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The Application of Oil and Gas Drilling Waste in Fine-Grained Concrete

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Abstract—The development of drilling waste recycling technologies is a crucial task, primarily due to their negative impact on the environment, the increasing need for state control over compliance with environmental legislation by oil production companies, and the absence of universal technological solutions for their recycling and neutralization. This article provides a brief overview of various methods to recycle drilling waste for the production of different materials. Using drilling waste located in the Tyumen region as an example, the study demonstrates the potential of incorporating them as additives in fine-grained concrete.

Keywords: drilling waste, fine-grained concrete, strength

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INTRODUCTION

The intensive growth of the oil and gas industry gives rise to the accumulation of various wastes, notably from drilling oil and gas wells, negatively impacting all facets of the environment, even when stored in pits. The scope of their adverse effects on the environment is extensive [1]. The primary toxic component in drill cuttings is oil and its fractions, which amass during the drilling process when they come into contact with crude oil. Mud pits containing toxic drilling waste occupy vast areas of land, taking them out of production. In the construction pits, the cutting down of trees and bushes, destruction of ground cover, and land alienation are prevalent. If the waterproofing of a mud pit is compromised, the soil becomes contaminated with chemicals present in drilling waste. Simultaneously, due to the migration of pollutants, there is a potential for contamination of underground aquifers [2]. Various studies are dedicated to exploring the mineralogical and geochemical specifics of drill cuttings and determining their toxicity, incorporating biotesting through modern methods [3].

The imperative to develop and implement technologies for processing drilling waste is pressing. There is a heightened focus on state control to ensure the adherence of oil production enterprises to environmental legislation [4]. While oil-producing companies have introduced various technological solutions for recycling drilling waste in recent years, a universal method for its neutralization and disposal remains elusive. Simultaneously, the storage of waste in temporary facilities and modern landfills, without subsequent disposal, leads to prolonged emissions of pollutants and irreversible depletion of secondary material resources [5].

Among the known methods of neutralizing drill cuttings (thermal, physical, chemical, physico-chemical, biological), a special group includes the thermal method, as well as a combination of chemical and thermal methods. This combination allows for the effective neutralization of drill cuttings, resulting in the production of a useful product. This method specifically removes the organic part of drill cuttings, mitigating its negative impact on the environment [5–7].

The scientific and technical literature presents various methods for utilizing drilling waste.

The authors of [1] propose a method for processing drill cuttings using filter casings. Additionally, technologies have been developed to produce ceramic proppant – a granulometric material utilized in the oil industry to enhance oil recovery from wells subjected to hydraulic fracturing – from drill cuttings [8, 9]. Ongoing research aims to substantiate and develop methods for recycling drill cuttings to obtain soils with physical and chemical properties meeting specific safety criteria for the natural environment. These recycled materials find applications in diverse areas, including land reclamation, construction of intra-village roads, highways, and access routes to drilling sites, as well as in the construction of embankments and the filling of well pad bases and flare installations [10–13].

An analysis of the literature underscores the versatility of waste from drilling oil and gas wells in the production of various building materials. This range encompasses concrete, cement, thermal insulation composites, cinder blocks, paving slabs, curb stones, brick, expanded clay, drill cuttings mixtures, facade tiles, and mineral wool slabs, among others [6, 14–18].

The primary objective of this study is to investigate the feasibility of using drilling waste as an additive in fine-grained concrete.

EXPERIMENTAL

For the research, samples of drilling waste from the Kamennoe oil field, situated in the territory of the Khanty-Mansiysk Autonomous Okrug of the Tyumen Region, were carefully selected.

The X-ray diffraction patterns of the samples were obtained using the D8 ADVANCE automatic diffractometer (Germany) with sample rotation in CuK_α radiation. X-ray phase analysis utilized the EVA search program with the PDF-2 powder data bank. The density of the sludge was determined pycnometrically.

To quantitatively analyze the elemental composition of the synthesized aluminosilicates, the energy-dispersive X-ray fluorescence method was used, employing a Shimadzu EDX 800 HS spectrometer (Japan). A weighed portion of the sample was ground in an agate mortar with boric acid (in a 2:1 ratio by weight) and placed in a mold with a 20 mm diameter. The emitter tablet was pressed for 2 minutes at a pressure of 5000 kg, after which it was positioned in the spectrometer for measurements. Each energy channel had an exposure time of 100 s. The radiation source was an X-ray tube with a Rh anode, and elemental concentrations were calculated using the fundamental parameters method through the spectrometer software package, excluding light elements. The relative error in determining the elemental composition did not exceed ±10%.

The thermal behavior of the sample was examined using a Q-1500 D derivatograph of the F. Paulik, P. Paulik, L. Erdei system from MOM (temperature determination accuracy ± 5°C).

