In addition, the possibility of using diopside crushed stone to obtain high-strength concrete must be solved by experimentally testing them in concrete.

3.3. Sand from screenings of crushing of the diopside rock
When removing mica from sand (permissible value in accordance with GOST 26633-2015 not more than 2%), sand from screenings of crushing of diopside rock fully met the requirements of GOST 31424-2010 and GOST 26633-2015.
Figure 3. Diffraction pattern of the diopside rock specimen №1 (a), specimen 2 (b).

Figure 4. Thermogram of the diopside rock.
4. Conclusion
In terms of chemical composition and mineralogical composition, this diopside rock belongs to medium-magnesian-silicate raw materials, mineral species in diopside rocks are distributed fairly evenly, and the content of the main components of the chemical composition of diopside rocks is on average: SiO₂ - 46.38%, CaO₂ - 16.53% and MgO₂ - 15.30%.

After examining the physical and mechanical properties of diopside aggregates (crushed stone and sand from crushing screenings), it can be concluded that the aggregates are suitable for producing heavy and fine-grained concrete of strength class up to 60 MPa, and to consider the possibility of using them to obtain high-strength concrete there is a need of the further research.

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