To investigate morphological characteristics and confirm the local elemental composition of drill cuttings, a high-resolution electron microscope Hitachi S5500 (Japan) was employed.

Particle size distribution analysis was conducted using a laser particle size analyzer HORIBA LB-550 (France).

For the production of concrete beams, the following components were utilized (in relation to the weight part of cement, taken as 1): superplasticizer S-3—0.01; sand—3; addition of drill cuttings—0.04–0.06, water—0.42. The water-cement ratio was maintained constant in all compositions (W/C = 0.42). Drill cuttings in powder form were added to an aqueous solution of superplasticizer S-3 and mixed with a mixer for 2 minutes until a homogeneous suspension was achieved. Cement was then poured into the bowl of a laboratory mixer (type 1.0203.01 from Testing), and water was added, followed by mixing for 30 s. The prepared suspension was added to the resulting mass and stirred for an additional 30 s. The subsequent step involved gradually introducing sand into the mixture and stirring at 140 rpm for 2 minutes and at 285 rpm for 30 s. The prepared mixture was manually placed in layers in a 3FK-70 (3FB-40) mold and vibrated on a vibrating platform (model SMZh-539) for 10 s. The mold with the samples was covered with glass, and after 1 day, the formwork was removed. The prepared samples were then placed in a normal curing chamber (model KPU-1M) on pads and stored for up to 27 days. The chamber maintained a temperature of 20°C and a relative humidity of 95%. After 3, 7, and 28 days from the manufacturing date, some of the samples were removed from the chamber. These samples were kept in natural room conditions for 4 h, with an air temperature within 20 ± 5°C and a relative air humidity of at least 55%. Subsequently, the samples were subjected to bending and compression tests on a combined machine (type 1.0244 from Testing).

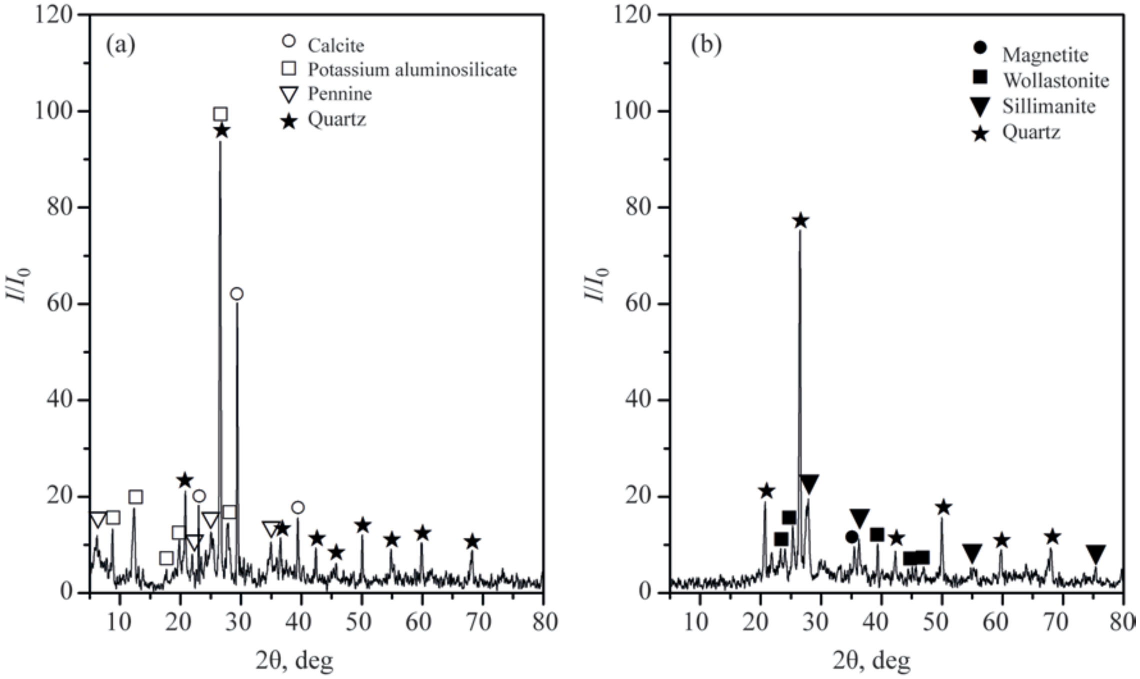


Fig. 1. Phase composition of drill cuttings after drying at a temperature of 85°C (a) and after heating to 900°C (b).

RESULTS AND DISCUSSION

A sample of drill cuttings is a finely dispersed mass with a liquid consistency, appearing in a dark gray color and carrying the distinct smell of petroleum products.

X-ray phase analysis of the dried sample at a temperature of 85°C revealed the presence of the following phases: calcite ($CaCO_3$), potassium aluminosilicate ($KAl_3Si_3O_{11}$), pennine ($Mg_{9.8}Al_{1.6}Fe_{0.6}(Si_{6.3}Al_{1.68}O_{19.96})OH_{15.}84$), and quartz ($SiO_2$) (Fig. 1a). The X-ray phase analysis of the non-volatile residue after heating the sample to 900°C (conducted with thermogravimetric analysis) displayed the presence of quartz (SiO_2), magnetite (Fe_3O_4), wollastonite ($CaSiO_3$), and sillimanite ($Al_2(SiO_4)O$) (Fig. 1b). The alteration in the phase composition of drill cuttings is linked to additional reactions occurring during thermal exposure, warranting further research.

The X-ray diffraction data are substantiated by the results of the quantitative determination of the elemental composition. The original sample exhibited the following elemental content in weight percent: Si—48.9; Fe—10.8; Al—22.1; Ca—7.7; K—3.6; Mg—2.7; Na—1.8; S—0.6.

The thermal analysis of drill cuttings (Fig. 2) revealed a total weight loss of approximately 18%. The endoeffect on the thermogram at 75°C is attributed to water loss, while the exoeffects at 311, 404, and 553°C are associated with the decomposition of the organic component of the cuttings (petroleum products). As the decomposition of petroleum products occurs up to 550–600°C, a sample fired at 600°C was used for further research. According to X-ray diffraction data, the phase composition of

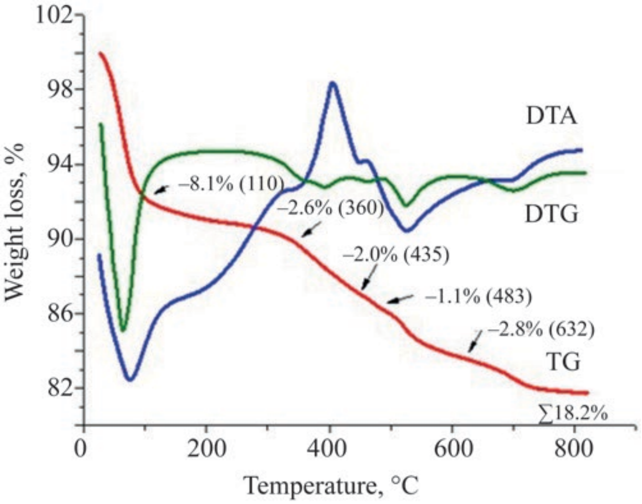


Fig. 2. TG/DTA/DTG of drill cuttings.

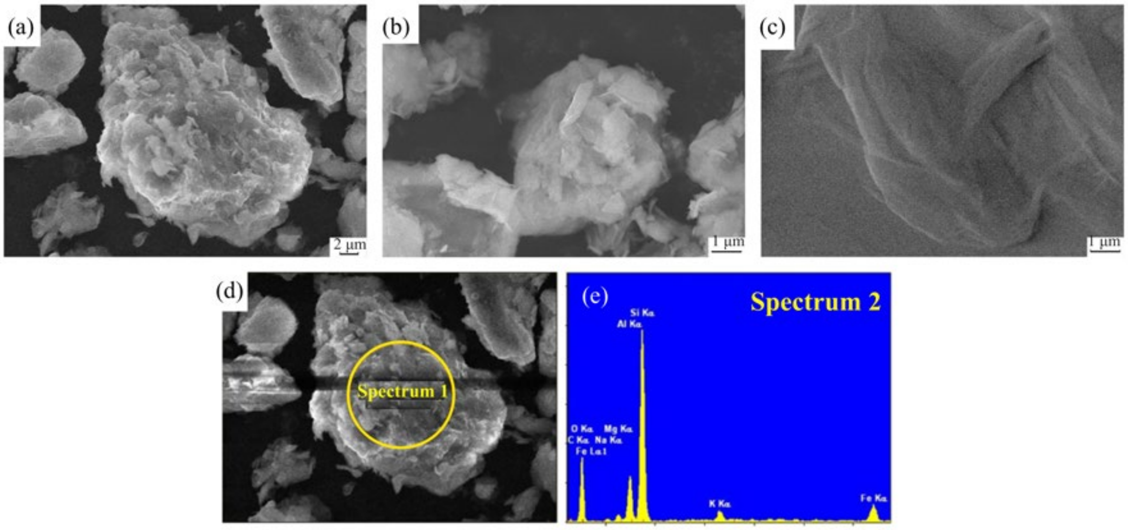


Fig. 3. SEM images of a drill cuttings sample at various magnifications (a—3000×; b—10 000×; c—100 000×) and the energy dispersive spectrum of a drill cuttings particle (d, e).

this sample is characterized by the presence of quartz (SiO_2), anhydrite ($CaSO_4$), calcite ($CaCO_3$), hematite (Fe_2O_3), potassium aluminosilicate ($KAl_3Si_3O_{11}$), and montmorillonite 14Å $Na_{0.3}(Al, Mg)_2Si_4O_{10}(OH)_2 \cdot xH_2O$.

Figure 3 displays microphotographs of drill cuttings after firing at 600°C.

As observed from the SEM images, drill cuttings after firing at 600°C consist of particles with various shapes.

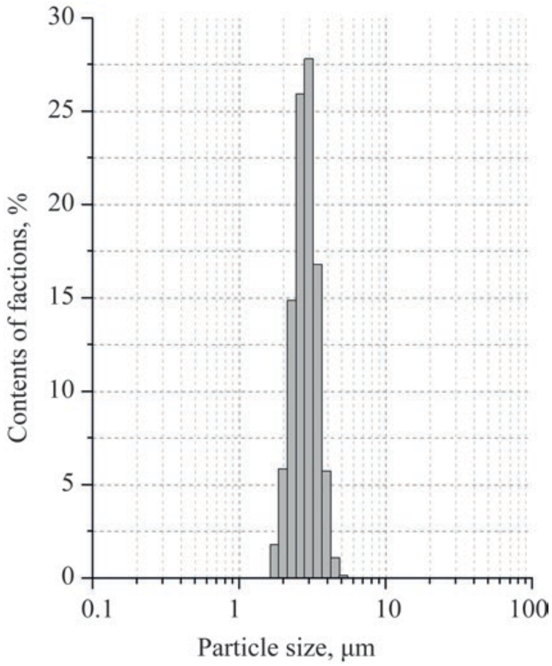
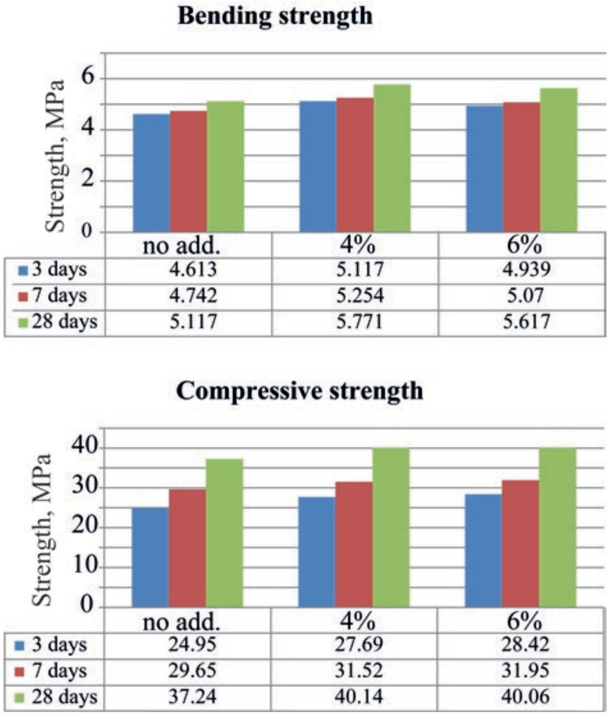


Fig. 4. Histogram of particle sizes of a drill cuttings sample after firing at a temperature of 600°C.



	no add.	4%	6%
🟦 3 days	4.613	5.117	4.939
🟥 7 days	4.742	5.254	5.07
🟩 28 days	5.117	5.771	5.617

	no add.	4%	6%
🟦 3 days	24.95	27.69	28.42
🟥 7 days	29.65	31.52	31.95
🟩 28 days	37.24	40.14	40.06

Fig. 5. The influence of the addition of drilling waste on the strength of fine-grained concrete in bending and compression.

SEM images reveal conglomerates of particles up to 20–30 μm in size, comprising smaller irregularly shaped particles ranging from 1 to 6 μm in size, as confirmed by the particle size distribution analysis (Fig. 4). Particles up to 5 μm in size with flat edges are noticeable, featuring petal-shaped particles ranging from 50 to 200 nm on their surfaces. The particles contain the elements Si, Al, K, Na, Fe, and Mg, consistent with X-ray diffraction and elemental analysis data.

The data on the strength characteristics of concrete, incorporating drilling waste at 4% and 6% by weight, are presented in Fig. 5.

The research findings indicate an enhancement in the tensile strength of fine-grained concrete after 28 days when incorporating drilling waste: a 13% increase in bending with a 4% addition and a 10% increase with a 6% addition; in compression, there is an 8% improvement for both cases.

These results demonstrate the viability of using large-tonnage drilling waste as an additive to fine-grained concrete. Further research is both scientifically and practically valuable to explore the impact of different quantities of drilling waste on the strength characteristics, water absorption, and frost resistance of fine-grained concrete. Additionally, investigating the effect of thermal treatment on the phase composition of the waste is necessary. Such studies contribute to developing specific practical recommendations for utilizing drilling waste with similar compositions in the construction industry.

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CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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